Egyptian Journal of Aquatic Biology & Fisheries

Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(6): 1975 – 2002 (2024)
www.ejabf.journals.ekb.eg

Simulation of Water Quality and Pollution Reduction of Qarun Lake, Egypt using 2D Hydrodynamic Ecological Modelling

Manar A. Basheer[1*], Khaled Abutaleb[1, 2, 3], Amal A. Mekawy[4], Nermine N. Abed[5]

[1]National Authority for Remote Sensing and Space Sciences, Cairo, Egypt
[2]Agricultural Research Council, Natural Resources and Engineering (ARC-NRE), Pretoria, South Africa
[3]School of Animal, Plant and Environmental Sciences, University of Witwatersrand, Private Bag X3, Johannesburg, 2050, South Africa
[4]The Regional Center of Mycology and Biotechnology, Al-Azhar University, Cairo, Egypt.
[5]Faculty of Science (Girls Branch), Al-Azhar University, Cairo, Egypt
***Corresponding author: mmanarmm2015@gmail.com**

ARTICLE INFO

Article History:
Received: Aug. 11, 2024
Accepted: Dec. 11, 2024
Online: Dec. 19, 2024

Keywords:
Qarun Lake,
MIKE 21,
Bioremediation,
Remote sensing,
Silver nanoparticle,
Ecological modelling,
Hydrodynamic model

ABSTRACT

Lake Qarun, one of largest and oldest lakes in Egypt, was declared as a nature reserve in 1989 to protect the biological, archaeological, and geological diversity. However, Lake Qarun is bearing a load due to various pollution types. This condition has resulted in unfavorable water. There is a greater combination between water pollution and health problem. For the protection of lake all waste waters should be managed and remediated appropriately. Bioremediation has been recognized to be environmently friendly and economical for treating the pollution of water bodies. Bioremediation uses naturally occurring bacteria, fungi, or plants for degradation or detoxification of harmful substances. Integration between nanomaterials and bioremediation has great potential to be effective and efficient. Therefore, myco-remediation using silver nanoparticles was chosen in this study. Ecological modelling using MIKE 21/3 was used for completion of the evaluation of lake water quality, bioremediation process, and to simulate the transport and fate of pollutants in the lake.

INTRODUCTION

Lakes provide several ecosystem services, such as biodiversity, climate change mitigation, fisheries, drinking water, recreation and tourism, and hydrological regulation **(Schallenberg *et al.*, 2013; Ventura *et al.*, 2023)**. Lakes operate as mirrors, reflecting the impacts of climate change and human activities on ecological components. Climate change, rapid population development, and increased human activity have all contributed to the recent acceleration of lake ecological changes around the world **(Shadrin *et al.*, 2016)**.

Although the importance of lakes is recognized, there are several pressures on lakes ecosystem services. Land use activities cause soil erosion. Soil particles transferred from land to water affect negatively on aquatic biota and ecosystems. Also, the presence of contaminants (such as industrial chemicals and biological pathogens) is a key factor limiting lake ecosystem services. The main sources of contaminants include treated sewage effluents, draining urbanized areas, and industrial effluents **(Schallenberg *et al.*, 2013)**.

There are several ways used for the protection of lake ecosystems and their watershed areas. From these ways, all waste waters from various sources should be treated appropriately. Water quality of lakes is a crucial factor in the successful management of natural resources. Poorly managed water will have a destructive impact on the quality of the environment **(Nemethy & Molnar, 2014)**.

Lake monitoring could provide an early warning of environmental damage. Monitoring a lake's physical, chemical, and biological health can swiftly reveal changes in many aspects of the ecosystem, and hopefully, dangerous effects can be removed before their consequences become uncontrollable. One of the most detrimental types of water pollution is microbial contamination, which can lead to the development of various diseases. Therefore, it's important to keep an eye on any microbial contamination in the Egyptian lakes **(Shaaban *et al.*, 2016)**.

The amount of useable water is directly impacted by poor water quality in a number of ways. While many countries list water quality as their top concern, the perception of the water crisis generally seems to be one of quantity. The contribution of polluted water to the water crisis has also been calculated in recent years using the loss of beneficial use, which is defined as water lost for beneficial agricultural, human, and ecological uses because of excessive contamination by bacteria, nutrients, metals, organic matter, salinity, and other toxic waste. Waterborne disease transmission has already established a strong connection between poor water quality and public health issues **(El-sayed, 2021)**.

Various traditional physio-chemical methods of wastewater treatment, though effective, are not easy for application on large scale. Conversely bioremediation has been documented to be environment-friendly and economical for treatment the pollution of water bodies **(Deshmukh *et al.*, 2016)**. Numerous physicochemical techniques have been researched and used in wastewater treatment. These techniques do, however, have a number of restrictions, including the need for chemical agents, increased costs, inadequate treatment, the production of secondary pollutants and substantial amounts of solid waste. These limitations made the application of biological methods a more appropriate alternative technique. Bioremediation is a new technology that was discovered recently. This technology primarily uses microorganisms to restore the contaminated environment to its pre-polluted state. Moreover, this technology, which uses non-pathogenic microorganisms, is affordable, simple, and environmentally friendly **(Al-Wasify *et al.*, 2017)**.

Given the importance of understanding the factors that affect microbial water quality, the temporal and spatial variability of microbial concentrations can be described using ecological modelling. Additionally, modeling can generate forecasts and predictions, as well as simulate various scenarios and situations **(Sokolova *et al*., 2013)**. There is an urgent need for effective water quality management techniques. To address this, a 2-D hydro-ecological model for the lake was developed using the MIKE 21 modeling system **(Assar *et al.*, 2015)**. The MIKE 21 model, developed by the Danish Hydraulic Institute (DHI), is one of the most widely used models. It includes modules for hydrodynamics, transport, ecology, particle tracking, mud transport, sand transport, and inland flooding **(Qiao *et al*., 2018)**. **Sokolova *et al.* (2013)** used MIKE 21 model and revealed that the temperature of the lake and the wind direction have a significant impact on the transport of pollutants in Lake Rådasjön. The water flow in the Göta älv River drives the movement of pollutants through the river. With the help of the created hydrodynamic models, the microbial water quality in Lake Rådasjön and the Göta älv River was successfully described. The results showed that the microbial water quality in the studied water sources is variable and inconstant. MIKE 21 software is vastly used for different applications. It has been utilized in modelling of tidal flows, oil spills, and water quality. The software has a feasible interface with productive tools aimed at preparing input and interpretation in addition to the presentation of outputs **(Negm *et al*., 2018)**. The current study aimed to use MIKE 21 ecological model to simulate the hydrodynamic and water quality of Lake Qarun and to simulate the spreading and fate of bacteria using ECO Lab module before and after treatment of wastewater.

MATERIALS AND METHODS

Study area

Lake Qarun is one of the largest lakes and the only enclosed saline lake in Egypt (Fig. 1). It is situated 83 kilometers southwest of Cairo in the western desert region of the Fayoum depression. The lake lies between 29^{o} 24$^{\backslash}$ and 29^{o} 33$^{\backslash}$ N in latitude and between 30^{o} 24$^{\backslash}$ and 30 ^{o} 49$^{\backslash}$ E in longitude. Its northern boundary is the desert, while its southern and southeast borders are made up of cultivated land. The surrounding farmed land supplies the lake with agricultural drainage water. Two enormous drains, El-Batts drain (at the northeast corner) and El-Wadi drain (near the mid-point of the southern shore), carry the drainage water into the lake **(Abou El-Gheit *et al*., 2012)**.

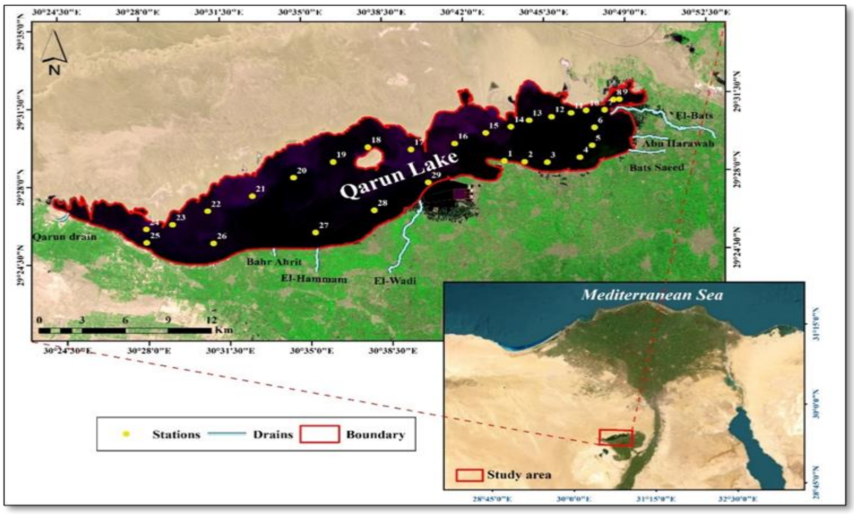


Fig. 1. The study area

Data collection

Sample collection

Water samples were collected from 29 sites (Table 1) distributed all over Lake Qarun seasonally (Table 2).

Physicochemical parameters analysis

Physical and chemical parameters (water temperature "°C", pH, turbidity, chlorophyll-a, chromophoric dissolved organic matter "cDOM", dissolved oxygen "DO", salinity, and total dissolved solids "TDS") were measured using Hydrolab HL7-Multiparameter Sonde Version 7 device.

Table 1. Coordinates of water samples locations in Lake Qarun

No.	Latitude (X)	Longitude (Y)	No.	Latitude (X)	Longitude (Y)
1	29º28'39"	30º43'34"	16	29º29'31"	30º41'29"
2	29º28'35"	30º44'27"	17	29º29'16"	30º39'34"
3	29º28'32"	30º45'25"	18	29º29'26"	30º37'43"
4	29º28'44"	30º46'51"	19	29º28'48"	30º36'12"
5	29º29'15"	30º47'23"	20	29º28'09"	30º34'28"
6	29º30'03"	30º47'31"	21	29º27'22"	30º32'40"
7	29º30'49"	30º47'59"	22	29º26'44"	30º30'43"
8	29º31'16"	30º48'23"	23	29º26'10"	30º29'11"
9	29º31'17"	30º48'38"	24	29º25'59"	30º27'46"
10	29º30'49"	30º47'11"	25	29º25'23"	30º28'03"
11	29º30'44"	30º46'31"	26	29º25'17"	30º30'55"
12	29º30'34"	30º45'41"	27	29º25'39"	30º35'20"
13	29º30'27"	30º44'42"	28	29º26'36"	30º37'54"
14	29º30'11"	30º43'55"	29	29º27'47"	30º40'15"
15	29º29'56"	30º42'49"			

Table 2. Date of sample collection

Season	Date
Spring	6/3/2021
Summer	10/7/2021
Autumn	19/10/2021
Winter	18/12/2021

Satellite image collection

Sentinel-2A satellite image in 19/10/2021 was freely downloaded from the United States Geological Survey (USGS) and was used in this study to extract lake boundary.

Ancillary data

Time series data of drain discharges were collected from the Egyptian Public Authority for Drainage Projects in Egypt, covering the period from January to August 2021. Bathymetric data (Fig. 2), consisting of 193,142 points distributed across the lake area, were also gathered. Additionally, weather data were obtained from NASA (https://power.larc.nasa.gov/data-access-viewer/).

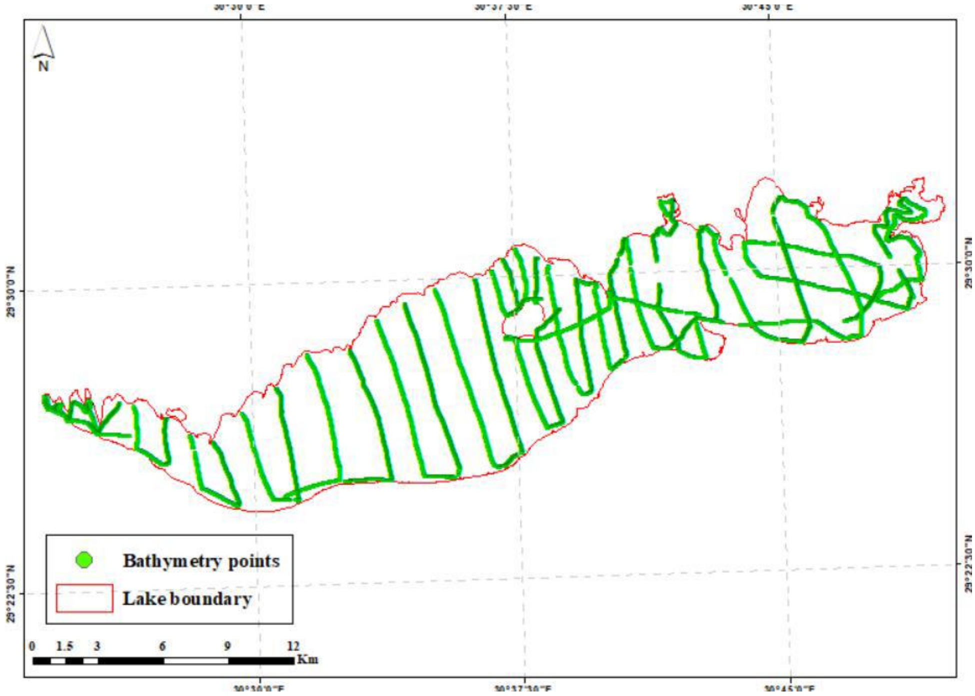


Fig. 2. Bathymetric data point distribution map

Geospatial interpolation

To map the spatial distribution of physicochemical parameters (water temperature, pH, turbidity, chlorophyll-a, cDOM, salinity, and TDS) along Qarun Lake, topo to raster interpolation method was used **(Arseni *et al.*, 2019)**.

Treatment of water sample with myco-synthesized silver nanoparticles

Water samples were treated with biosynthesized silver nanoparticles, which were prepared using green technology in our previous study **(Basheer *et al.*, 2023)**. The bacterial counts before and after treatment were then used as inputs for the hydrodynamic model in this study.

Modelling technique using MIKE software

A coupled hydrodynamic–water quality model (two different modules of the MIKE 21 program) has been used; Hydrodynamic and ECO lab modules **(Xu *et al.*, 2023)**.

Models description

a) MIKE21

MIKE 21 is professional hydrodynamic flow transport modelling software developed by Danish Hydraulic Institute (DHI), used for simulation of water flow and water quality in estuaries, seas, bays, and lakes.

b) Hydrodynamic module

The hydrodynamic model (HD) simulates fluctuations in water levels and flow over time, depending on changes in various forces. Before running the model, several inputs must be provided, including bathymetry, mesh files, time parameters, water surface level, velocity, boundary conditions, and other forcing functions such as wind speed, wind direction, evaporation, and source discharge **(Galal & Youssef, 2023)**.

According to **Li *et al.* (2020)**, the basic motion equation of 2D unsteady water flow is as follows:

Continuity equation:

$$\frac{\partial h}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = 0 \qquad (1)$$

Momentum equation:
In the X direction:

$$\frac{\partial h\bar{u}}{\partial t} + \frac{\partial h\bar{u}^2}{\partial x} + \frac{\partial h\bar{u}\bar{v}}{\partial y} = f\bar{v}h - gh\frac{\partial \eta}{\partial x} - \frac{h}{\rho_0}\frac{\partial p_a}{\partial x} - \frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x} + \frac{\tau_{sx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} - \frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y}\right) + \frac{\partial}{\partial x}(hT_{xx}) + \frac{\partial}{\partial y}(hT_{xy}) + hu_sS \qquad (2)$$

In the Y direction:

$$\frac{\partial h\bar{v}}{\partial t} + \frac{\partial h\bar{u}\bar{v}}{\partial x} + \frac{\partial h\bar{v}^2}{\partial y} = -f\bar{v}h - gh\frac{\partial \eta}{\partial y} - \frac{h}{\rho_0}\frac{\partial p_a}{\partial y} - \frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y} + \frac{\tau_{xy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} - \frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}\right) + \frac{\partial}{\partial x}(hT_{xy}) + \frac{\partial}{\partial y}(hT_{yy}) + hv_sS \qquad (3)$$

Where x, y, and z are coordinates; t is time in seconds; h is the water column depth; ρ_0 is the water density; u, v, and w are the velocity components in the three directions; g is the acceleration due to gravity; f is the Coriolis force coefficient; S, u_s, and v_s are the discharge and discharge speed of the pollution point source respectively; $\bar{u}$ and $\bar{v}$ are the average values of the velocity at the vertical depth; $h\bar{u}$ and $h\bar{v}$ are lateral stress; $T_{xx}=2A(\partial\bar{u}/\partial x)$, $T_{xy}=A(\partial\bar{u}/\partial y+\partial\bar{v}/\partial x)$ and $T_{yy}=2A(\partial\bar{u}/\partial y)$, A is the eddy viscosity coefficient of the horizontal flow.

An equation for the transport of water pollutants is the hydrodynamic advection diffusion model (AD). Convection, diffusion, and other transport processes of dissolved pollutants in water can be simulated when paired with the HD model. The migration equation was resolved by applying the law of conservation of mass and taking into account the convective diffusion and degradation factors in pollutant migration processes:

$$\frac{\partial}{\partial t}(h\,c) + \frac{\partial}{\partial x}(\bar{u}\,h\,c) + \frac{\partial}{\partial y}(\bar{v}\,h\,c) + K_d\,h\,c - S = \frac{\partial}{\partial x}\left(h\,\lambda_x\frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(h\,\lambda_y\frac{\partial c}{\partial y}\right) \qquad (4)$$

Where, c is pollutants concentration; K_d the linear attenuation coefficient; λx and λy is the x, y diffusion coefficient, respectively.

c) MIKE 21 ECO Lab

A module called ECO Lab was used to model ecological circumstances, water quality, and the distribution of heavy metals in lakes, bays, estuaries, and coastal regions. Through the advection-dispersion process, HD module and the ECO Lab module were coupled **(Khwairakpam *et al.*, 2021; Zheng *et al.*, 2024)**.

d) Models set up for Lake Qarun

Mike 21 hydrodynamic and ECO Lab model for Qarun Lake was developed from January 2021 to August 2021. Simulation starts with digital generalization of the real water. As stated by **Wong and Teo (2023)**, the steps involved are as follows: (1) preparing bathymetric and topographic data (Fig. 3); (2) dividing unstructured meshes (Fig. 4); (3) establishing the time series file (Figs. 5 and 6) as the model's boundary condition; (4) setting up the parameters, and running simulation; and (5) post-processing the results (validating the model).

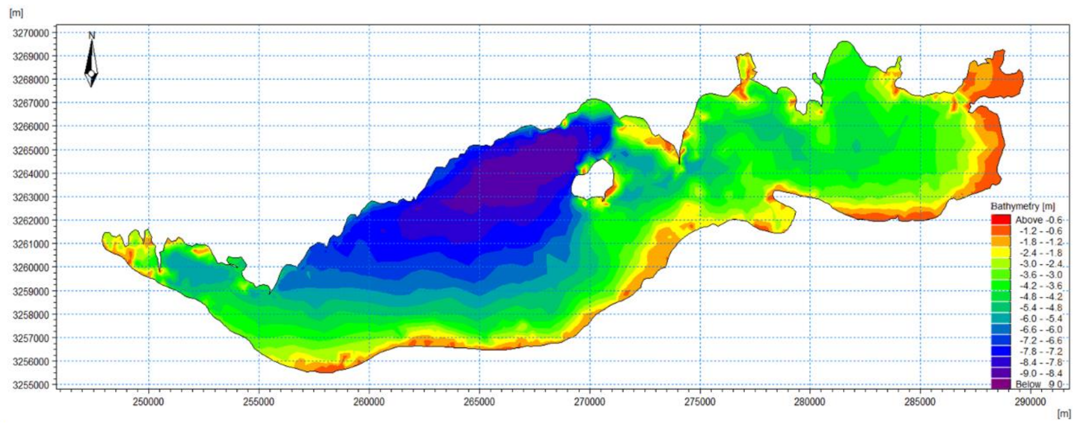


Fig. 3. Bathymetry of Lake Qarun

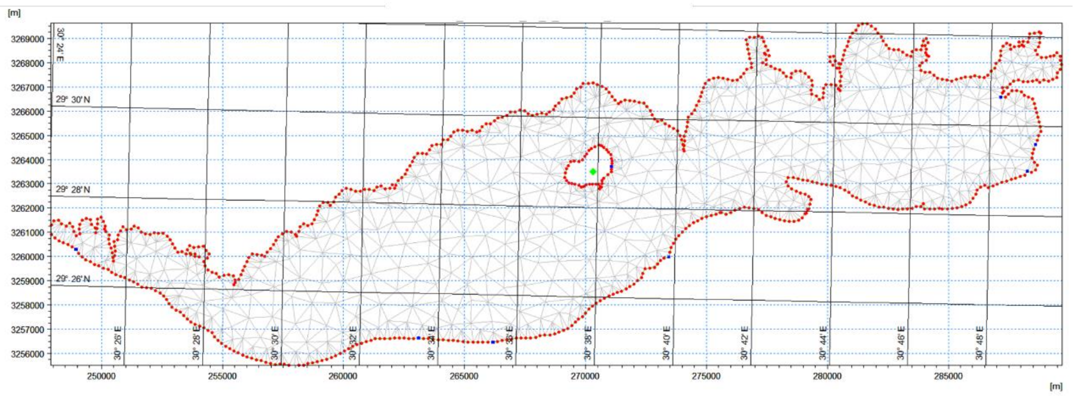


Fig. 4. Generated mesh for Lake Qarun

e) Parameter Setting

The governing equation formula, water depth, Manning coefficient, wind action (including wind direction and speed), sources, and time series data were the primary parameters set in the hydrodynamic model. The higher-order precision method of the hydrodynamic shallow water equation was selected. The model simulation used a primary time step length of 60 seconds, a total of 480,680 time steps, and a Courant number (CFL) value of 0.8. The default Smagorinsky coefficient of MIKE21 (0.28) was applied as the horizontal eddy viscosity coefficient, as recommended by **Li *et al.* (2020)**.

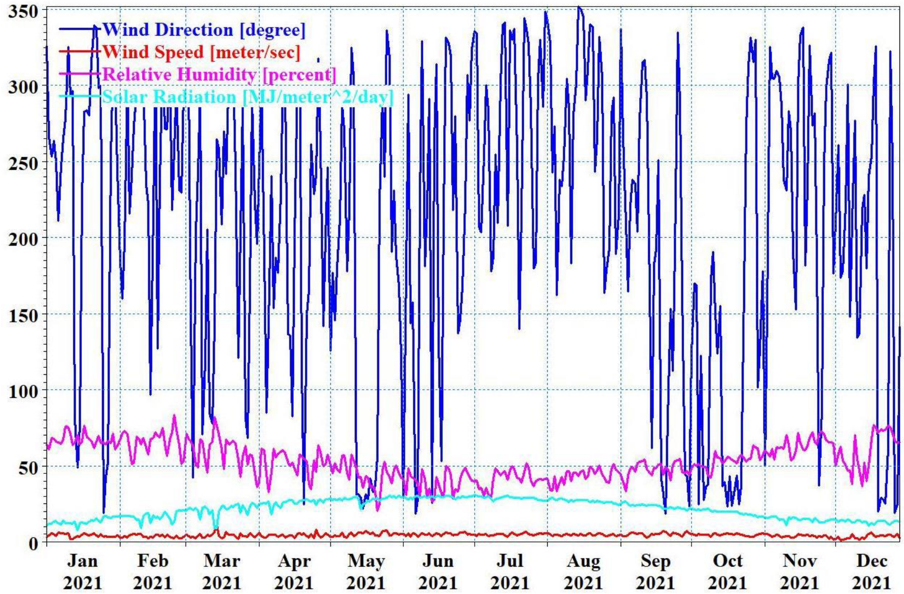


Fig. 5. Time series data of wind action, relative humidity, and solar radiation

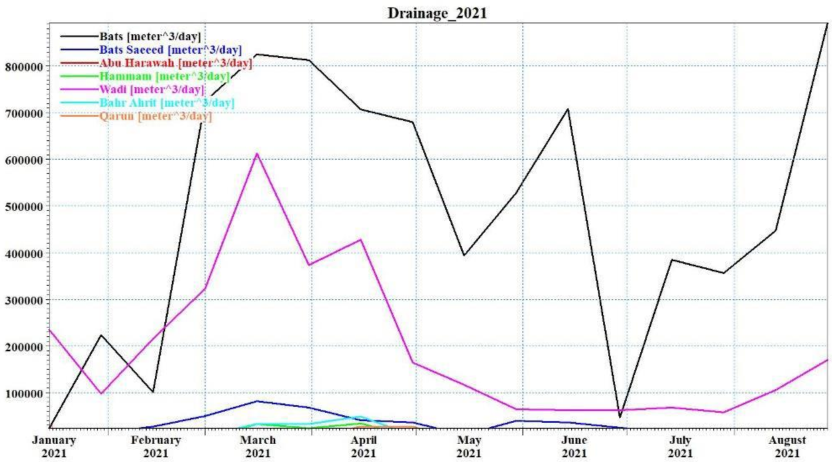


Fig. 6. Discharge time series data of Lake Qarun drains

f) Validation of model parameters

Data on the specified verification points was taken from the output result in order to validate the model and calibrate its parameters. The water temperature and salinity values measured at the five points (Fig. 7) were verified from February to August.

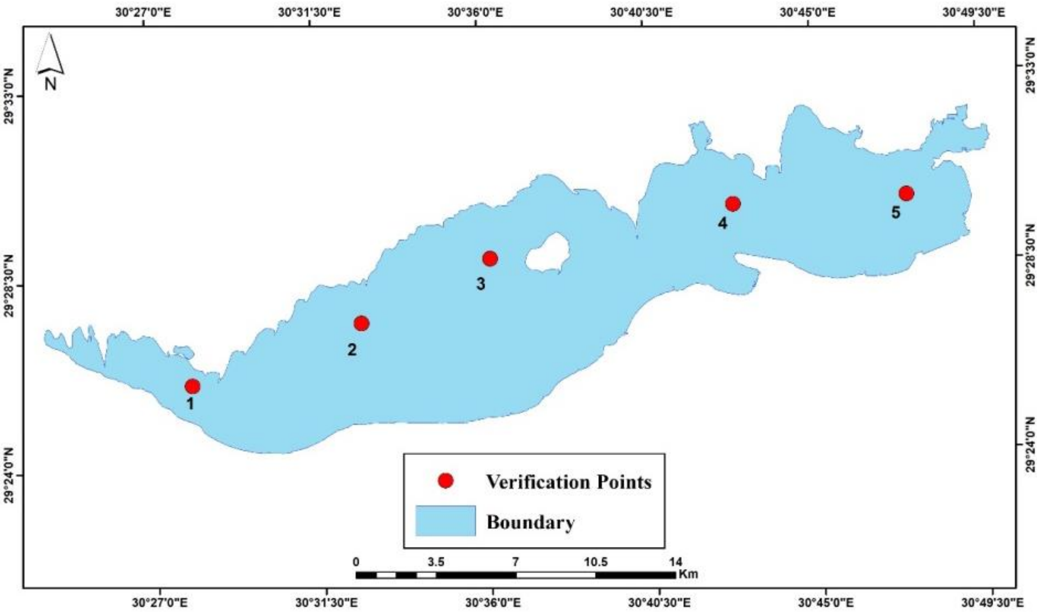


Fig. 7. Selected verification points

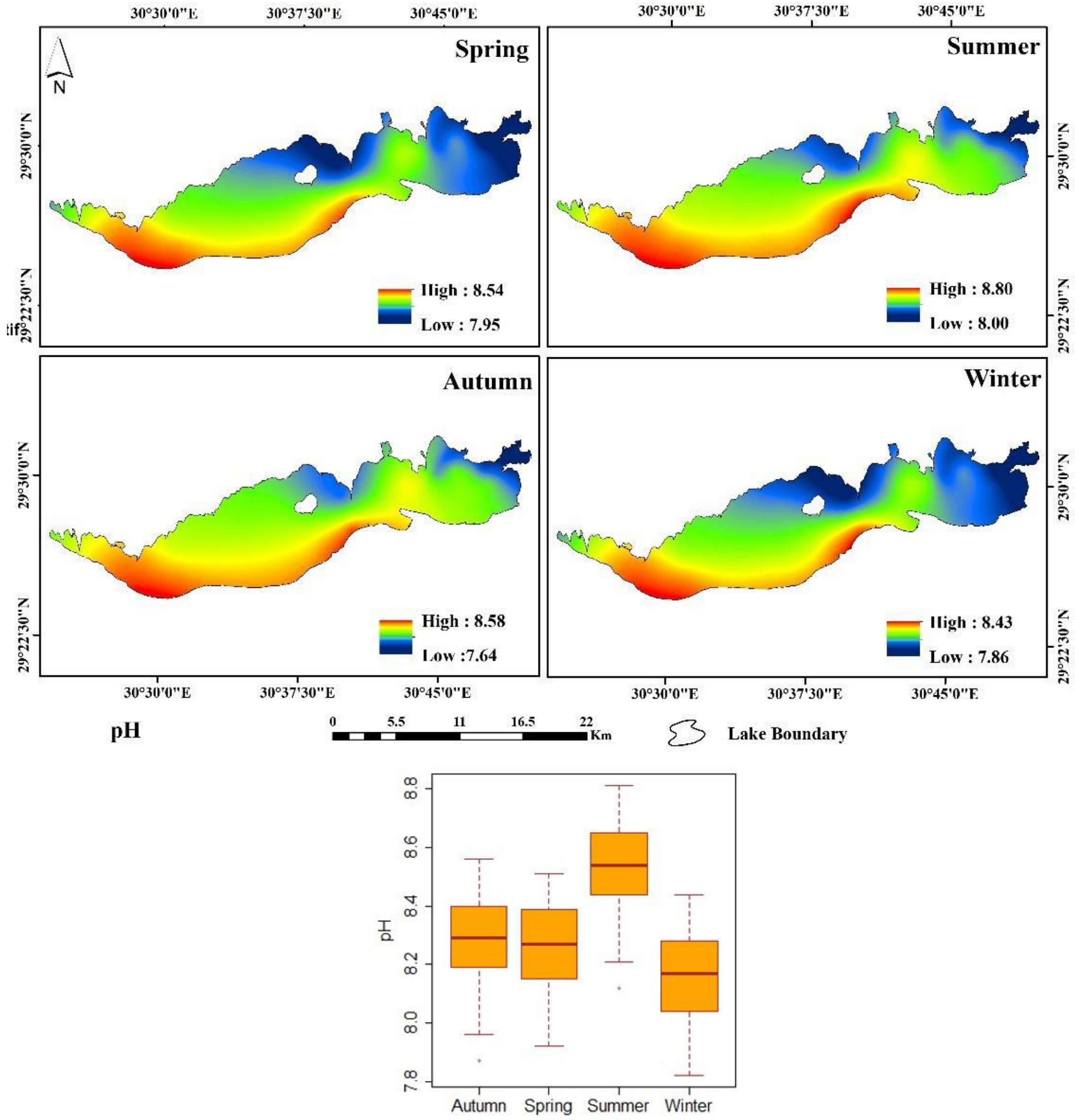
g) Scenario analysis

To determine the impact of contaminants on the Lake, gain a better understanding of the circulation of contaminants within the lake, and develop possible scenario and solutions to restore the aquatic life, correlation between measured water quality parameters and bacterial counts before and after treatment with biosynthesized silver nanoparticles from our previous study **(Basheer *et al.*, 2023)** was applied to get the equation that should be applied to simulate the status of whole lake after treatment. The coefficients of determination between water quality parameter values and bacterial counts were calculated.

RESULTS AND DISCUSSION

Geospatial interpolation of physicochemical parameters

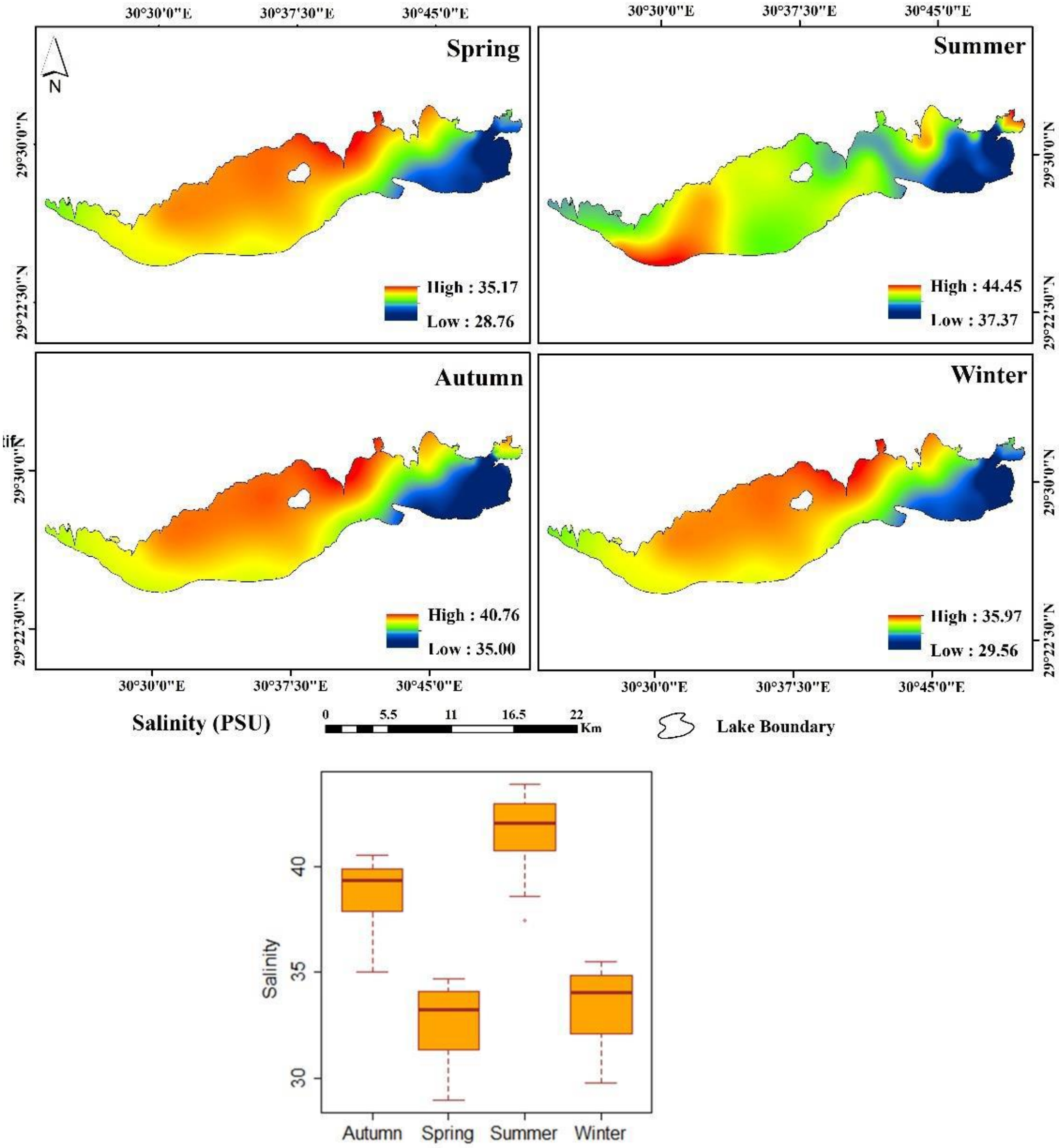
Analysis of physicochemical parameters of the lake revealed that water quality characteristics are seriously impacted by the sources of pollution. One of the most important factors affecting the quality of water and its usefulness for different purposes is pH **(Lemessa *et al.*, 2023)**. Weak alkaline water was observed in Qarun Lake where pH ranged from 7.64 to 8.80, the highest pH values recorded in summer, while the lowest values in the winter (Fig. 8). The pH values have mean of 8.30 and median of 8.29, the first quartile was 8.15 (which means that 25% of values are below 8.15), while the third quartile was 8.48 (which means that 75% of the values below 8.48).



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
7.82	8.15	8.29	8.30	8.48	8.81

Fig. 8. Seasonal pH level of Qarun Lake

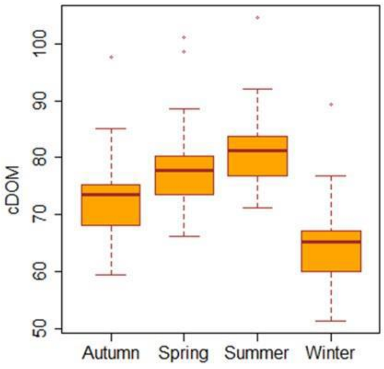
The results also revealed that pH levels increased from east to west, with the most alkaline water commonly found in the western part of the lake. The water in the eastern part of the lake is influenced by freshwater discharged from drains, which flows from east to west, explaining the higher salinity levels in the western sections (Fig. 9). The increased salinity in Lake Qarun is largely attributed to the high evaporation rate **(El-Agri *et al*., 2022; Seif *et al*., 2023)**. Salinity values ranged from a low of 28.76 PSU in spring to a high of 44.45 PSU in summer. The mean salinity was 36.64 PSU, with a median of 35.47 PSU. The first quartile was 33.70 PSU, while the third quartile was 40.24 PSU.



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
28.76	33.70	35.47	36.64	40.24	44.45

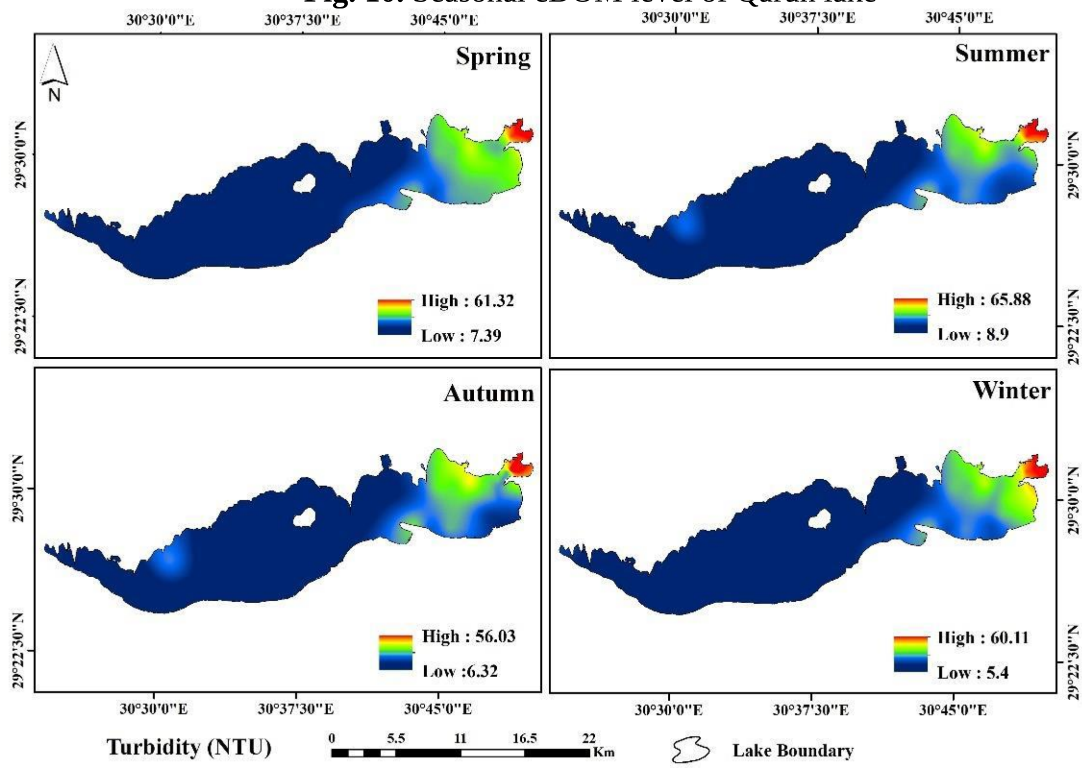
Fig. 9. Seasonal salinity level of Qarun Lake

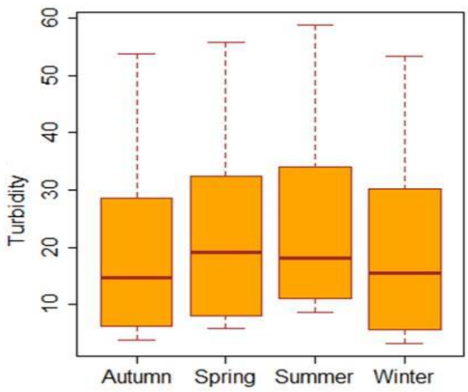
Unlike salinity, cDOM (Fig. 10) showed the highest level in the east of the lake facing El-Bats drain. The highest values of cDOM were recorded in summer with 109.57ppb, while the lowest values were recorded in winter with 51.03ppb, the mean was 74.10ppb, the median was 74.56ppb, the first quartile was 67.09ppb, while the third quartile was 79.72ppb. The high levels of chromophoric dissolved organic matter (cDOM), primarily from agricultural and domestic waste, play a significant role in increasing turbidity levels (Fig. 11). Turbidity values ranged from 5.4 NTU in winter to 65.44 NTU in summer. The mean turbidity was 20.30 NTU, with a median of 17.71 NTU. The first quartile was 7.64 NTU, and the third quartile was 65.88 NTU.



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
51.03	67.09	74.56	74.10	79.72	109.57

Fig. 10. Seasonal cDOM level of Qarun lake

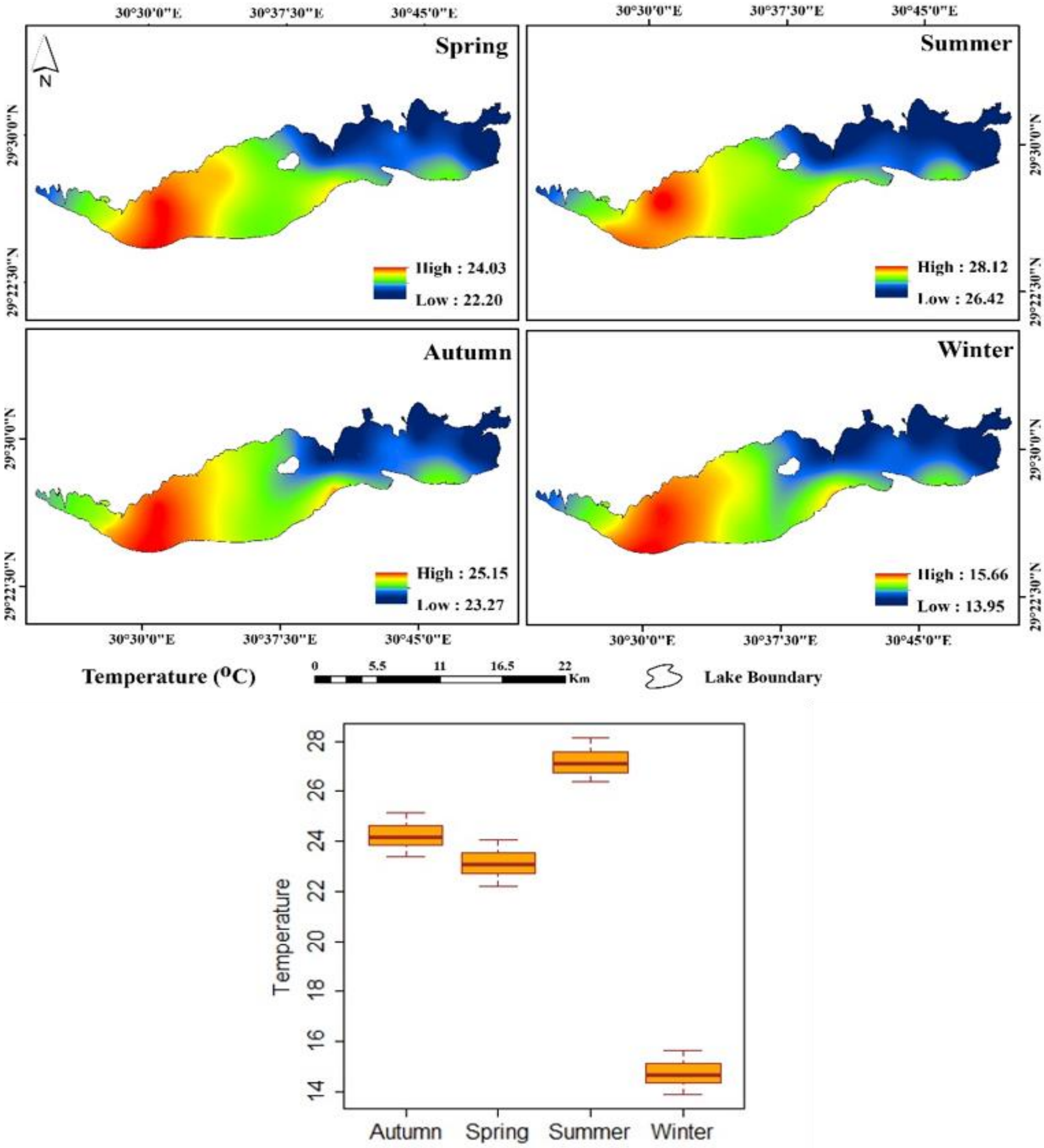




Min.	1st Qu.	Median	Mean	3rd Qu	Max.
5.40	7.64	17.71	20.30	31.12	65.88

Fig. 11. Seasonal turbidity level of Qarun Lake

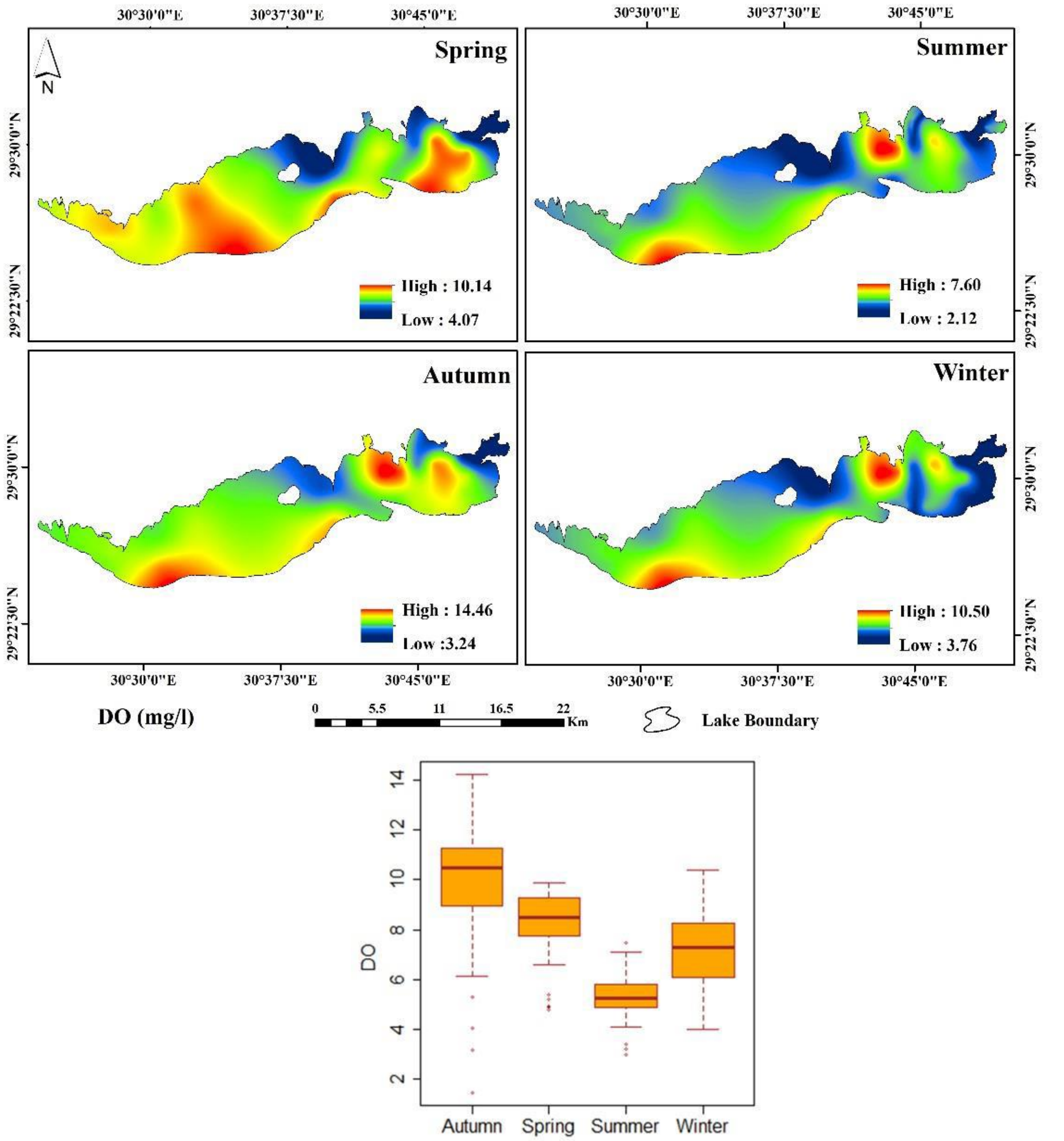
The continuous discharge of wastewater from the main drains into the lake results in a decrease in water temperature near the drains (Fig. 12). Temperature values ranged from 13.95°C in winter to 28.12°C in summer, with a mean of 22.33°C, a median of 23.74°C, a first quartile of 20.55°C, and a third quartile of 25.45°C.



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
13.89	20.55	23.74	22.33	25.45	28.14

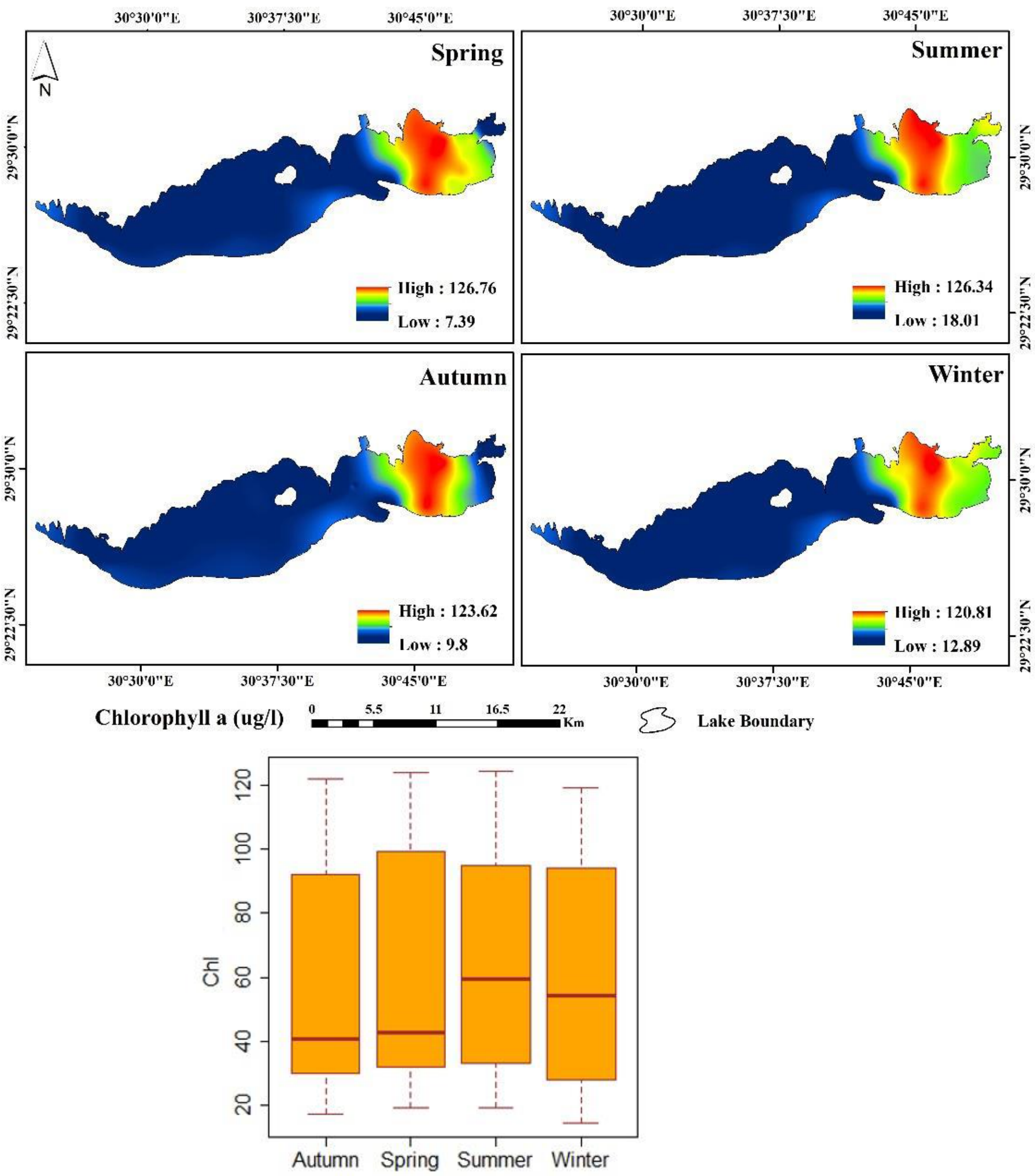
Fig. 12. Seasonal temperature level of Qarun Lake

DO represents the amount of oxygen freely available in water, which gives indication about the presence of flora and fauna in the water **(Sallam & Elsayed, 2018)**. DO is critical for survival of aquatic organisms. Fish and other aquatic species depend on the DO concentration of a water body for breathing **(El-Agri *et al.*, 2022)**. DO values ranged from 2.12mg/ l in summer to 14.46mg/ l in winter, with mean of 7.54mg/ l, median of 7.66mg/ l, first quartile of 5.38mg/ l, and third quartile of 9.32mg/ l. The low levels of dissolved oxygen (DO) indicate a high oxygen demand in the water. The elevated bacterial count from wastewater explains the reduced DO levels (Fig. 13) and the increased chlorophyll-a concentrations (Fig. 14) in the eastern part of the lake. Chlorophyll-*a* values ranged from 7.39µg/ l in spring to 126.34µg/ l in summer, with a mean of 62.9µg/ l, a median of 44.42µg/ l, a first quartile of 30.18µg/ l, and a third quartile of 94.99µg/ l.



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
2.12	5.38	7.66	7.54	9.32	14.46

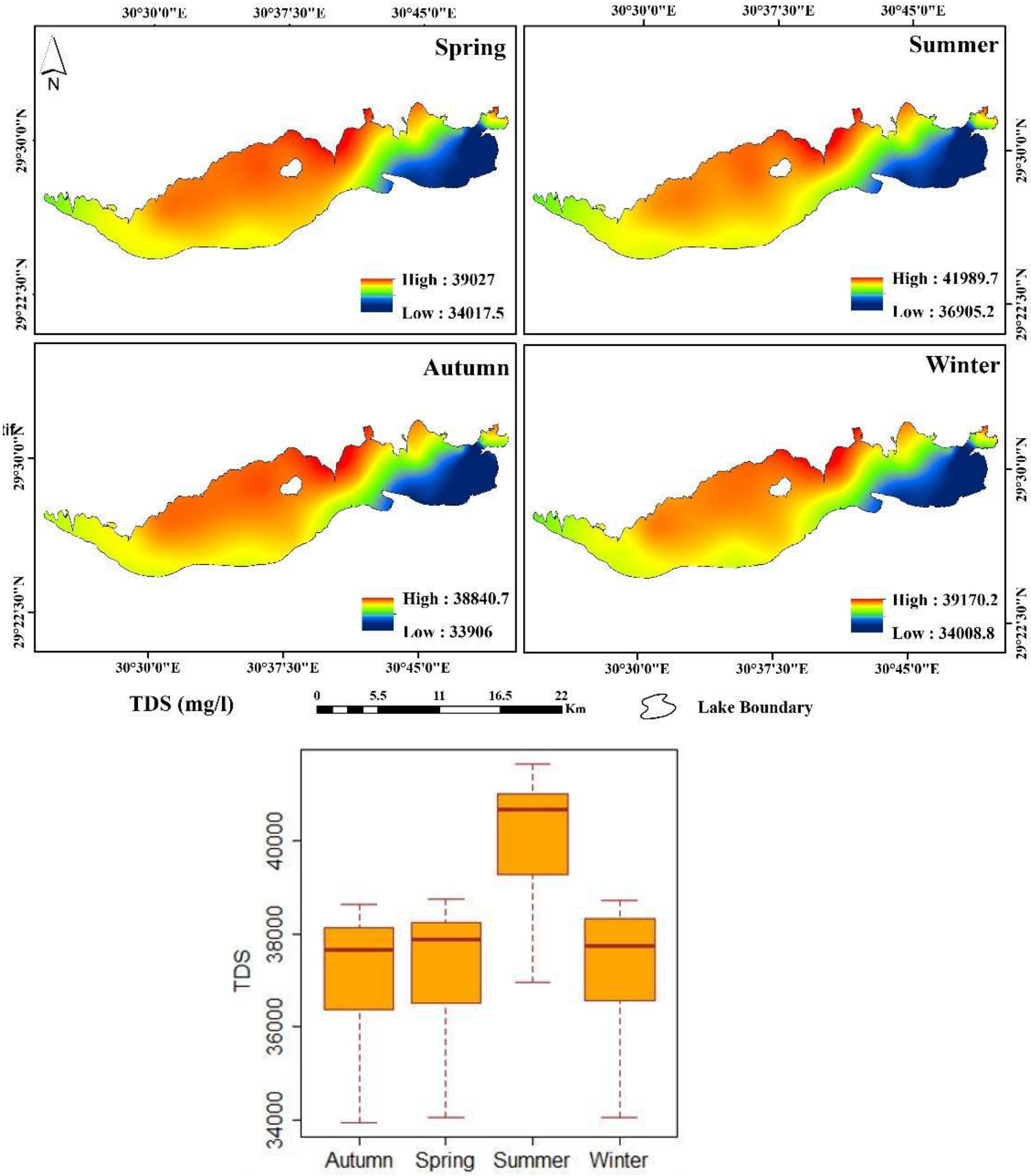
Fig. 13. Seasonal DO level of Qarun Lake



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
14.48	30.18	44.42	62.92	94.99	124.07

Fig. 14. Seasonal chlorophyll-*a* level of Qarun Lake

Fig. (15) exhibits the low level of TDS at the sites close to the drains as a result of the dilution effect of the brackish wastewater. The lowest values of TDS recorded in autumn with 33906mg/ l, while the highest values recorded in summer with 41989.7mg/ l, with mean of 37894mg/ l, median of 37945mg/ l, first quartile of 36760mg/ l, and third quartile of 38638mg/ l.



Min.	1st Qu.	Median	Mean	3rd Qu	Max.
33950	36760	37945	37894	38638	41650

Fig. 15. Seasonal TDS level of Qarun Lake

Correlation between water quality parameters and bacterial count

Correlation was applied to assess the quantitative relations between the water quality parameters and bacterial counts (before and after treatment) measured at all sampling sites (Fig. 16). Among the various regression models, the models having the highest R^2 value were selected for the estimation of bacterial count after treatment and for the prediction of its spatial distribution. The correlation plots expressed the distribution of each variable (diagonal); the bivariate scatter plots between each pair of parameters; and the correlation values with significance levels expressed in asterisk (*).

Correlation analysis showed significant positive correlation between TVBC (before treatment) and cDOM (r = 0.59), moderate positive correlation with turbidity (r = 0.44), negative correlation with DO, pH, and chlorophyll-a (r = –0.41, –0.27, and –0.20, respectively) and weak negative correlation with temperature, (r = –0.1), while no correlation with salinity and TDS.

In case of total viable bacterial count (TVBC) (after treatment), correlation analysis showed a moderate positive correlation with cDOM and turbidity (r = 0.45 and 0.42), a weak negative correlation with DO, pH, chlorophyll-*a*, and temperature (r = –0.34, –0.26, –0.13, and –0.10, respectively), while no correlation with salinity and TDS. TC and FC (before treatment) with salinity, TDS, and DO show weak negative correlation (r = –0.20, –0.20, and –0.11, respectively), and no correlation with pH, turbidity, chlorophyll-a, cDOM, temperature. Correlation between TC (after treatment) and chlorophyll-*a* having weak positive correlation (r = 0.14), weak negative correlation with TDS, salinity, and cDOM (r = –0.24, –0.23, and –0.13), and no correlation with pH, DO, temperature, and turbidity. FC (before treatment) did not correlate with pH, DO, temperature, and turbidity, but have weak positive correlation with chlorophyll-*a* (r = 0.17), and weak negative correlation with cDOM, salinity and TDS.

Negative correlation between pH, TDS, and turbidity in this study is consistent with results of **Aram *et al.* (2021)**. The negative correlation of pH and DO with TVBC, TC, and FC is considered a natural phenomenon **(Seo & Kim, 2019)**, attributed to the consumption of DO by coliform bacteria and the resultant reduction in pH due to carbon dioxide. The observation in this study is in line with the results of **Olalemi and Okunade, (2024)** that revealed that an increase in pH or salinity have a negative impact on the growth and survival of bacteria. The results also supported the findings of **Islam *et al.* (2017)** who proved the negative correlations between water salinity and bacterial counts.

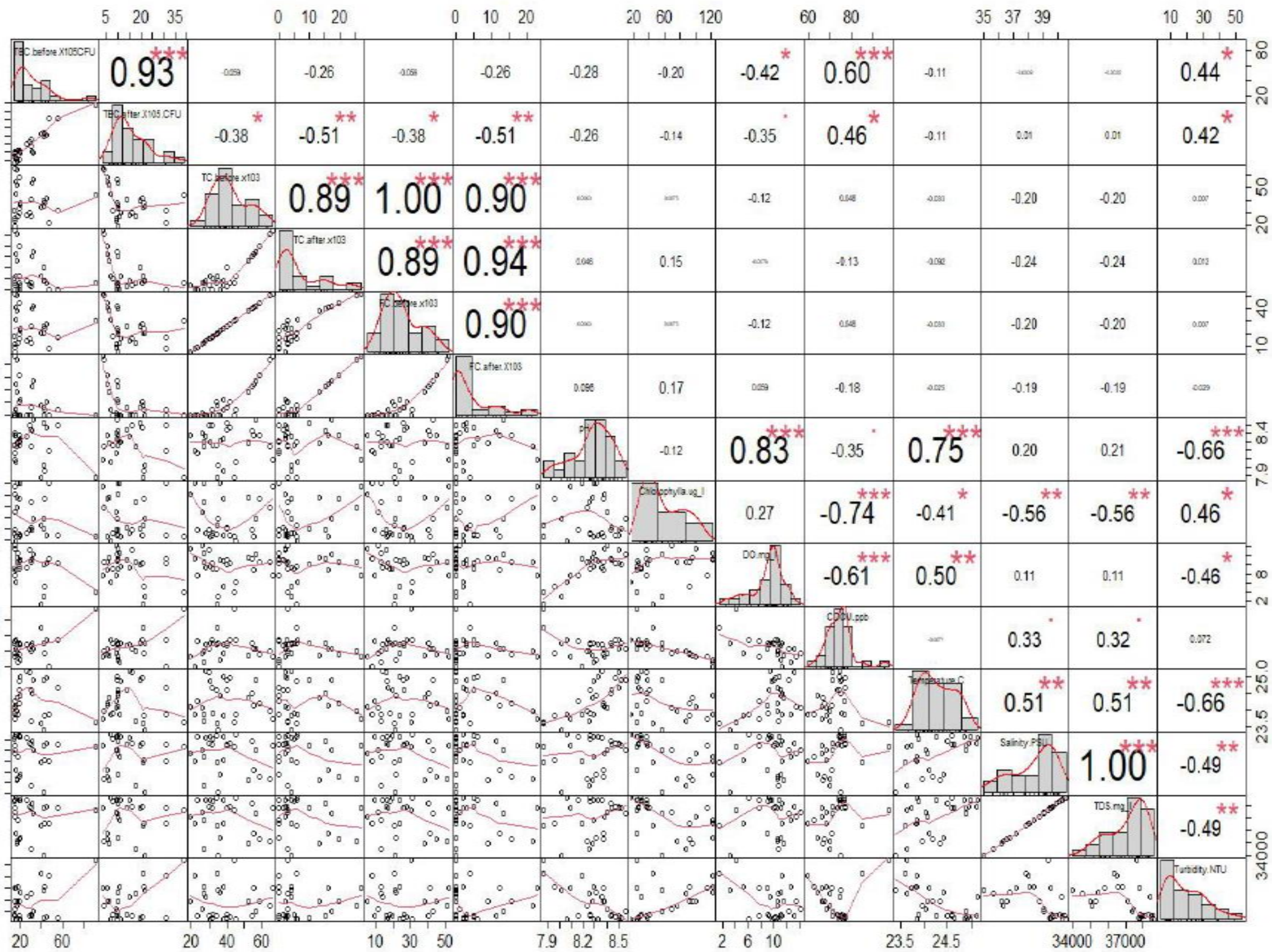
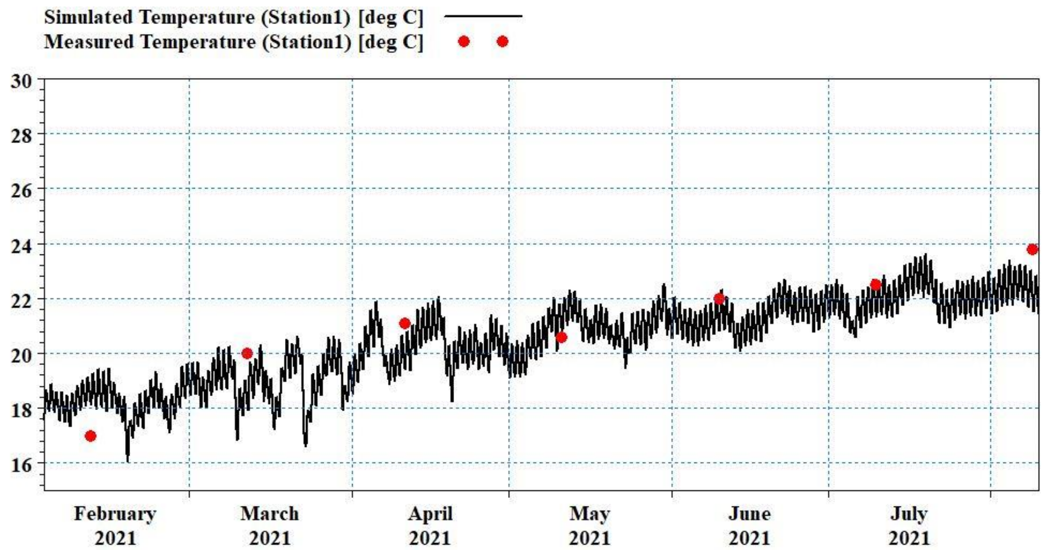


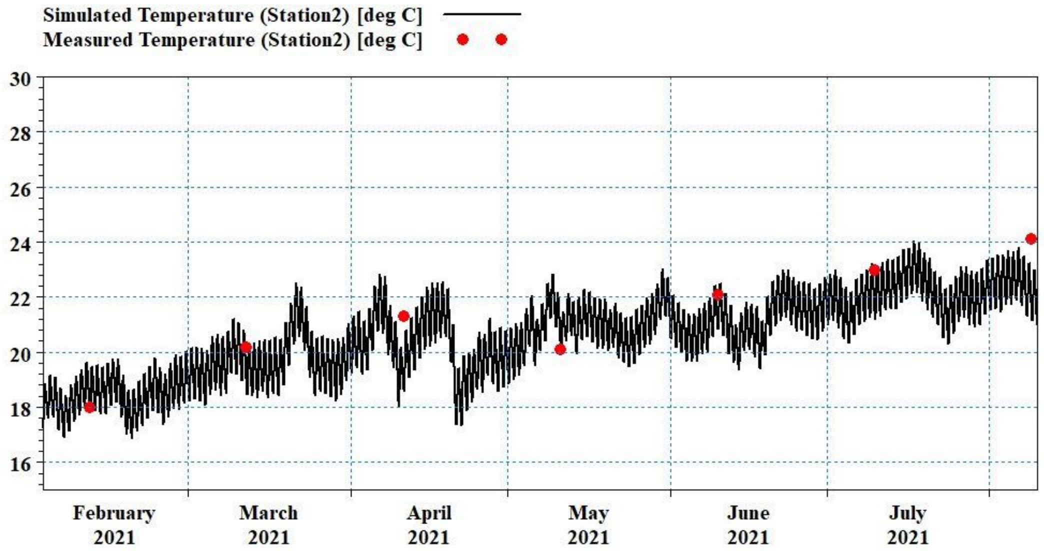
Fig. 16. Spearman correlation plots between water quality parameters and bacterial counts (before and after treatment), (n = 29). *p ≤ 0.05; ***P* ≤ 0.01; ****P* ≤ 0.001

Modelling results

Model validation

A comparison was conducted between the simulated and measured water temperature and salinity at sampling sites 1, 2, 3, 4, and 5, as illustrated in Figs. 17 and 18, respectively. The results demonstrated a strong correlation with the observed data for both parameters.





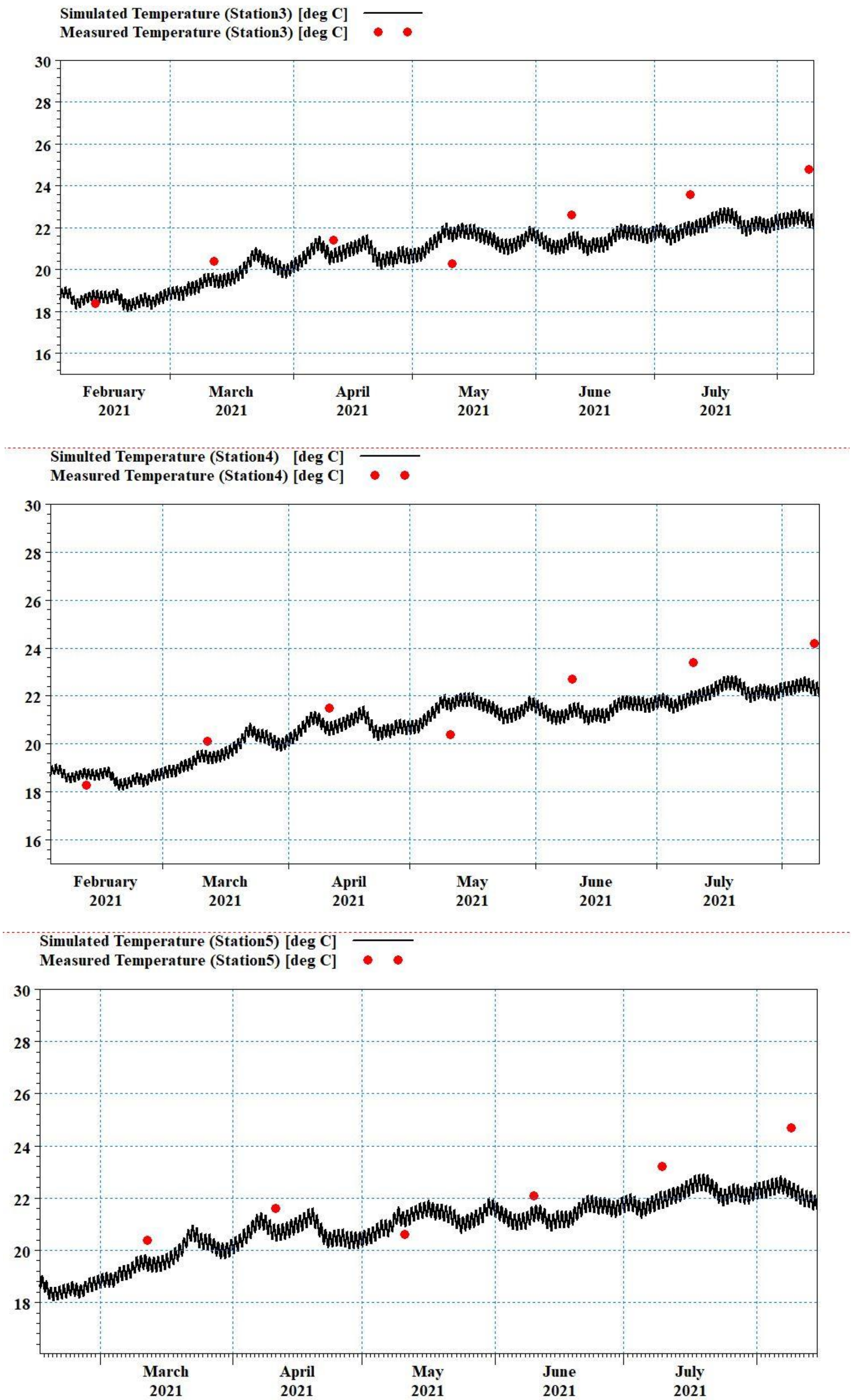
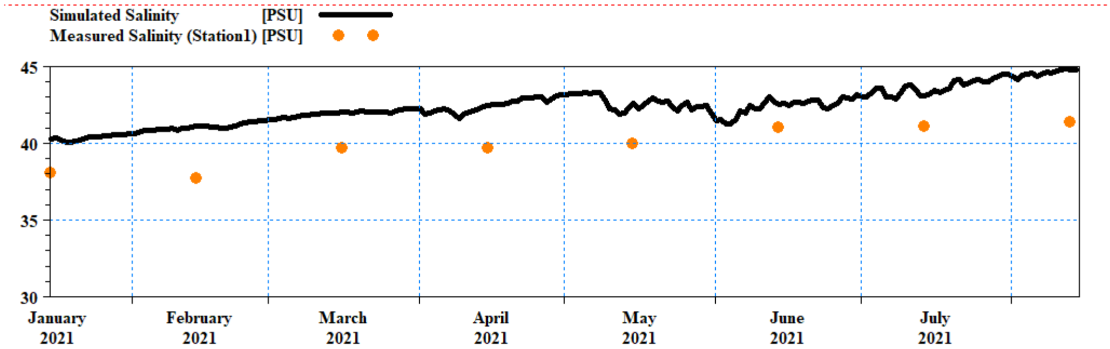
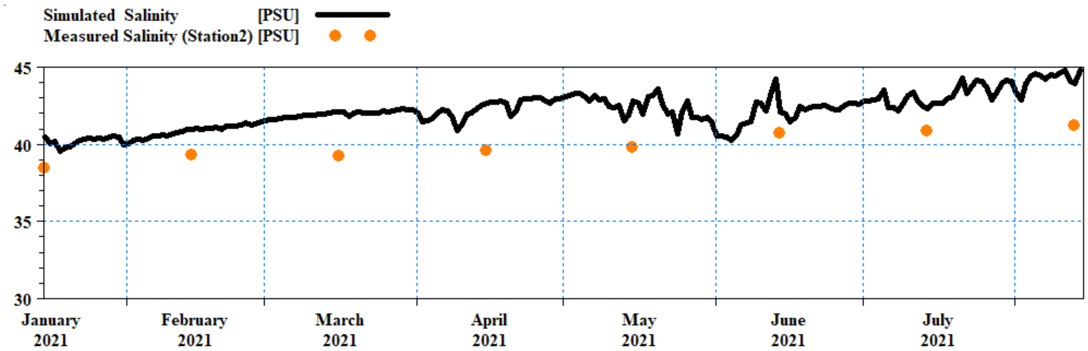
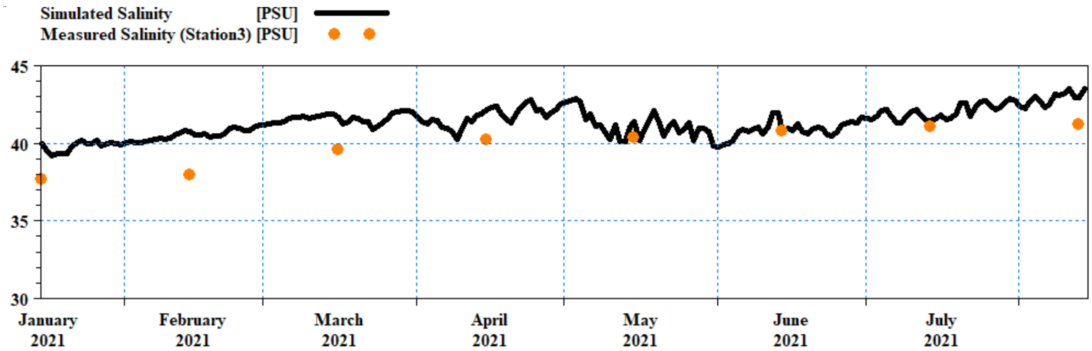
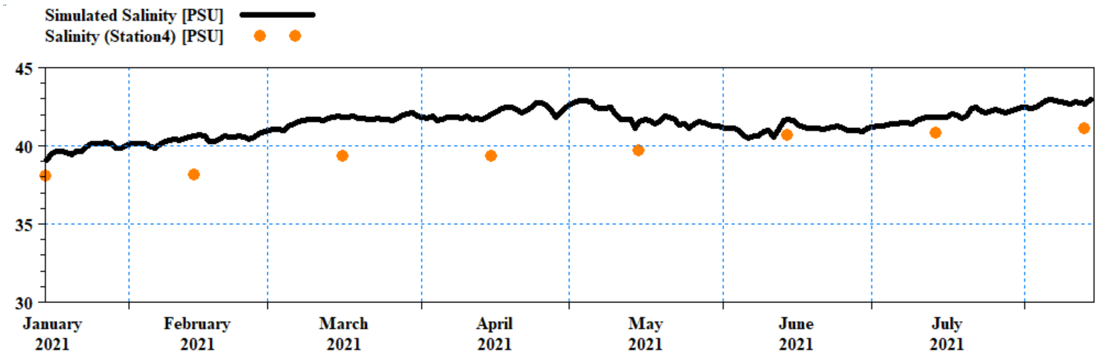


Fig. 17. Simulated and measured water temperature at the five verification sites


Simulated Salinity [PSU]
Measured Salinity (Station1) [PSU]
45
40
35
30
January 2021
February 2021
March 2021
April 2021
May 2021
June 2021
July 2021


Simulated Salinity [PSU]
Measured Salinity (Station2) [PSU]
45
40
35
30
January 2021
February 2021
March 2021
April 2021
May 2021
June 2021
July 2021


Simulated Salinity [PSU]
Measured Salinity (Station3) [PSU]
45
40
35
30
January 2021
February 2021
March 2021
April 2021
May 2021
June 2021
July 2021


Simulated Salinity [PSU]
Salinity (Station4) [PSU]
45
40
35
30
January 2021
February 2021
March 2021
April 2021
May 2021
June 2021
July 2021

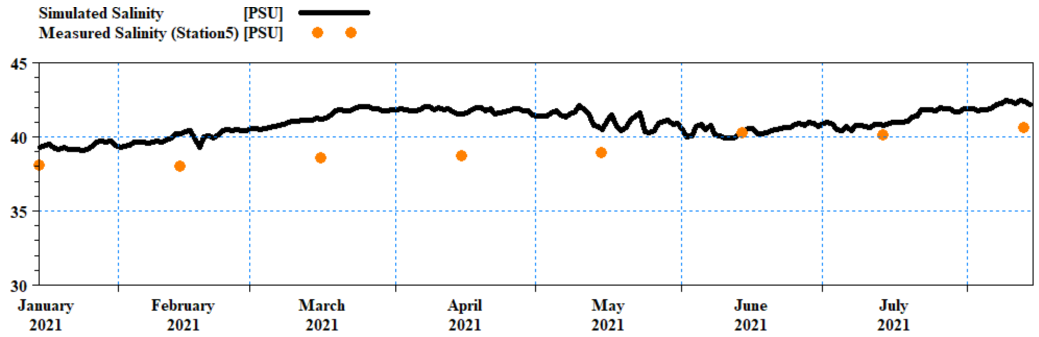


Fig. 18. Simulated and measured water temperature at the five verification sites (February – August)

The model results for water temperature and salinity showed a similar distribution pattern to the measured data. The temperature results (Fig. 19) indicated lower temperatures in front of the drains, while the salinity results (Fig. 20) demonstrated an increase in salinity from east to west, which is consistent with findings by **El-Zeiny *et al.* (2019)**.

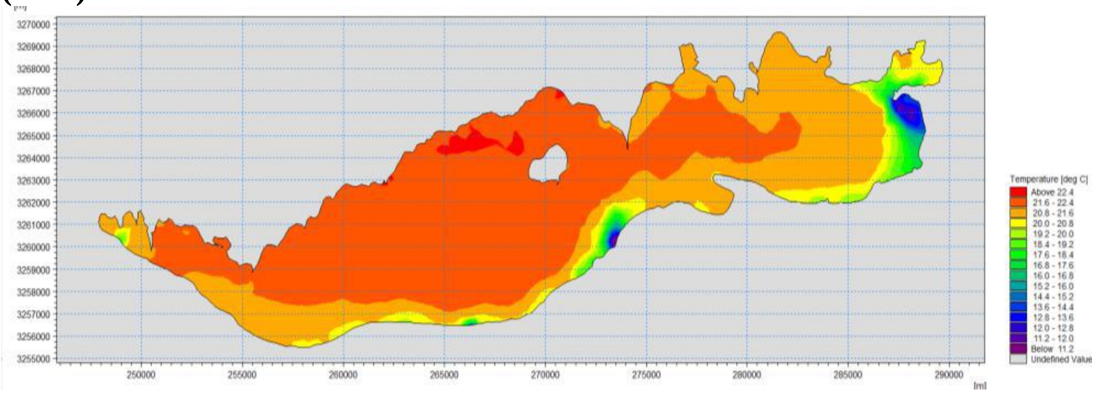


Fig. 19. Water temperature simulation result

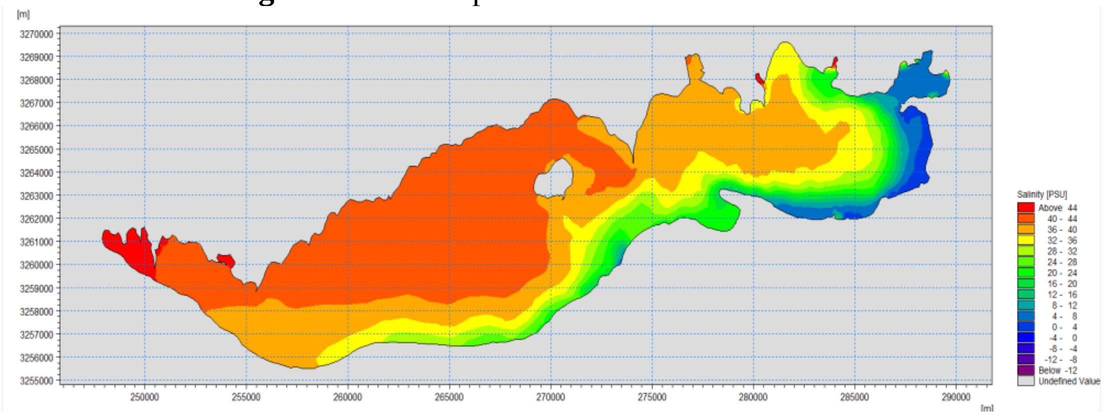


Fig. 20. Water salinity simulation result

Model simulation results

The modelling results highlighted the significant contribution of drains (as a source of contamination) to the total bacterial counts in Lake Qarun, particularly in the eastern part, and their impact on water quality. The model depicted the peak in total coliform (TC) and fecal coliform (FC) counts observed during the summer, followed by spring, with winter showing the lowest counts. Figs. (21, 22) compare the modelling results for TC and FC distribution during the summer season, before and after treatment. The results show the highest bacterial counts in the eastern part of the lake and near the main drain before treatment, and a significant decrease in bacterial counts after treatment.

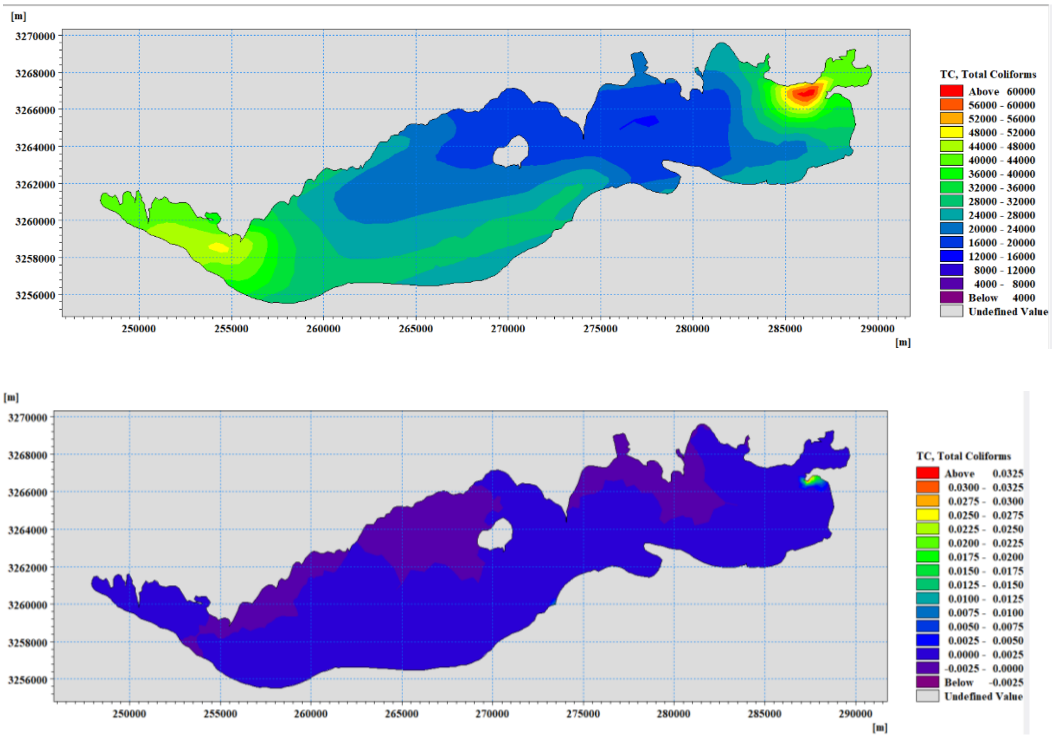


Fig. 21. TC simulation in summer 2021: **a)** Before treatment; **b)** After treatment

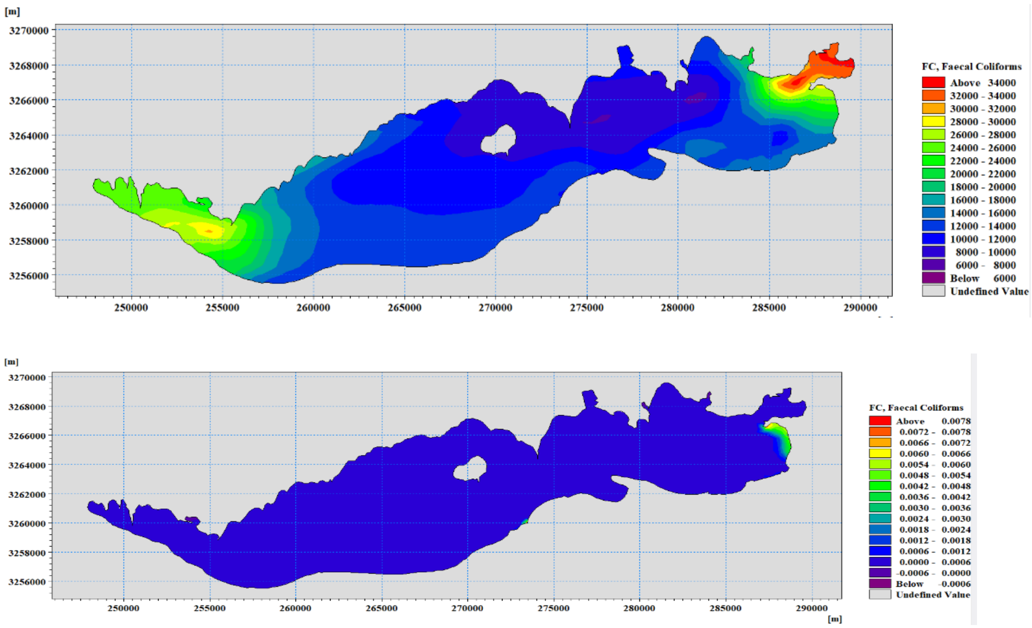
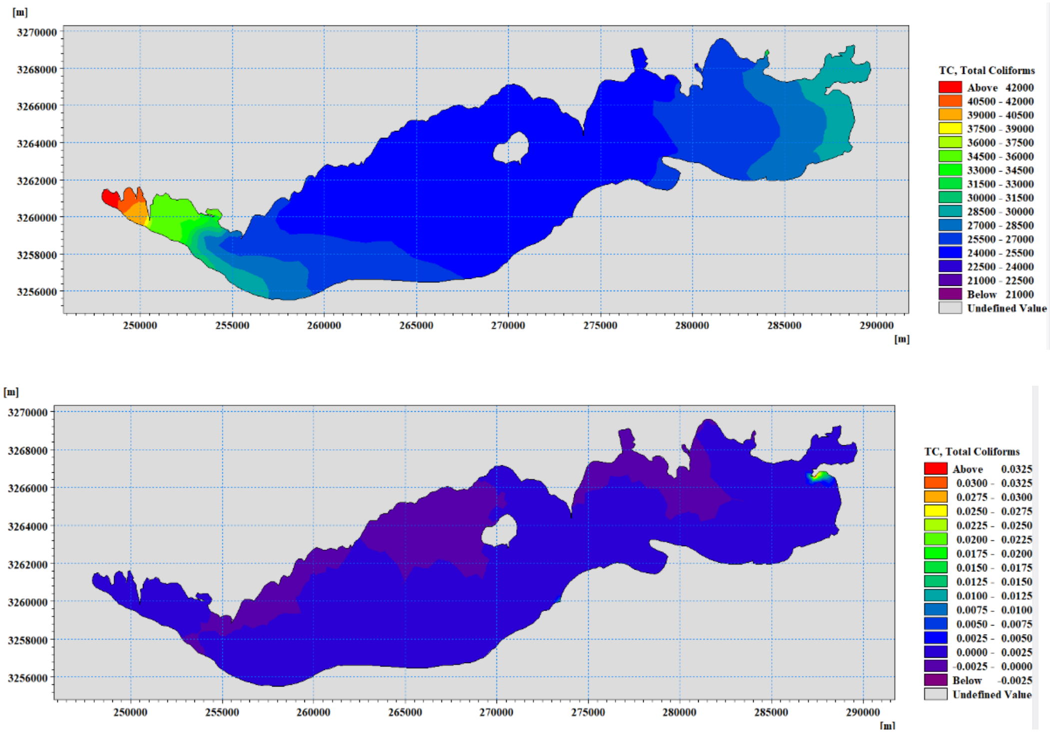


Fig. 22. FC simulation in summer 2021: **a)** Before treatment, **b)** After treatment

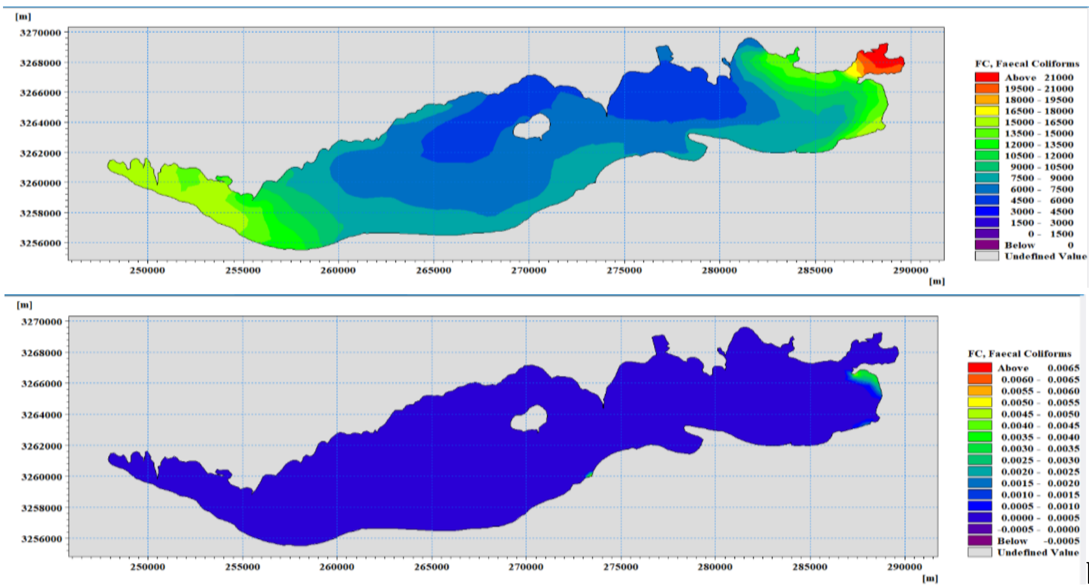
Figs. (23, 24) show the modeling results for the spring season, illustrating the distribution of total coliform (TC) and fecal coliform (FC). The bacterial counts in spring were lower than those in summer, with the highest counts still observed in the eastern part of the lake. After treatment, the bacterial counts decreased significantly. According to the modelling results, after contamination enters the lake through the water flow from the drains, the contaminants spread throughout the wider sections of the lake.



a

b

Fig. 23. TC simulation in spring 2021: **a)** Before treatment; **b)** After treatment

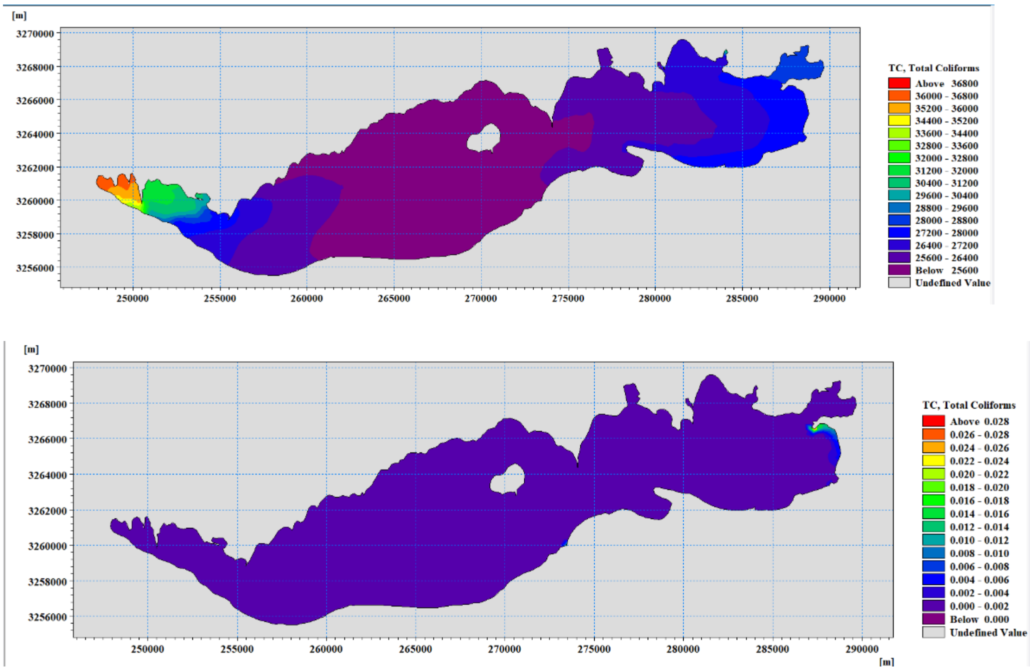


a

b

Fig. 24. FC simulation in spring 2021: **a)** Before treatment; **b)** After treatment

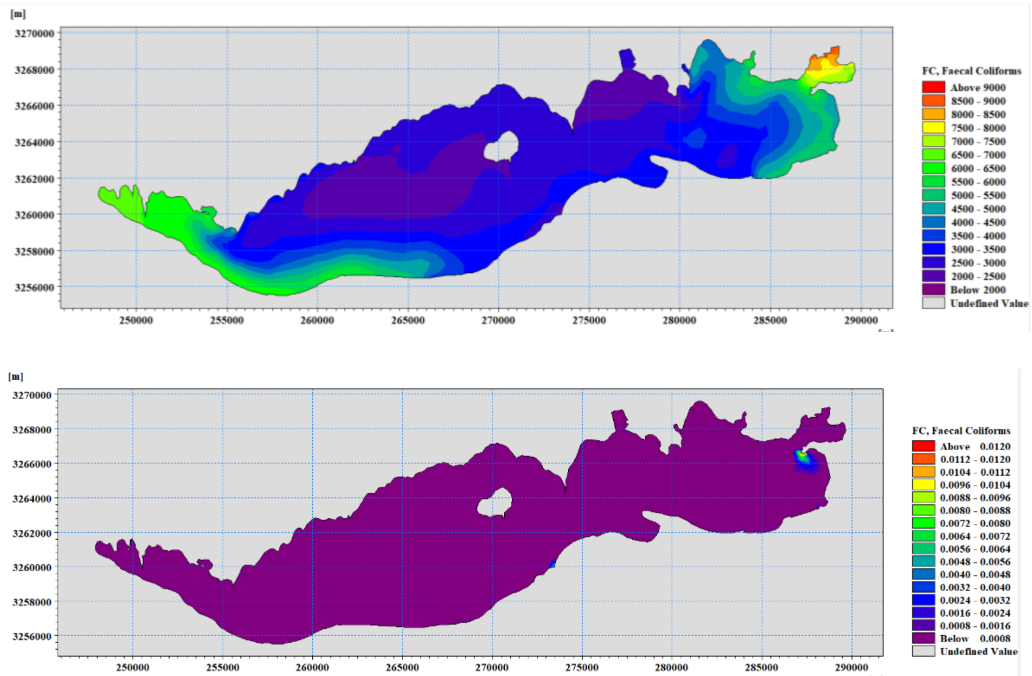
Figs. (25, 26) show the result of modelling for winter season with the lowest bacterial count of TC and FC distribution before and after treatment; the results also proved the high efficiency of the treatment against bacterial count. The modelling results, based on the scenario of treatment using biosynthesized AgNPs, demonstrated that the bacterial counts of TC and FC could be significantly reduced through wastewater treatment, leading to an improvement in the water quality of the lake.



a

b

Fig. 25. TC simulation in winter 2021: **a)** Before treatment; **b)** After treatment



a

b

Fig. 26. FC simulation in winter 2021: **a)** Before treatment; **b)** after treatment

CONCLUSION

Efforts to remediate contaminated sites have become increasingly valuable in response to the adverse health effects of pollution. Traditional methods often only transfer contaminants to different phases, incurring high costs and generating hazardous waste. Bioremediation, however, is a promising, cost-effective solution that utilizes natural biological processes to eliminate various contaminants. In lake water management, it is essential to predict pathogen migration to assess the microbial load entering the lake, as well as the distribution and fate of these microorganisms. Ecological modeling provides a clear understanding of lake hydrodynamics, contaminant fate, and water quality after bioremediation.

Understanding the movement and fate of contaminants, as well as the contributions from different fecal sources, is critical to improving microbiological water quality and preventing waterborne diseases. In this study, an integrated hydrodynamic and water quality model (ECO Lab) was used to model the fate and movement of coliform bacteria in Lake Qarun. In 2021, a hydrodynamic model was developed and calibrated based on salinity and temperature measurements. Bacterial count data from various sources were input into the ECO Lab model, and the model's outputs closely matched the observed data. Finally, the model was used to assess the impact of wastewater treatment on bacterial levels. The results indicated that wastewater treatment would significantly improve the microbial water quality of Lake Qarun. This study highlights the dynamics of bacterial movement, the contribution of different fecal sources to contamination, and the effectiveness of silver nanoparticle-based wastewater treatment in improving water quality in Lake Qarun.

REFERENCES

Abou El-Gheit, E.; Abdo, M. and Mahmoud, S. (2012). Impacts of blooming phenomenon on water quality and fishes in Qarun Lake, Egypt. International Journal of Environmental Science and Engineering, 3, 11-23.

Al-Wasify, R. S.; Ali, M. N. and Hamed, S. R. (2017). Biodegradation of dairy wastewater using bacterial and fungal local isolates. Water Science and Technology, 76(11), 3094-3100.

Aram, S. A.; Saalidong, B. M. and Osei Lartey, P. (2021). Comparative assessment of the relationship between coliform bacteria and water geochemistry in surface and ground water systems. Plos one, 16(9), e0257715.

Arseni, M.; Voiculescu, M.; Georgescu, L. P.; Iticescu, C. and Rosu, A. (2019). Testing different interpolation methods based on single beam echosounder river surveying. Case study: Siret River. ISPRS International Journal of Geo-Information, 8(11), 507.

Assar, W.; Elshemy, M. and Zeidan, B. (2015). Water Quality Modeling for Lake Burullus, Egypt, Part I: Model Calibration. ..Mansoura Engineering journal, 40.

Basheer, M. A.; Abutaleb, K.; Abed, N. N. and Mekawey, A. A. (2023). Mycosynthesis of silver nanoparticles using marine fungi and their antimicrobial activity against pathogenic microorganisms. *Journal of Genetic Engineering and Biotechnology*, *21*(1), 127.

Deshmukh, R.; Khardenavis, A. A. and Purohit, H. J. (2016). Diverse metabolic capacities of fungi for bioremediation. Indian journal of microbiology, 56(3), 247-264.

El-Agri, A. M.; Emam, M. A.; Gaber, H. S.; Hassan, E. A. and Hamdy, S. M. (2022). Integrated use of biomarkers to assess the impact of heavy metal pollution on *Solea aegyptiaca* fish in Lake Qarun. Environmental Sciences Europe, 34(1), 74.

El-sayed, M. (2021). Microbial and Physico-Chemical Assessment of Wastewater Plants Before Discharge in Qarun Lake, El-Fayoum Governorate, Egypt. Al-Azhar Journal of Pharmaceutical Sciences, 63(1), 173-193.

El-Zeiny, A. M.; El Kafrawy, S. B. and Ahmed, M. H. (2019). Geomatics based approach for assessing Qaroun Lake pollution. The Egyptian Journal of Remote Sensing and Space Science, 22(3), 279-296.

Galal, E. M. and Youssef, H. Z. (2023). Flushing characteristics of a marina using a 2D Hydrodynamic Model: Case study of the new extension of Al-Wakrah Port, Qatar. Port-Said Engineering Research Journal, 27(1), 54-67.

Islam, M. M.; Hofstra, N. and Islam, M. A. (2017). The impact of environmental variables on faecal indicator bacteria in the Betna river basin, Bangladesh. Environmental Processes, 4, 319-332.

Khwairakpam, E.; Khosa, R.; Gosain, A. and Nema, A. (2021). Water quality assessment of Loktak Lake, Northeast India using 2-D hydrodynamic modelling. SN Applied Sciences, 3, 1-10.

Lemessa, F.; Simane, B.; Seyoum, A. and Gebresenbet, G. (2023). Assessment of the Impact of Industrial Wastewater on the Water Quality of Rivers around the Bole Lemi Industrial Park (BLIP), Ethiopia. Sustainability, 15(5), 4290.

Li, X.; Huang, M. and Wang, R. (2020). Numerical simulation of Donghu Lake hydrodynamics and water quality based on remote sensing and MIKE 21. ISPRS International Journal of Geo-Information, 9(2), 94.

Negm, A. M.; Bek, M. A. and Abdel-Fattah, S. (2018). Egyptian Coastal Lakes and Wetlands: Part I: Characteristics and Hydrodynamics (Vol. 71): Springer.

Nemethy, S. A. and Molnar, G. (2014). Sustainable management of lakes in connection with mitigation of adverse effects of climate change, agriculture and development of green micro regions based on renewable energy production. EQA-International Journal of Environmental Quality, 13(13), 21-35.

Olalemi, A. O. and Okunade, A. S. (2024). Effect of some physicochemical parameters on the decay rate of enteric bacteria isolated from River Owena, Nigeria. Environmental Sciences Europe, 36(1), 1-14.

Qiao, H.; Zhang, M.; Jiang, H.; Xu, T. and Zhang, H. (2018). Numerical study of hydrodynamic and salinity transport process in Pink Beach wetlands of Liao River Estuary, China. Ocean Science Discussions, 1-29, doi:10.5194/os-2017-102.

Sallam, G. A. and Elsayed, E. A. (2018). Estimating relations between temperature, relative humidity as independed variables and selected water quality parameters in Lake Manzala, Egypt. Ain Shams Engineering Journal, 9(1), 1-14.

Schallenberg, M.; de Winton, M. D.; Verburg, P.; Kelly, D. J.; Hamill, K. D. and Hamilton, D. P. (2013). Ecosystem services of lakes. Ecosystem services in New Zealand: conditions and trends. Manaaki Whenua Press, Lincoln, 203-225.

Seif, E.; Shokr, H.; Youssef, A. M.; Sharaf Eddeen, M.; Diab, Y. and Imam, Y. E. (2023). Climate change effect on water temperature and evaporation in Lake Qarun. Water Science, 37(1), 1-10.

Seo, M.; Lee, H. and Kim, Y. (2019). Relationship between coliform bacteria and water quality factors at weir stations in the Nakdong River, South Korea. Water, 11(6), 1171.

Shaaban, M.; Ibrahim, H.; Ahmed, A. and Hanafi, M. (2016). Distribution of bacteria in Lake Qarun, AL Fayoum, Egypt (2014 -2015) in relation to its physical and hydrochemical characterization. Journal of Bioscience and Applied Research, eISSN, 601-615.

Shadrin, N. V.; El-Shabrawy, G. M.; Anufriieva, E. V.; Goher, M. E. and Ragab, E. (2016). Long-term changes of physicochemical parameters and benthos in Lake Qarun (Egypt): Can we make a correct forecast of ecosystem future. Knowledge and management of aquatic ecosystems, (417), 18.

Ventura, M.; Careddu, G.; Calizza, E.; Sporta Caputi, S.; Argenti, E., Rossi, D. and Costantini, M. L. (2023). When Climate Change and Overexploitation Meet in Volcanic Lakes: The Lesson from Lake Bracciano, Rome's Strategic Reservoir. Water, 15(10), 1959.

Wong, H.L. and Teo, F.Y. (2023). Hydrodynamic modelling and shape optimisation of second-generation coastal reservoirs in consideration of algal bloom occurrence. Environment, Development and Sustainability, 1-37, https://doi.org/10.1007/s10668-023-03069-4.

Xu, C.; Ren, Z.; Huang, S.; Li, J., Zi, Y. and Hu, X. (2023). Simulation Study on the Impact of Water Flow Regulation Based on the MIKE 21 Model in a River Water Environment. Sustainability, 15(13), 10313.

Zheng, Y.; Wang, X.; Li, S.; Dong, G.; Wang, Q.; Chen, Y. and Xue, S. (2024). Numerical simulation model of water quality evolution in urban rivers considering adsorption–desorption process of nitrogen and phosphorus in sediments. *Journal of Hydrology*, *636*, 131104.

Websites: https://power.larc.nasa.gov/data-access-viewer/.