Blue Economy

Volume 1 | Issue 2 Article 10

2023

Ecological Assessment Of Drainage Water Input On The Water Quality Of A Coastal Estuary, Mediterranean Coast Of Egypt

Fatma A. Zaghloul
National Institute of Oceanography and Fisheries, NIOF, Egypt

Hoda A. E. Hemaida
National Institute of Oceanography and Fisheries, NIOF, Egypt

Hayat M. Faragallah
National Institute of Oceanography and Fisheries, NIOF, Egypt

Ahmed A. Radwan
National Institute of Oceanography and Fisheries, NIOF, Egypt, aa_radwan@yahoo.com

ISSN: 2805-2986 – e-ISSN: 2805-2994

RESEARCH ARTICLE

Ecological Assessment of Drainage Water Input on the Water Quality of a Coastal Estuary: The Mediterranean Coast of Egypt

Fatma A. Zaghloul [a], Hoda A.E. Hemaida [b], Hayat M. Faragallah [b], Ahmed A. Radwan [c,*]

[a] Marine Hydrography Lab, National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt
[b] Marine Chemistry Lab, National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt
[c] Physical Oceanography, National Institute of Oceanography and Fisheries, NIOF, Cairo, Egypt

Abstract

El Mex Bay, located west of Alexandria City, is identified as a hot spot of pollution along the Mediterranean coast of Egypt. It is a large, shallow, and turbid water body of socioeconomic importance. However, El Mex Bay receives a large amount of untreated industrial wastewater, as well as agricultural runoff from different land-based sources.

A comprehensive environmental study was carried out seasonally during 2020−2021. To evaluate the effect of this discharged wastewater on the water quality of El Mex Bay.

The physicochemical parameters were measured at both the surface and near-bottom water at nine stations.

Principal component analysis indicated that the dissolved inorganic nitrogen is largely controlled by the water quality of the Bay. The pollution index was calculated based on standard and measured water quality parameters, which indicated that El Mex Bay is highly eutrophic and heavily polluted to different degrees. The residence time of El Mex Bay water fluctuated between 3.97 and 10.05 days in winter 2020 and spring 2020, respectively. Regarding sustainable development, improving the integrated management of water quality, raising agricultural efficiency, and preserving the environment. It is necessary to create a wastewater purification plant on the El Mex pumping station to benefit from it in many fields.

The study thus recommends the discharge of treated and recycling of anthropogenic wastes to control eutrophication and pollution.

Keywords: El Mex bay, Environmental parameters, Principal component analysis, Residence time, Trophic state, Water quality

1. Introduction

The El Mex Bay is a large, shallow, and turbid estuary of socioeconomic importance located west of Alexandria City. It receives large amounts of untreated industrial wastewater from petrochemicals, pulp, metal planting dyes, and textiles, agricultural runoffs, and sewage wastes from the adjacent Lake Mariut through the El Umum Drain. These conditions cause pronounced eutrophication and drastic environmental changes. El Mex Bay demonstrated wide-range variations in its surface salinity on a spatial scale relative to the dispersal pattern of the discharged wastewater. The salinity of the near-shore waters sustained usually low values, increasing seaward to exceed 39.8 ‰ in the open part of the bay (Shaltout, 2008).

Water pollution is a serious threat to marine ecosystems. Estuaries and coastal areas are the most suitable areas for wastewater discharges from man-made activities. Urbanization imposes a physical and chemical load on surrounding water bodies,

Received 9 July 2023; revised 18 October 2023; accepted 22 October 2023.
Available online 24 January 2024

* Corresponding author. Physical Oceanography Lab, POC, National Institute of Oceanography and Fisheries (NIOF), Cairo, 21556, Egypt
E-mail addresses: dr.zaghloul89@yahoo.com (F.A. Zaghloul), Hoda.hemaida@gmail.com (H.A.E. Hemaida), hm.faragllah@niof.sci.eg (H.M. Faragallah), aa_radwan@yahoo.com (A.A. Radwan).

https://doi.org/10.57241/2805-2994.1009

changing the ecosystem and leaving a record of disturbance in the sediments of water bodies (Haas, 2002; Vaalgamaa, 2004). The Mediterranean Sea is generally characterized by a nutrient decrease from west to east, resulting in variations in the structure of the pelagic food web (Kress, 2003; Pujo-Pay et al., 2011). Nutrients act as raw materials for the organisms within the ecosystem to build up their cells and tissues and to continue their growth, but without them, the organism will not be able to survive. The discharges into El Mex Bay caused an increase in nutrient levels, which consequently became eutrophic. Eutrophication is a complex process, which occurs both in fresh and marine waters, where excessive development of certain types of algae disturbs the aquatic ecosystems and becomes a threat to animal and human health. The primary cause of eutrophication is an excessive concentration of plant nutrients, which cause phytoplankton to grow and may use up all the oxygen in the water, leaving none for other marine life (WHO, 2002). An ecosystem is a closed system, where everything that it requires to activate the system comes within the system itself.

Much of the high temporal and spatial variability in physical, chemical, and biological conditions in estuaries occurs through seasonal and interannual variability in freshwater flow (Kimmerer, 2002). Estuaries receiving high organic and inorganic inputs act as nutrient traps, eventually developing the processes of eutrophication (de Jonge et al., 2002). Globally, these systems have been the focus of research programs aimed at understanding anthropogenic influences (Bricker et al., 1999).

Water quality monitoring is a strategy essential for determining the chemical, physical, and biological characteristics that allow the early detection of potential sources of pollution, and the water quality information is very important in supporting the planning and management of coastal and marine areas under the influence human activities (Dodds and Smith, 2016; Mahmoud et al., 2020). The principal component analysis (PCA) and factor analysis effectively estimated the water quality through a water quality index (Zaghloul et al., 2020). Fathy et al. (2012) used PCA to investigate the water quality of three sites located in the coastal area in front of Alexandria.

El Mex Bay attracts the attention of many authors, consequently, several chemical studies were carried out to monitor its water quality (Mahmoud, 1979, 1985, 1995; Farag, 1982; Said et al., 1993; Fahmy et al., 1995; Tayel et al., 1996; Mahmoud and Deek, 1997; Abou-Tahoun, 1999; Shoukry, 1999; Masoud et al., 2001; Abdel-Halim, 2004; Nessim et al., 2010; Abdel-Rhman, 2013; Shreadah et al., 2014; Okbah et al., 2017).

The present work aimed to monitor the physical–chemical parameters and study the impact of dissolved nutrient input from uncontrolled land-based discharges (industrial, agricultural, and domestic) in El Mex Bay to assess water quality. Besides a comparison was made with previous studies to highlight the changes that have occurred due to the increase in the volume of discharged water.

2. Materials and methods

2.1. Study area

The El Mex Bay is a relatively large coastal embayment west of Alexandria, with an average depth of ~10.2 m and a surface area of ~15.56 km^2 (Fig. 1). It is elliptical and extends for about 15 km between El Agami headlands to the west and the Western Harbour to the east. Despite being an important fishing area, El Mex Bay is heavily polluted, receiving huge amounts of agricultural, industrial, and sewage discharges from the adjacent Lake Mariut through the El Umum Drain. According to the Drainage Research Institute, the volume of the wastewater varied between 7 × 10^6 and 8 × 10^6 m^3/day, which is supposed to increase with the growing population density of Alexandria City.

2.2. Sampling and analysis

Surface water samples were collected seasonally from winter 2020 to spring 2021 from nine stations (Stations 1 and 2 representing El Umum Drain water, while stations from 3 to 9 represent El Mex Bay). Near-bottom water samples were collected

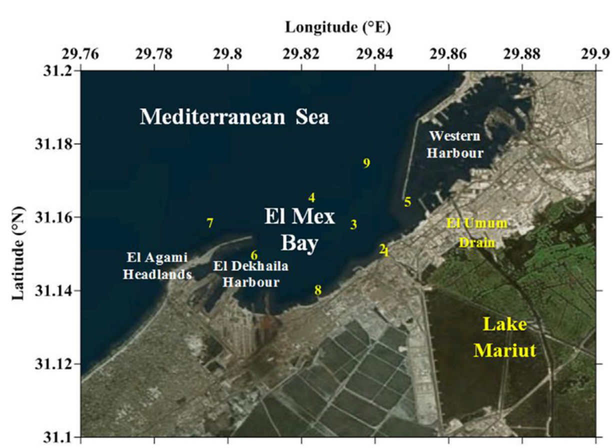

Fig. 1. Map showing sampling stations from El Mex Bay during 2020–2021.

from six stations (3, 4, 5, 6, 7, 9). However, the rest stations are shallow.

The surface water temperature was measured *in situ* using a calibrated thermometer. Salinity was determined using a multiparameter (model, YSI556MPS). The classical Winkler method, modified by Grasshoff et al. (1999) was used for the determination of dissolved oxygen (DO). The oxidizable organic matter (OOM) was measured according to FAO (1976). Dissolved inorganic nutrients (DIN) [nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), and silicate (SiO_4)] were measured according to Grasshoff et al. (1999).

2.3. Water pollution index

The following formula was applied to calculate the pollution index (PI) in El Mex Bay (Nemerow and Sumitomo, 1970):

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_M^2 + (C_i/L_{ij})_R^2}{2}}$$

Where: L_{ij}: Standard water quality parameter for each parameter at specified water quality purpose (j), C_i:: measured water quality parameters I; PI_j: the pollution index

Water quality purpose (j); $(C_i/L_{ij})_M$: maximum value of C_i/L_{ij} and $(C_i/L_{ij})_R$: average value of C_i/L_{ij}.

$0 \geq PI_j \leq 1$: good quality, $1 \geq PI_j \leq 5$: lightly polluted, $5 \geq PI_j \leq 10$: moderately polluted, and $PI_j \geq 10$: highly polluted.

2.4. Trophic states based on nutrient salts

The trophic state was estimated based on inorganic nutrient data (P-PO_4, N–NO_3, N–NO_2, N–NH_4) following the methods outlined by OSPAR (2003), Ignatiades et al. (1992), and Ferreira et al. (2011), which categorize the aquatic system into various trophic levels: high (H), good (G), poor (P), and B (bad) water types (Table 1).

2.5. Residence time

It is calculated according to El Gindy et al. (1986) as follows:

Table 1. Boundary values between ecological quality classes for water variables.

Nutrient element	H/G	G/M	M/P	P/B
Nitrite and nitrate	5 μM	10 μM	20 μM	40 μM
Ammonium	1 μM	2 μM	4 μM	8 μM
Phosphate	0.4 μM	0.8 μM	1.4 μM	μM

$$t = \frac{V\,(S_i - S_o)}{S_i \times QR}$$

Where t is the residence time, S_o the salinity in the surface layer, S_i the salinity in subsurface layer, V, the volume of the water in the Bay, and QR is the amount of water from through the El Umum Drain added to the basin.

2.6. Statistical analysis

The statistical analysis was performed using IBM® SPSS® 18, USA. PCA was conducted on $\log_{10}$ (X+1) transformed and standardized data to estimate the most significant factor affecting water quality in El Mex Bay.

3. Results

3.1. Physicochemical parameters of El Mex Bay water

3.1.1. Water temperature

The water temperature ranged in El Umum Drain between 16.4 and 28.2 °C with an annual average of 21.6 ± 3.78 °C. The surface water temperature of El Mex Bay fluctuated between 17.2 and 27.9 °C with an annual average of 22.1 ± 4.32 °C. While in the near-bottom layer, the temperature ranged from 17.4 to 27.3 °C and an annual average of 21.6 ± 3.78 °C (Fig. 2).

3.1.2. Water salinity

The water at El Umum Drain was characterized by low salinity due to the freshwater input, where it ranged between 3.61 in January 2020 and 4.75 in June 2021, with an annual average of 4.05. The salinity values at El Umum Drain depend mainly on the amount of wastewater discharged through the Drain. The salinity values at different stations varied according to their distance from the source of the discharged water. At the surface layer of El Mex Bay, salinity fluctuated between 11.3 (St.4, in winter 2020) and 39.06 (St. 5, in summer 2020) with an annual average of 34.96. In the near-bottom water, it ranged from 38.3 (Sts. 5 and 6, in spring 2021) to 38.95 (Sts.4 and 6, in summer 2020) with an annual average of 38.44 (Fig. 3).

The salinity increased at the bottom water compared with those recorded on the surface water, due to the mixing with freshwater (Fig. 3).

3.1.3. Dissolved oxygen

El Umum Drain water was characterized by low oxygen content, where it ranged between 5.54 mg/l in the spring of 2021 and 11.34 mg/l in the winter of

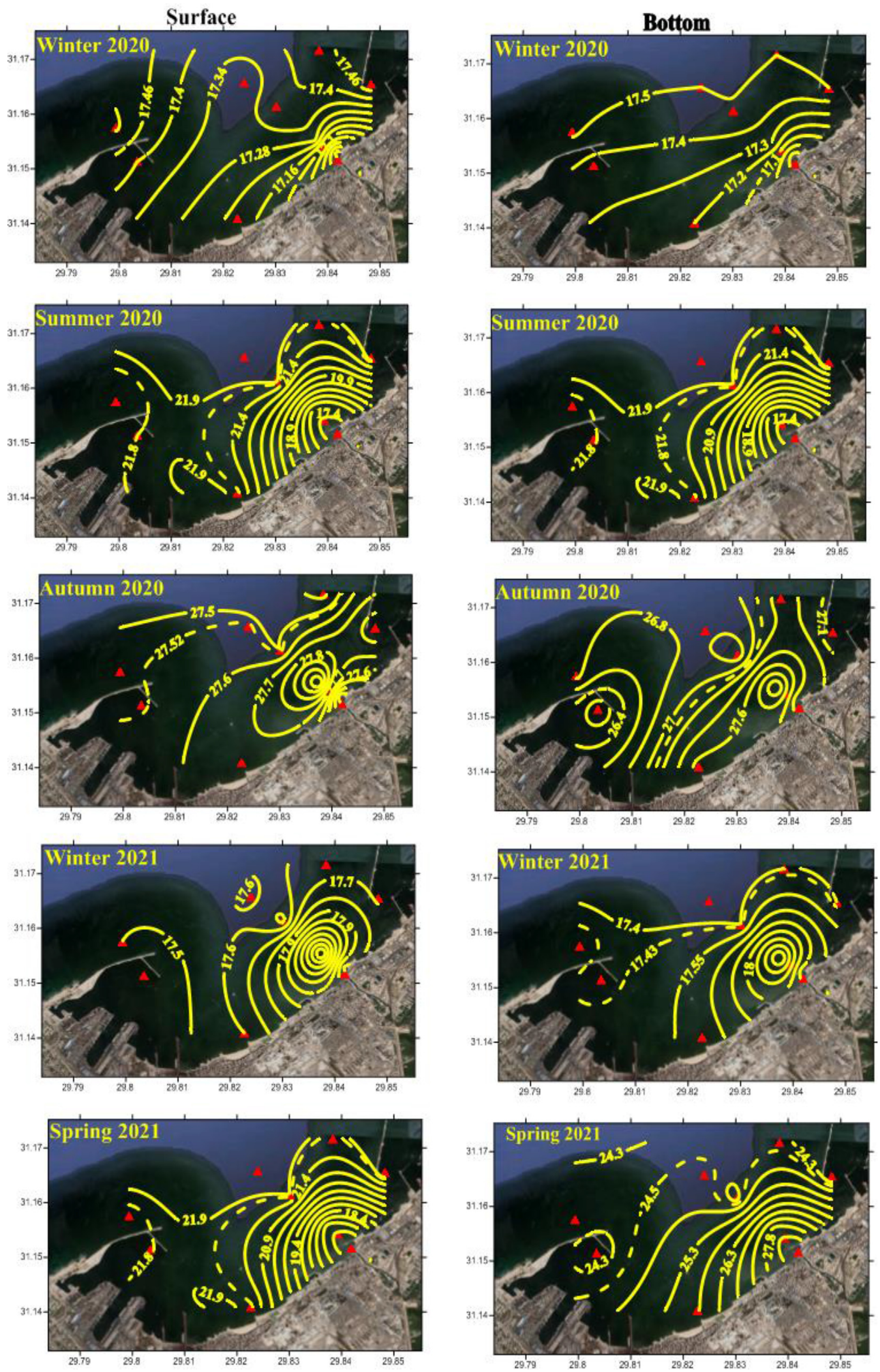

Fig. 2. Distribution of water temperature (°C) at the surface and near-bottom layers in El Mex Bay during 2020–2021.

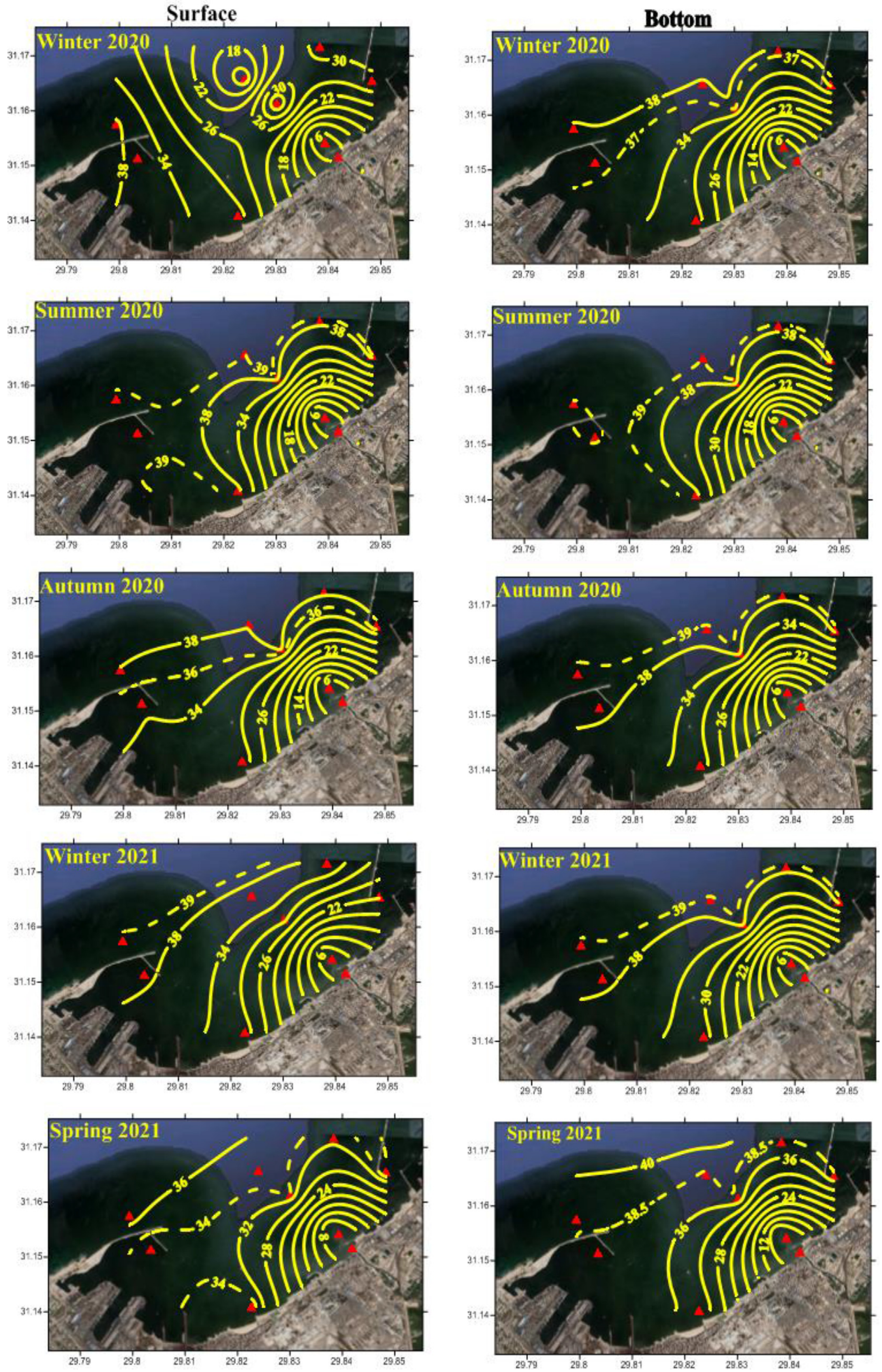

Fig. 3. Distribution of water salinity at the surface and near-bottom layers in El Mex Bay during 2020–2021.

2021 with an average of 7.55 mg/l. The DO in the summer was slightly higher due to the water turbulence and mixing processes, which led to an increase in the dissolution of the atmospheric oxygen.

The amount of DO in the surface water of El Mex Bay ranged from 3.89 mg/l (St. 4, in autumn 2020) to 20.41 mg/l (St. 5, in summer 2020) with an annual average of 9.0 mg/l.

In the near-bottom water, DO ranged from 3.08 mg/l (St. 4, in autumn 2020) to 16.85 mg/l (St. 5, in summer 2020) with an annual average of 8.4 mg/l (72.6 %). Similarly, the average values of DO in the surface water were higher in the summer of 2020 and spring 2021 (14.44 and 11.017 mg/l, respectively).

The average values of DO, in general, showed noticeable local variations, whereas the annual averages fluctuated between a minimum of 8.3 mg/l (119.0 %) at station 7 and a maximum level of 10.0 mg/l (141.7 %) at station 5 (Fig. 4).

3.1.4. *Oxidzable organic matter*

The values of OOM at El Umum Drain ranged from 8.16 mgO_2/l in winter 2021 to 13.96 mgO_2/l in spring 2021, with an annual average of 11.96 mgO_2/l.

Seasonal and regional variations of OOM of El Mex Bay are illustrated in Fig. 5, where the minimum is 0.64 mgO_2/l (St. 7, in summer 2020) and the maximum is 31.04 mgO_2/l (St. 5, in spring 2021), yielding an annual average of 6.3 mgO_2/l. However, the absolute values of OOM in the near-bottom water, ranged from 0.64 mgO_2/l (St. 7, in winter 2021) to 12.16 mgO_2/l (St. 7, in summer 2020), with an annual average of 4.31 mgO_2/l. The average values of OOM fluctuated between 2.3 mgO_2/l in winter 2020 and 9.5 mgO_2/l in the summer season.

The seasonal variation of OOM presented abrupt fluctuations during the year due to the external manipulation of the Bay. The average of OOM in El Mex Bay water ranged between a minimum of 2.08 mgO_2/l in winter 2021 and a maximum of 12.94 mgO_2/l in spring 2021. For near-bottom water, the average values of OOM fluctuated between 2.3 mgO_2/l in winter 2020 and 9.5 mgO_2/l in the summer season with an annual average of 4.31 mgO_2/l.

3.1.5. *Ammonium (NH_4–N)*

Ammonium concentration at El Umum Drain reached a maximum value of 173.5 μm/l during spring 2021 and a minimum of 2.4 μm/l in autumn 2020, with an annual average of 100.2 μm/l. With respect to the surface water of El Mex Bay, NH_4–N concentration ranged from 1.3 μm/l at station 7 in winter 2021 to 101.5 μm/l at station 8 in winter 2020 with an annual average of 32.1 μm/l. Although the amount of NH_4–N in the seawater (St. 7) is small compared with that of drainage water, it is relatively high if compared with normal seawater. In the near bottom, it fluctuated between 1.9 μm/l at station 7 in winter 2021 and 37.9 μm/l at station 5 in the same season, with an annual average of 11.2 μm/l. Seasonally, ammonium concentration attended an average of 10.9 μm/l in winter 2021 and 66.3 μm/l in winter 2020 for the surface layer of El Mex Bay. The concentration of NH_4–N in the near-bottom water is lower than that in the surface water (Fig. 6), except at station 7 in the winter of 2020 and stations 3, 5, and 6 in the winter of 2021.

3.1.6. *Nitrite (NO_2–N)*

Seasonal variation of nitrite concentrations at El Umum Drain ranged between 6.88 μm/l in winter 2021 and 30.2 μm/l during autumn 2020 with an annual average of 19.84 μm/l. The concentrations of NO_2–N at the surface layer of El Mex Bay showed a considerable seasonal and regional variation (Fig. 7), where it ranged from 0.15 μm/l (St. 7, winter 2021) to 23.5 μm/l (St. 8, spring 2021). NO_2–N concentration at the El Umum Drain was higher than that recorded in the surface water of the Bay. However, it ranged from 0.175 μm/l (St. 7, winter 2021) to 7.625 μm/l (St. 3, summer 2020) for the near-bottom layer. The average value fluctuates between 0.61 μm/l in winter 2021 and 12.85 μm/l in spring 2021 at surface water and ranges from 0.63 μm/l in winter 2021 to 1.57 μm/l in winter 2020 at the near-bottom water (Fig. 7), while the average value of the surface water in El Mex Bay reached 5.52 and 1.8 μm/l for the surface and near-bottom layer.

3.1.7. *Nitrate (NO_3–N)*

The concentration of NO_3–N at the El Umum Drain ranged from 19.61 μm/l in spring 2021 and 64.45 μm/l during autumn 2020 with an annual average of 38.86 μm/l. The concentrations of NO_3–N in the surface water of El Mex Bay (Fig. 8)ranged from 1.61 μm/l (St. 7 in winter 21) to 41.72 μm/l (St. 5 in summer 2020), with an annual average of 20.85 μm/l. Seasonal variation of the average concentration of nitrate in the surface layer of El Mex Bay fluctuated between 4.51 μm/l in winter 2021 and 29.15 μm/l in summer 2020. However, the near-bottom water ranged from 3.36 μm/l in the autumn season to 37.30 μm/l in the summer of 2020.

This data showed that the concentration of NO_3–N in the surface water is higher than those recorded in the near-bottom water during most of the year except in summer 2020.

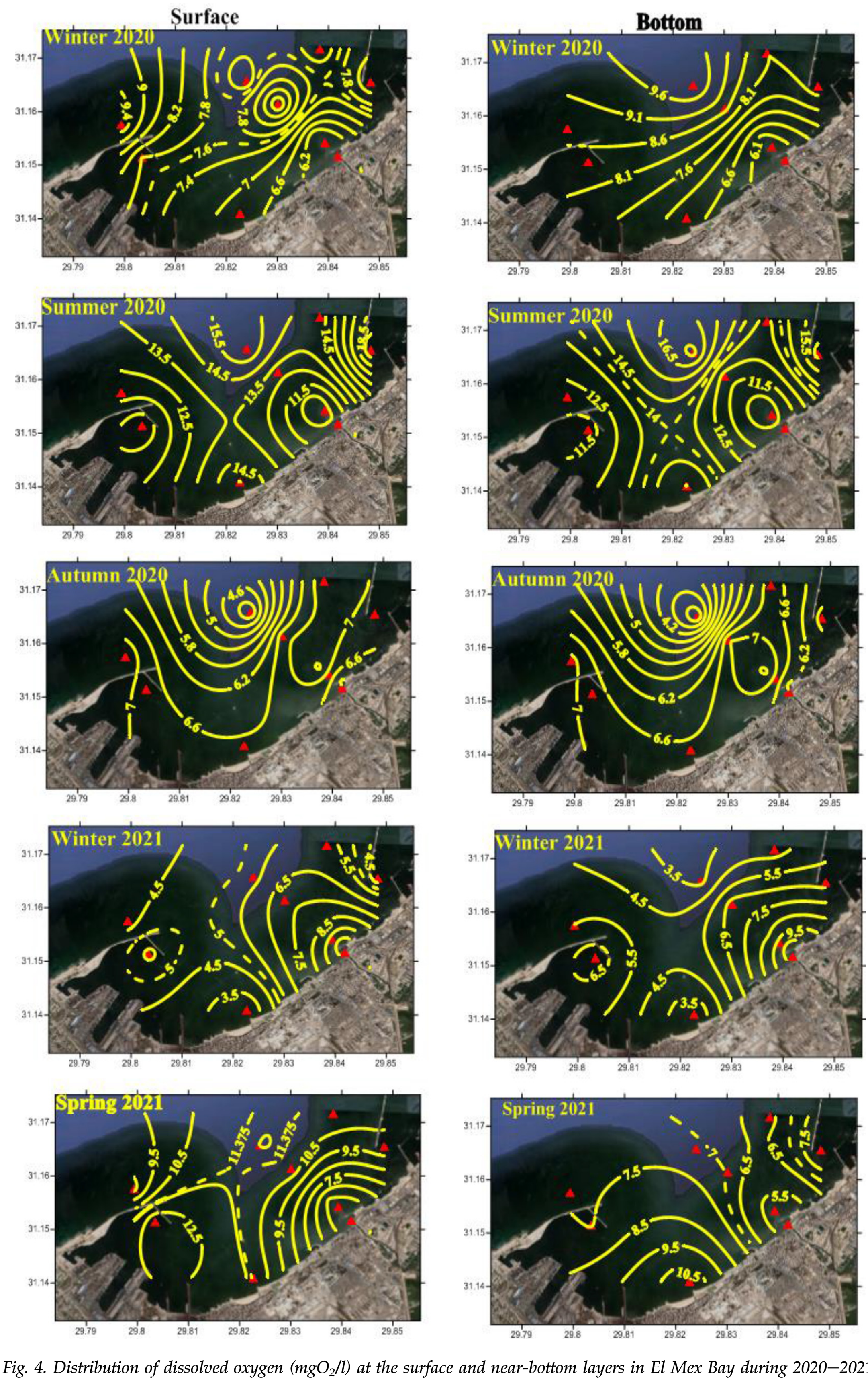

Fig. 4. Distribution of dissolved oxygen (mgO$_2$/l) at the surface and near-bottom layers in El Mex Bay during 2020−2021.

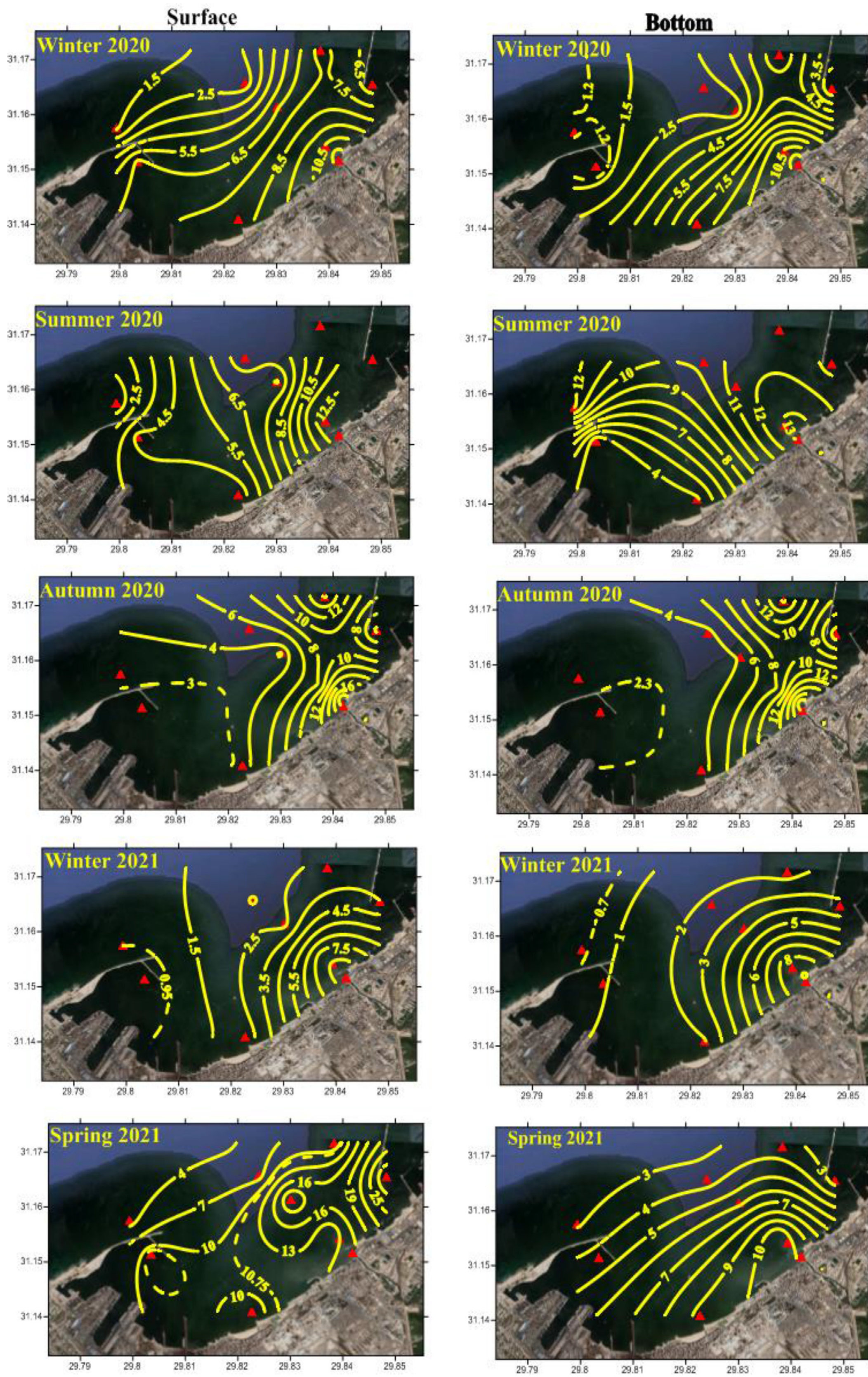

Fig. 5. Distribution of oxidizable organic matter (mgO_2/l) at the surface and near-bottom layers in El Mex Bay during 2020−2021.

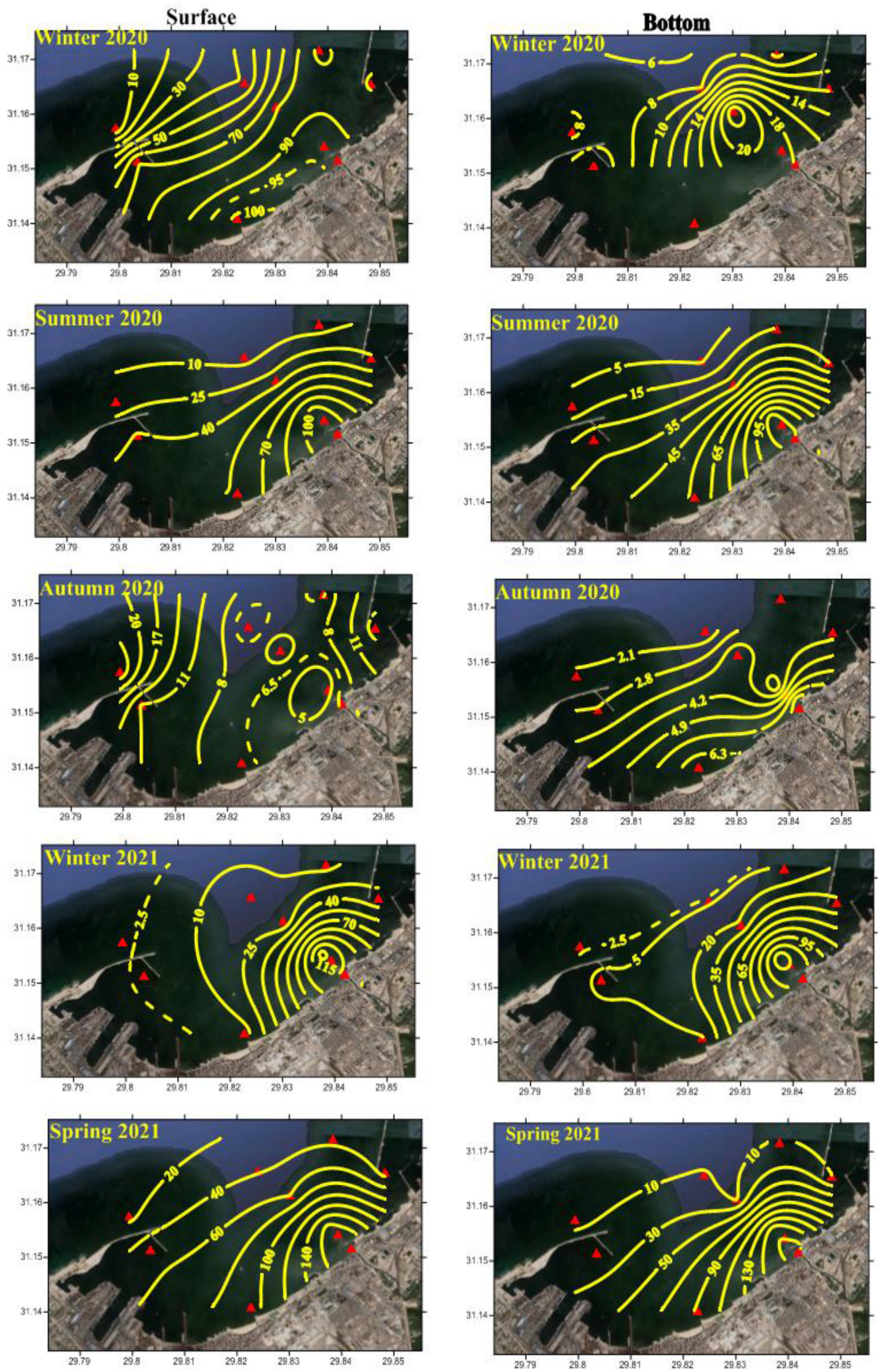

Fig. 6. Distribution of ammonium (μm/l) at the surface and near-bottom layers in El Mex Bay during 2020–2021.

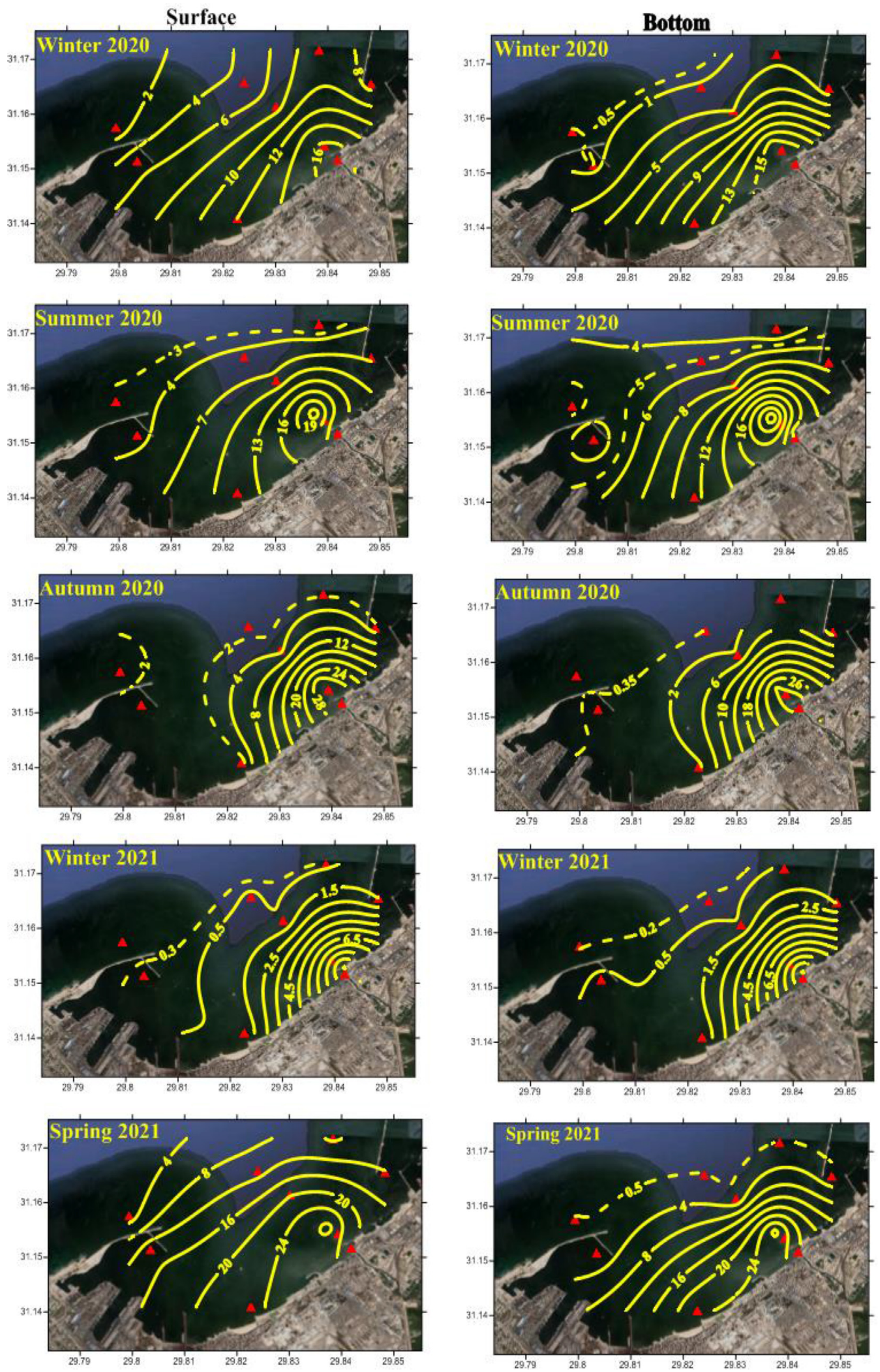

Fig. 7. Distribution of nitrite (μm/l) at the surface and near-bottom layers in El Mex Bay during 2020–2021.

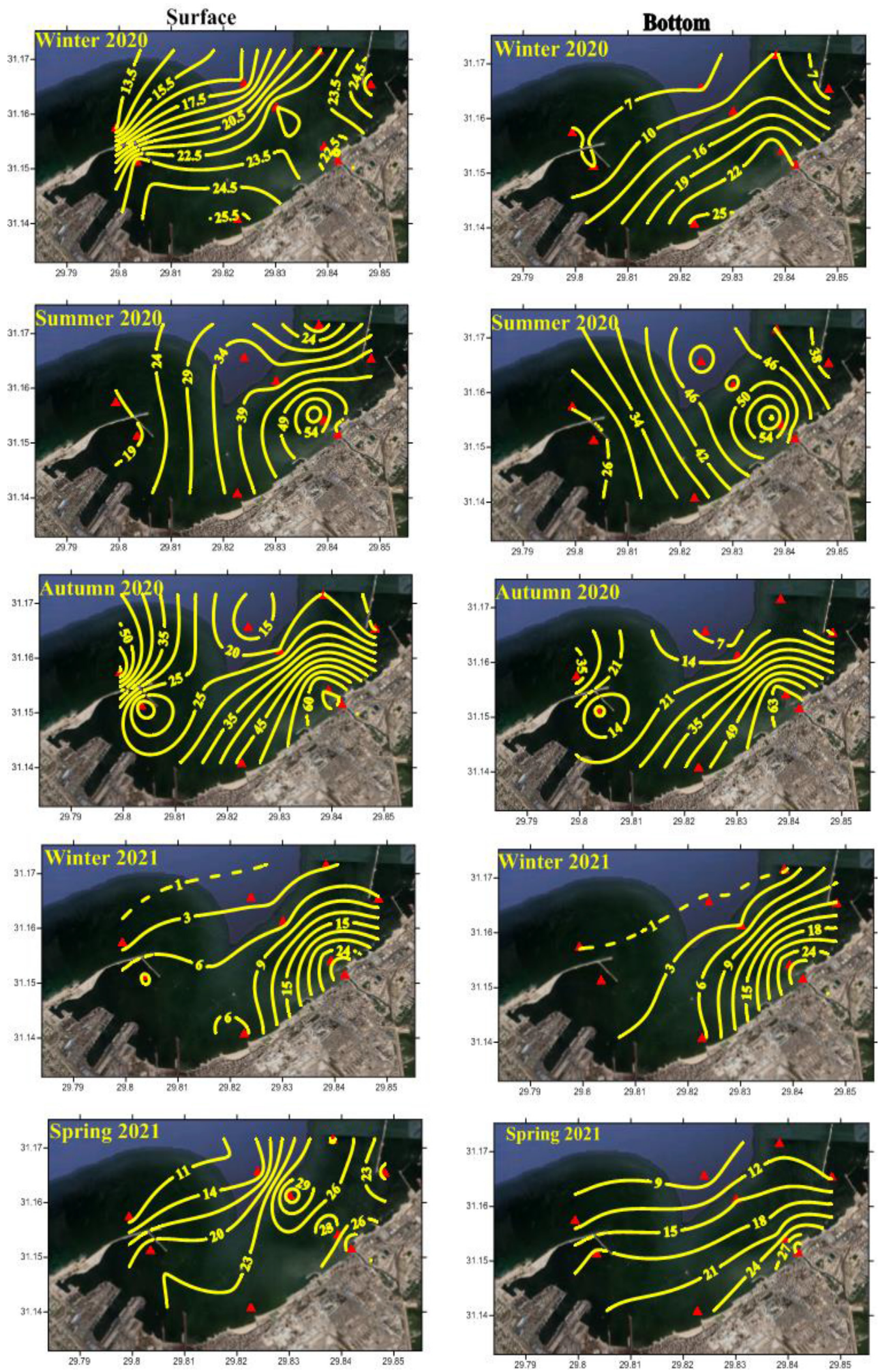

Fig. 8. Distribution of nitrate (μm/l) at the surface and near-bottom layers in El Mex Bay during 2020−2021.

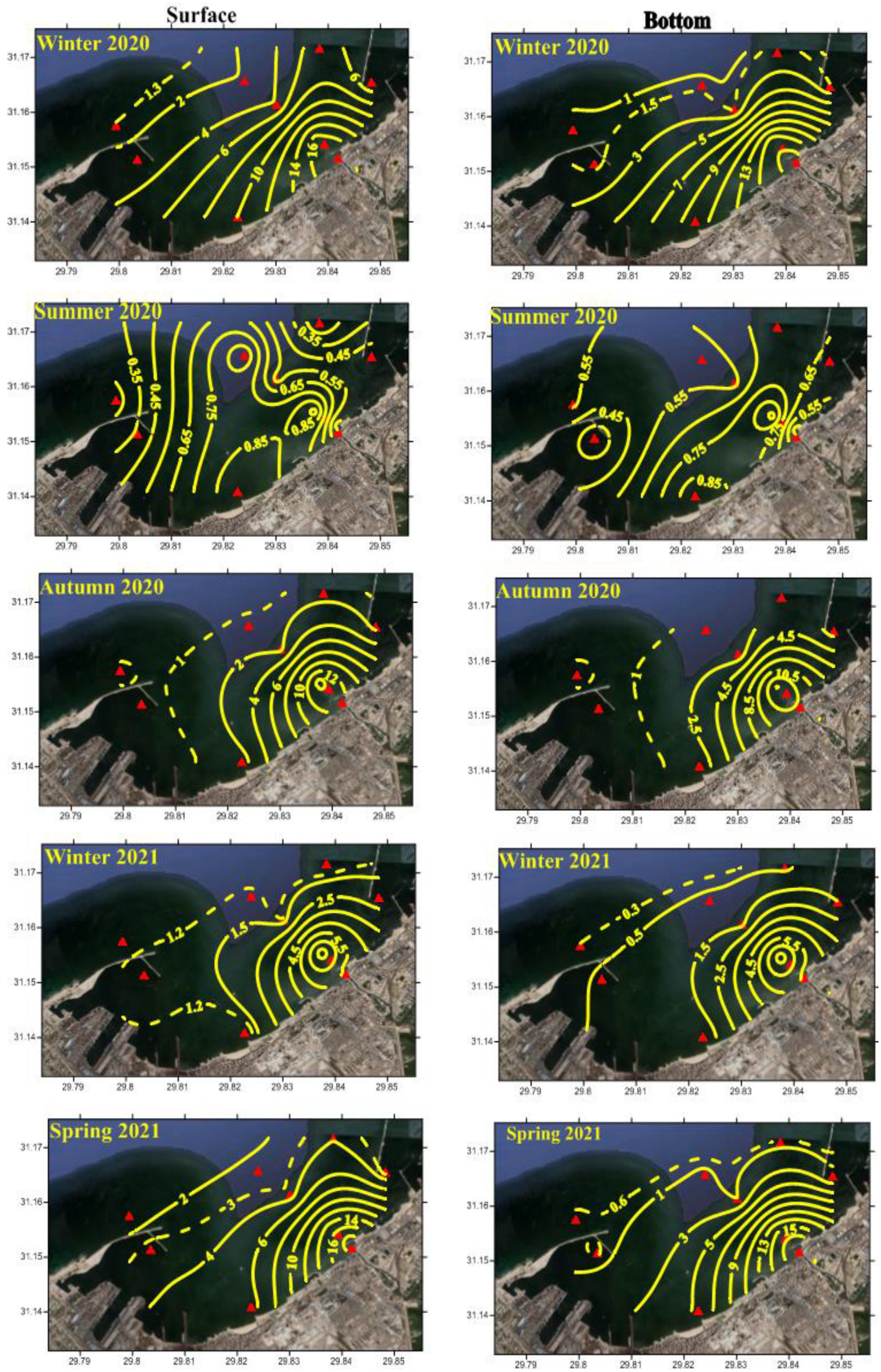

Fig. 9. Distribution of phosphate (μm/l) at the surface and near-bottom layers in El Mex Bay during 2020−2021.

3.1.8. Reactive phosphate (PO_4–P)

Phosphate concentration in the El Umum Drain ranged from 0.42 μm/l in the summer of 2020 to 19.03 μm/l in the spring of 2021, with an annual average of 10.95 μm/l.

The variation of PO_4–P concentration in the surface water of El Mex Bay (Fig. 9) showed that spatial concentrations of phosphate fluctuated between 0.16 μm/l at station 9 in summer and 10.04 μm/l at station 8 during winter 2020 with an annual average of 2.2 μm/l. With respect to the near-bottom water, it ranged from 0.26 μm/l (St. 6, summer 2020) and 1.98 μm/l (St. 9, winter 2020), yielding an annual average of 1.0 μm/l. Spatially, the surface water of El Mex Bay ranged between 0.52 μm/l in summer 2020 and 4.56 μm/l in winter 2020. At the near-bottom layer, however, the average content of PO_4–P ranged between 0.54 μm/l in summer 2020 and 1.456 μm/l in winter 2020.

The horizontal distribution of reactive phosphate in all seasons except in summer indicated that water at the El Umum Drain was characterized by the highest levels and decreased seawards. The surface waters of the Bay have more concentrated reactive phosphate than the bottom and increase in the western of the El Umum Drain than the eastern, especially in winter 2020.

3.1.9. Reactive silicate (SiO_4–Si)

Significant changes in silicate content were detected at El Umum Drain, where it ranged from 28.2 μm/l in winter 2021 to 250.6 μm/l in spring 2021, with an annual average of 130.4 μm/l (Fig. 10). It is noticeable that the silicate concentrations in surface waters of El Mex Bay stations varied between maximum values of 92.8 μm/l (St. 3, winter 2020) and minimal of 0.16 μm/l (Sts. 7, 8, and 9, summer) yielding an annual average of 26.9 μm/l. With respect to the near-bottom water, the silicate content fluctuated between 0.61 μm/l (St. 7, winter 2021) and 70.5 μm/l (St. 5, summer) with an annual average of 15.7 μm/l.

3.1.10. N/P ratio

The annual average of N/P ratios for the present study is 14.5, 27.05, and 28.1 for El Umum Drain, surface water, and in the near-bottom layer of El Mex Bay, respectively. At El Umum Drain (Sts. 1 and 2), the N/P ratio decreased from 300.8 during the summer to 24.6 in winter, 2021 reaching a minimum value in autumn (7.4). However, surface waters of El Mex Bay (Sts. 3–9), the N/P ratio reached a maximum level of 133.6 during summer and minimum levels of 12.3, 23.0, and 25.4 during winter 2021, 2020, and spring, respectively.

With respect to the near-bottom water, the N/P ratio decreased from 126.3 during the summer, reaching a minimum level of 14.0, 14.3, and 17.3 during winter 2020, autumn, and winter 2021, respectively.

3.2. Trophic states based on nutrients

The international organizations have proposed values among the most popular flux measurements for assessing eutrophic levels (Table 1), and have been also suggested as merit indicators of trophic levels: high (H), good (G), poor (P), and B (bad). Regarding inorganic nitrogen (nitrite and nitrate), El Umum Drain stations (Table 2) were P/B during all seasons except in winter. However, El Mex Bay water was M/P during the winter season, 2020 except at station 7, which was G/M. In the summer of 2020, most stations were P/B except that stations 6 and 7 recorded M/P and station 9 G/M. During autumn 2020, stations 3 and 9 attained M/P; stations 4, 5, and 6 recorded G/M, whereas stations 7 and 8 reached P/B. Winter 2021 is the best, all stations represented H/G. In spring 2021, stations 3, 4, 5, and 8 represented P/B; stations 6 and 9 recorded M/P, while station 7 attained G/M. Generally, H/G formed 15.6 %: from the records, 13.3 % of G/M, 33.3 % M/P, and 37.8 % P/B.

Regarding ammonium (NH_4–N) content, the data collected in El Umum Drain stations were P/B except during the autumn season. However, El Mex Bay water was divided into three groups, where H/G reached station 7 during the winter of 2020 and 2021. M/P was recorded at station 4 during both summer and autumn 2020. At stations 8 and 9 during autumn 2020 and winter 2021 and at station 6 in winter 2021, P/B recorded at the reset of stations contributed 73.3 % of all records, H/G accounted for 4.4 %, and M/P shared by 22.2 %.

However, the phosphate content at El Umum Drain stations, sustained P/B during most of the seasons except in the summer of 2020 as it reached H/G. El Mex Bay water, during winter 2020, all stations recorded P/B except station 7 sustained M/P. Summer, 2020, is the best, all stations reached H/G while station 8 reached G/M. In autumn, 2020, most stations attained M/P except stations 4 and 6 recording G/M. However, in winter 2021, two groups of stations exhibited different behaviors, the first group, stations 3–6 repressed M/P, while

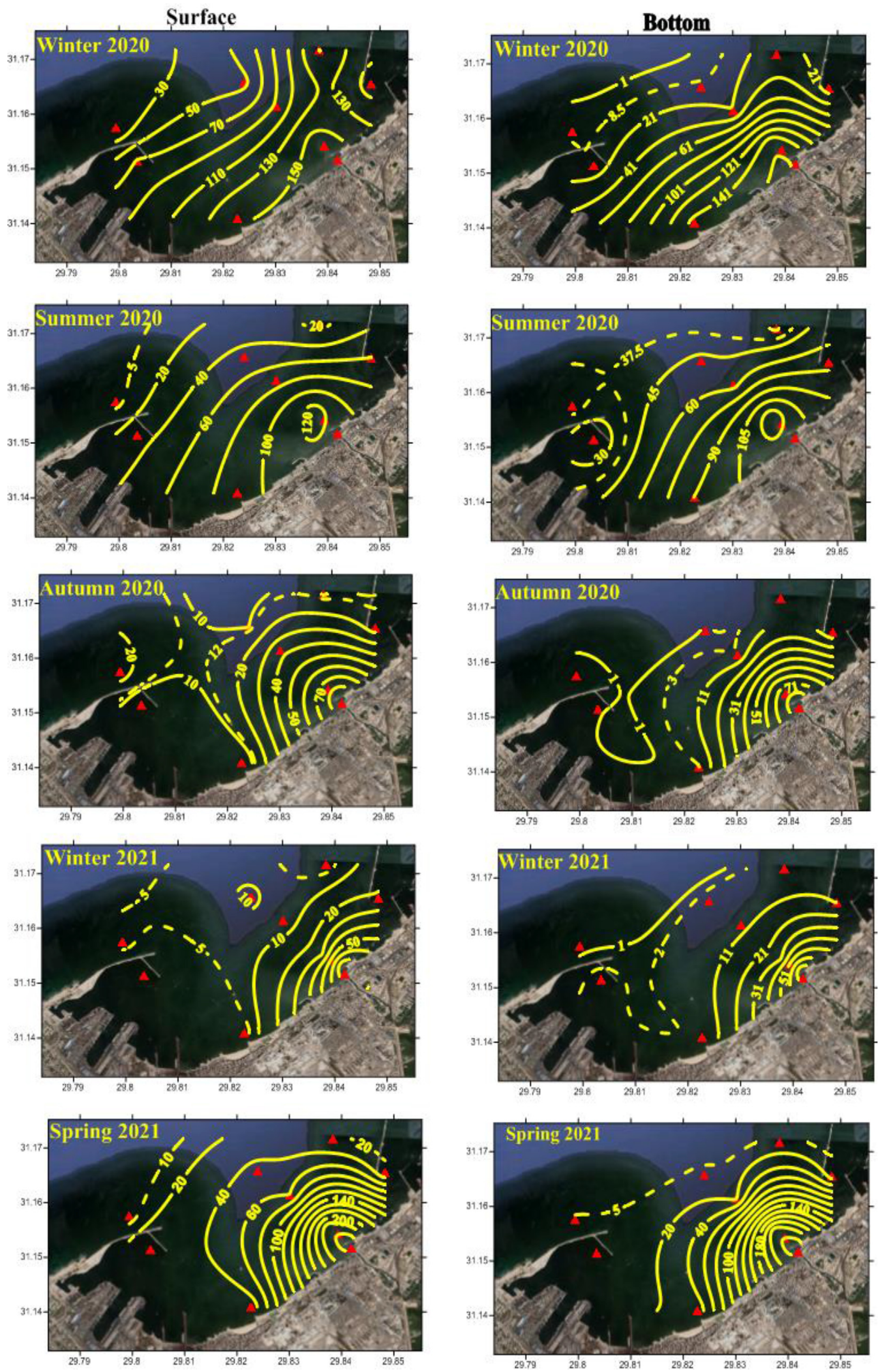

Fig. 10. Distribution of silicate (μm/l) at the surface and near-bottom layers in El Mex Bay during 2020–2021.

Table 2. Seasonally water quality classes.

Seasons	Parameters	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8	St. 9
Winter 2020	NH_4^+	P/B	P/B	P/B	P/B	P/B	P/B	H/G	P/B	P/B
	$NO_2^-+NO_3^-$	M/P	M/P	M/P	M/P	M/P	M/P	G/M	M/P	M/P
	PO_4^-	P/B	P/B	P/B	P/B	P/B	P/B	M/P	P/B	P/B
Summer	NH_4^+	P/B	P/B	P/B	M/P	P/B	P/B	P/B	P/B	M/P
	$NO_2^-+NO_3^-$	P/B	P/B	P/B	P/B	P/B	M/P	M/P	P/B	G/M
	PO_4^-	H/G	H/G	H/G	H/G	H/G	H/G	H/G	G/M	H/G
Autumn	NH_4^+	M/P	M/P	P/B	M/P	P/B	P/B	P/B	M/P	M/P
	$NO_2^-+NO_3^-$	P/B	P/B	M/P	G/M	G/M	G/M	P/B	P/B	M/P
	PO_4^-	P/B	P/B	M/P	G/M	M/P	G/M	M/P	M/P	M/P
Winter 2021	NH_4^+	P/B	P/B	P/B	P/B	P/B	M/P	H/G	M/P	M/P
	$NO_2^-+NO_3^-$	P/B	M/P	H/G	H/G	H/G	H/G	H/G	H/G	H/G
	PO_4^-	P/B	P/B	M/P	M/P	M/P	M/P	G/M	G/M	G/M
Spring	NH_4^+	P/B	P/B	P/B	P/B	P/B	P/B	P/B	P/B	P/B
	$NO_2^-+NO_3^-$	P/B	P/B	P/B	P/B	P/B	M/P	G/M	P/B	M/P
	PO_4^-	P/B	P/B	P/B	P/B	P/B	P/B	P/B	P/B	P/B

stations 7, 8, and 9 attained higher G/M. In spring 2021, all stations represented P/B.

Generally, in El Umum Drain, B/P represented 76.7 % of all records, in addition to 16.7 % of M/P and 6.6 % of H/G. The surface waters of El Mex Bay attained 13 % of the records representing H/G, 11.5 % of G/M, 28.5 % of M/P, and 47.0 % of P/B.

3.3. Principal component analysis

Regarding El Umum Drain (Table 3), three factors with eigenvalues more than 1 were identified with 82.796 % total variance. Varimax rotated component matrix gave an overview of the nature of loading among the parameters. PC1, PC2, and PC3 have a covariance of 30.99, 27.23, and 24.57 %, respectively. PC1 represented a positive loading each of water salinity, NH_4, PO_4, and SiO_4 (0.548, 0.541, 0.791, and 0.819, respectively). This was confirmed with a positive correlation between SiO_4 and each of salinity, NH_4, and PO_4 ($r = 0.46$, 0.564, and 0.495, $P < 0.05$, respectively). A negative loading was observed with DO, NO_3, and DIN/P (−0.80, −0.631, and −0.573, respectively). PC2 had a positive loading of each temperature, OOM, NO_2, and NO_3 (0.665, 0.585, 0.812, and 0.589, respectively). In addition to a negative loading with salinity, NH_4 and DIN (−0.557, −0.747, and −0.561, respectively). PC3 had a positive loading of OOM, DIN, and DIN/P (0.556, 0.617, and 0.594, respectively).

The surface water of El Mex Bay (Table 3) had three factors with eigenvalues more than 1 and a total variance sum of 77.382 %. Varimax rotated component matrix gives an overview of the nature of loading among the parameters. PC1, PC2, and PC3 have covariance of 10.83, 19.623, and 16.93 %, respectively. PC1 represented a positive loading

Table 3. Varimax rotated component matrix of physicochemical parameters in El Mex Bay during 2020–2021.

Component matrixes									
Area	El Umum Drain			Surface water			Near-bottom layer		
Components	1	2	3	1	2	3	1	2	3
Temp	0.493	0.665	0.201	0.192	0.514	0.632	0.083	0.729	0.451
Sal	0.548	−0.557	−0.089	−0.092	0.584	−0.005	0.494	0.705	−0.26
DO	−0.8	−0.493	0.05	0.44	0.697	−0.31	0.848	−0.204	0.209
OOM	−0.111	0.585	0.556	0.526	0.299	0.541	0.845	0.104	0.263
NH^{4+}	0.541	−0.747	0.302	0.922	−0.301	−0.138	0.541	−0.415	−0.49
NO^{2-}	0.201	0.812	0.346	0.892	0.083	0.205	0.909	−0.171	0.137
NO^{3-}	−0.631	0.589	0.357	0.572	0.571	0.008	0.876	0.135	0.234
PO^{4-}	0.791	0.437	−0.367	0.811	−0.45	−0.007	−0.445	−0.483	0.559
SiO^{4-}	0.819	−0.044	0.468	0.87	−0.254	−0.275	0.894	−0.259	0.214
DIN	0.471	−0.561	0.617	0.982	−0.061	−0.076	0.934	−0.118	−0.057
DIN/P	−0.573	−0.374	0.594	0.019	0.721	−0.564	0.863	0.075	−0.304
% of variance	30.992	27.233	24.571	40.826	19.623	16.933	48.618	19.469	13.327
Cumulative %	30.992	58.225	82.796	40.826	60.449	77.382	48.618	68.087	81.414

Extraction method: principal component analysis.
[a]Three components extracted.

with each of DO, OOM, NH_4, NO_2, NO_3, PO_4, SiO_4, and DIN (0.44, 0.526, 0.922, 0.892, 0.572, 0.811, 0.87, and 0.982, respectively), which can demonstrate autochthonous sources of all nutrient content. PC2 had a positive loading of each temperature, water salinity, DO, NO_3, and DIN/P (0.514, 0.584, 0.697, 0.571, and 0.721, respectively), while it had negative loads with PO_4 (−0.45). PC3 had a positive loading for both temperature and OOM (0.632 and 0.541, respectively) and DIN/P (−0.564).

Regarding the near-bottom layer of El Mex Bay (Table 3), it had three factors with eigenvalues more than 1 that were identified and had 81.414 % total variance sum. Varimax rotated component matrix gives an overview of the nature of loading among the parameters. PC1, PC2, and PC3 have a covariance of 48.62, 19.47, and 13.33 %, respectively. PC1 represented a positive loading each of DO, OOM, NH_4, NO_2, NO_3, SiO_4, DIN, and DIN/P (0.848, 0.845, 0.541, 0.909, 0.876, 0.894, 0.934, and 0.863, respectively), while it has a negative loading with PO_4 (−0.445). This is similar to that recorded in the surface layer. PC2 had a positive loading for both temperature and salinity (0.729 and 0.705, respectively). In addition to negative loading with NH_4 and PO_4 (−0.415 and −0.483, respectively). PC3 had a positive loading for both temperature and PO_4 (0.451 and 0.559, respectively), while it has a negative loading with NH_4 (−0.49).

3.4. Water pollution index

The water quality index measured according to Nemerow and Sumitomo (1970), indicated that all stations were heavily polluted, particularly stations 1 and 2, which represented El Umum Drain water (Fig. 11).

3.5. Residence time

The residence time of El Mex Bay water during the study period, as shown in Table 5, varied seasonally from 10.05 days in spring 2020 to 5.65 days in autumn 2020 and then 3.97 days during winter 2020 with 6.95 days in summer 2021 and 8.08 days during autumn 2021 (QR values are found in Table 4).

4. Discussion

The physicochemical characteristics of El Mex Bay water exhibited a wide range of variations, induced by hydrodynamic conditions, land runoff, and algal growth. The effect of wastewater discharges on the water quality of El Mex Bay is attributed to the main land-based source, mainly from El Umum Drain (Table 5). The volume of discharged water from El Umum Drain to El Mex Bay, according to the Drainage Research Institute, increases from 1 year to the other. Thus, its amount during 2020–2021 'the present study,' is higher than that discharged during 1982–1983, 1988, 1995–1996, and 2003–2004 as reported by Mahmoud (1985); Said et al. (1993); and Mahmoud et al. (2005), respectively.

It is clear that there is an increase in the amount of most nutrients; changes can be attributed to many

Table 4. Residence time (t) of El Mex Bay during the study period (2020–2021).

Seasons	Residence time (*t*) (days)
Spring 2020	10.05
Autumn 2020	5.65
Winter 2020	3.97
Summer 2021	6.95
Autumn 2021	8.08

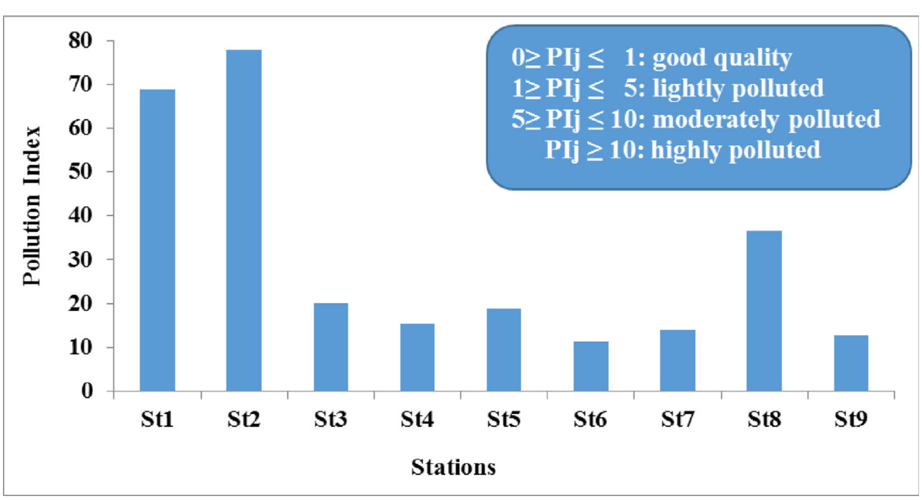

Fig. 11. Pollution index of different stations collected from El Mex Bay during 2020–2021.

Table 5. Volumes of water discharged to El Mex Bay through El Umum Drain (× 10^6 m^3), according to the Drainage Research Institute.

Seasons	Previous study				Present study (QR values)	
	1982—1983	1988	1995—1996	2003—2004	2020	2021
Summer	230	520.978	207	588.73	816.36	509.5
Autumn	257	450.704	207	705.44	647.76	638.2
Winter	222	744.381	205	658.98	816.16	708.6
Spring	246	490.528	185	510.45	504.1	353.5
Total/year	2865	2206.591	2412	2452.65	2784.38	2209.8

factors, including the variability of land-based sources, the changes in industrial production quality and activities, and the effect of sea hydrographical parameters.

4.1. Water temperature

Generally, the thermal stratification in El Mex Bay differed from one season to the other; during the winter season, there is a slight increase in the water temperature in the near-bottom layer than the surface layer, while during the autumn and spring seasons, it showed an opposite case than that recorded in the winter season. However, during the summer season, there is no thermal stratification (similar values of water temperature were recorded in both layers). This is due to the increase in the amount of water discharged from the El Umum Drain and to the shallowness of El Mex Bay (not exceeding 10.2 m).

Compared with the previous results (Table 6), the water temperature of El Mex Bay increased over the different years. Therefore, the difference between minimum values and its maximum increases with the years. It recorded 14 °C during 1988 (Said et al., 1993) to 15.0 °C during 2003/2004 (Mahmoud et al., 2005). All of these are due to changes in the air temperature (climatic changes) and the shallowness of the Bay.

4.2. Salinity

Salinity is an important factor that affects the marine environment. In the present investigation, salinity was used as an indicator to reflect changes resulting from mixing of fresh and seawater and subsequently, it reflects the degree of contamination in the aquatic environment. The lowest salinity level during winter 2020 observed at El Mex Bay (St. 4, 11.3) coincided with the increasing amount of rainwater, agricultural, sewage, and industrial wastewater discharge into the Bay. However, the maximum value of salinity during summer at El Mex Bay (St. 5, 39.06) might be driven by the wind action results in water mixing, which reduces the dilution effect of wastewater discharge through the El Umum Drain.

The horizontal distribution of salinity in the El Mex Bay at different seasons was characterized by the presence of two distinct water layers: an upper brackish layer and a lower diluted seawater. At the surface water, a significant variation of salinity was observed due to the discharge of outfalls from the El Umum Drain. The stratification in water salinity is clearer during most of the year except in the summer season. This is similar to the distribution of water temperature as mentioned previously.

Compared with the previous study, the water salinity in El Umum Drain decreases gradually with the years (Table 6). The minimum values of water salinity in El Mex Bay decrease from one year to the other according to the increased amount of water discharged from the El Umum Drain. It attained 16.24 in 1988 (Said et al., 1993), 13.83 during 1993/1994 (Tayel et al., 1996), and 11.3 in the present study.

4.3. Dissolved oxygen

DO is a major component in an aquatic ecosystem, which determines the quality of water and supports aquatic life. Foehrenbach (1969) concluded that the oxygen content is a reflection of organic loading, nutrient input, and biological activity. DO concentration indicates how well aerated the water is and varies according to several factors such as season, time of day, temperature, and salinity.

Generally, the studied area could be divided into water masses according to the oxygen saturation percentage; the wastewater that is characterized by a poor saturation condition (80.2 %), and seawater with a high saturated one (128 %), on average. The high values of oxygen, which correspond to oversaturation (293.2 %) at El Mex Bay are accompanied by the lowest of each water temperature and organic matter contents and the highest water salinity as well as strong agitation of water under wind effect. The minimum value, however,

Table 6. Comparison between current and previous records of some physicochemical parameters of surface waters at both El Umum Drain (A) and El Mex Bay (B).

Study period	Temp °C	Salinity	pH	DO	OOM	NH_4	NO_2	NO_3	PO_4	SiO4	References
				$mgO_2/_l$		µm					
[A]											
April, 1982–June, 1983					05.17–13.6	11.85–80.12	–	10.93–38.91	2.02–35.86		Mahmoud (1985)
January, 1988–December, 1988	14.20–28.41	4.97–7.24	7.50–8.50	0.81–3.12	1.46–9.94	7.54–40.74	0.63–4.87	0.08–19.5	0.55–9.26		Said et al. (1993)
January, 1992–January, 1993					05.84–31.21	49.23–131.2	1.25–4.75	5.78–14.5	2.95–5.2		Mikhail (1997)
Summer and Winter 1999	15.1–29.2	4.21–5.32	7.35–7.45	1.91–3.51					8.04–10.42		Masoud et al. (2001)
Spring 2003–2004		3.5–4.32	7.25–7.93	0.62–3.48	15.10–19.00	14.98–30.68	16.35–21.38		4.36–26.15	241.9–346.43	Nessim et al. (2005)
Summer 2003–Spring 2004	15–29	3.0–6.66	7.36–7.96	0.64–6.88		3.61–294.08	0.05–24.03	13.4–106.32	4.84–25.27	26.02–218.69	Mahmoud et al. (2005)
Autumn 2007–Spring 2008	15.1–29.3	2.86–6.99	7.10–8.60	0.85–4.67	004.4–100.0	12.8–373.8	0.0–124	0.7–5.12	1.8–29.0		Nessim et al. (2010)
Spring 2010–Summer 2011	23.6	2.80	8.10	2.02	14.84	65.1	12.33	9.88	4.83	77.59	Shreadah et al. (2014)
Winter 2020–Winter 2021	16.4–28.2	3.60–4.80		04.50–11.40	08.2–14.0	2.4–173.6	6.9–30.2	19.6–64.5	0.42–19.8	28.2–250.6	Present study
[B]											
April, 1982–June, 1983					0.8–10.08	0.0–36.72	–	0.21–27.28	0.22–5.41		Mahmoud (1985)
October 1982 to August 1983		5.2–38.44				5.78–34.6		6.3–21.0	4.2–19.43		Dorgham (1987)
January 1988–December, 1988	14.8–28.9	16.24–38.68	7.23–8.35	1.60–3.68	0.95–5.29	3.78–31.91	0.41–17.24	0.17–17.49	0.70–7.39		Said et al. (1993)
January, 1992–January, 1993					0.62–14.9	0.27–131.2	0.1–4.5	1.16–20.45	0.55–8.3*		Mikhail (1997)
October, 1993–August, 1994	16.75–29.6	13.83–23.35	8.31–8.74	5.11–6.17	3.96–10.06						Tayel et al. (1996)
February–December, 1995		3.68–38.5		0.23–8.2		0.0–132.1		4.81–58.0	0.28–17.2	11.4–159.8	Soliman and Gharib (1998)
Late spring, early summer, 1995						1.1–1.54	0.028–0.056	0.09–0.98	0.107–0.375	0.12–1.88	Fahmy et al. (1999)
March–December, 1996	16.4–29.1	0.6–39.6	6.06–8.84	2.6–9.6		2.13–127.8		0.0–71.0	0.32–48.0		Dorgham (1997)
Summer and Winter, 1999	15.8–30.5	9.76–34.67	7.78–8.35	4.14–9.23					0.87–6.33		Masoud et al. (2001)
April, 2003–April, 2004	15–30	14.13–36.7	8.2–10.07	0.48–26.4		21.0–47.34	0.025–1.2	0.43–106.2	0.13–28.3	0.85–284.93	Mahmoud et al. (2005)
Spring 2003–2004	19–29	28.3–32	7.53–7.93	1.21–4.18	3.4–16.64	0.16–643	2.74–3.83		1.02–2.25	15.4–50	Nessim et al. (2005)
Autumn 2007–Spring 2008	25.5–29.9	6.13–37.06	7.15–8.35	4.89–7.37	5.2–10.0	9.6–56.2	1.8–11.3	6.3–21.2	1.5–4.1	14.5–59.6	Nessim et al. (2010)

(*continued on next page*)

Table 6. (continued)

Study period	Temp °C	Salinity	pH	DO	OOM	NH_4	NO_2	NO_3	PO_4	SiO4	References
				mgO_2/l		μm					
Spring 2008–Winter 2008	18–31	3.71–40.09	7.28–8.55	1.17–8.45	0.96–8.4						Okbah et al. (2013)
Spring 2010–Summer 2011	18–29	14.5–42.3	7.36–8.97	0.65–22.26	1.2–34.4	0.15–233.3	0.3–22.85	0.2–56.22	0.7–30.45	0.48–99.86	Shreadah et al. (2014)
September, 2012–April, 2013	16.05–29	2.25–38.87	7.05–7.60	ND-3.15	0.48–3.52	4.18–219.13	0.1–10.02	0.05–66.7	0.1–17.36	1.72–213.09	Okbah et al. (2017)
Winter 2020–Winter 2021	17.2–27.9	11.3–39.1		3.9–20.4	0.64–31.04	1.3–101.5	0.15–23.5	1.01–41.72	0.16–10.04	0.16–92.8	Present study

coincided with high OOM content. The surface water was well oxygenated, and its concentration at both two layers of the Bay is mostly similar values (no stratification), except during the spring season; its value showed a slight decrease near the bottom.

Compared with the previous results (Table 6), the average values reported by Tayel et al. (1996), Mahmoud et al. (2005), and Shreadah et al. (2014) are 4.29, 12.3, and 6.81 mgO_2/l. However, the present value attained 9 mgO_2/l. Thus, the present study indicates that the Bay has a good DO regime, most notably during the summer as a result of turbulent mixing caused by prevailing strong winds. The DO in waters tends to have lower concentrations by decreasing the temperature during winter.

4.4. Oxidizable organic matter

The oxidizable organic matter has been used as a basic water quality parameter to assess organic pollution, adversely affecting aquatic life, principally through oxygen depletion.

Organic matter plays a major role in aquatic systems. It affects the biochemical process, nutrient cycling, biological availability, and chemical transport and interaction. Duursma (1961) showed that dissolved organic substances might be attributed to the decomposition of dead phytoplankton and detritus rather than the excretion of living cells. Förstner and Wittmann (1981) pointed out that the organic matter in aquatic systems consists of the remains of biologically produced sources, and the synthetic organic substances originate from agricultural and industrial applications.

The values of OOM in El Umum Drain ranged from 8.16 mgO_2/l in winter 2021 and 13.96 mgO_2/l in spring 2021, with an annual average of 11.96 mgO_2/l. This value is higher than that recorded in the surface water of El Mex Bay (6.25 mgO_2/l).

In the five seasons, the OOM in the surface is higher than that recorded in the near bottom except in summer 2020. High values of OOM may be due to the allochthonous origin of sewage and/or autochthonous source through the decomposition of biota remains. The increasing organic supply introduced into the restricted studied area under the relatively slow rate of self-purification results in the elevation of OOM content at El Mex Bay.

Compared with the previous result (Table 6), it showed that the present result is a much higher value than that recorded by Nessim et al. (2010), Okbah et al. (2013, 2017), and Shreadah et al. (2014) in the same region of investigation.

4.5. Inorganic nitrogen species (NH_4–N, NO_2–N, NO_3–N)

DIN concentrations (the sum of ammonium, nitrite, and nitrate) in the El Mex Bay water were relatively high. Generally, the high levels of DIN were affected directly by the discharged water from the El Umum Drain, which contained high amounts of agricultural fertilizers.

4.5.1. Ammonium

Ammonium is an important and often the primary source of nitrogen for the phytoplankton of oligotrophic regions. The increase in the concentration of ammonia (NH_3) leads to toxicity and death for fishes and other aquatic organisms, but ammonium ion (NH_{4^+}) has no effect on aquatic organisms or fishes. Ammonia concentrations encountered in water vary from water vary from less than 0.714 mM l^{-1}.NH_4 -N in some natural surface and ground waters to more than 2142.85 mM l^{-1}in some wastewaters (Okbah et al., 2017).

In the present study, ammonium has been the majority of DIN about 63 and 55 % for El Umum Drain and El Mex Bay, respectively.

Generally, the ammonium in the surface and bottom water showed a distribution similar to each other in most seasons. The highest concentration of it in the surface water of the Bay was recorded in front of the El Umum Drain, particularly during both winter 2020 and spring 2021. This could be attributed to wastewater discharge through the El Umum Drain as well as the high content of OOM. In the Bay, it increases westward direction. The surface water attained a higher concentration than the bottom. Almost all the combined inorganic nitrogen in anoxic waters was found as ammonium ions (Riley and Skirrow, 1965). Compared with the previous result (Table 6), the average concentration of NH_4 in the El Mex region, is increased over the years, as it recorded 18.98 μm/l during 2003–2004 (Mahmoud et al., 2005). During 2007–2008 in accordance with Nessim et al. (2010), it attained an annual average of 31.7 μm/l, while it reached 32.1 μm/l in the present study (2020–2021).

4.5.2. Nitrite

Nitrite is a minor constituent of DIN and is characterized as an intermediate compound, which is derived either from the oxidation of ammonia or the reduction of nitrate and can be removed from solution during nitrogen assimilation by phytoplankton (Schuler et al., 1953). In the present study, nitrite comprises ~12.5 % of DIN in the El Umum Drain, and 9.0 % in the El Mex Bay. The data showed a decrease in the average nitrite content in the winter of 2021 at both El Umum Drain, in the surface layer and near the bottom of El Mex Bay water. This might be due to the increase in the oxidation rate of nitrite to nitrate. As a result of the biological denitrification of nitrite; which converts it into cellular amino acids through the photosynthetic process and by a transaminase enzyme which ultimately provides the fats, fatty acids, amino acids, nucleic acids, protein, organic acids, and other organic compounds necessary for growth and reproduction of these organisms (Munawar, 1970). However, the maximum values of nitrite recorded during spring season may be attributed to the excretion of extracellular nitrite by phytoplankton (Riley and Skirrow, 1965). High averages reported during spring at the Drain and surface water of the Bay may be due to the allochthonous input by the El Umum Drain, in addition to autochthonous sources resulting from decaying of organic matter and oxidation processes. Generally, the distribution of NO_2–N at the surface water is higher than that recorded in the near-bottom layer. However, they showed the same pattern. It is noticeable that the concentration of nitrite in the present study is higher than that recorded in the previous studies in the same region. Comparing with the previous result (Table 6), the average concentration of NO_2 in the El Mex region, increases with years, as it recorded a value of 1.13 μm/l during 2003–2004 (Mahmoud et al., 2005). During 2010–2011 (Shreadah et al., 2014) it attained 4.74 μm/l in accordance with the present study, it reached 5.5 μm/l (2020–2021).

4.5.3. Nitrate (NO_3–N)

The nitrate compound is considered a major nitrogenous compound in the aquatic environment. The behavior of nitrate is important in the nitrogen metabolism in natural water (Seike et al., 1990). Its behavior may be attributed to biological, chemical, or physical factors. Nitrate is considered the most stable oxidation state in the presence of oxygen in water. In anaerobic conditions in the aquatic environment, nitrification takes place, converting ammonia and nitrite to nitrate.

Consumption of nitrate compounds by phytoplankton in the study area can be considered the main reason for decreasing nitrate concentrations in the Bay water. Higher concentrations of nitrate in the study area may be due to large quantities of nitrate fertilizers and organic matter, which are discharged from the El Mex Pumping station through the El Umum Drain to El Mex Bay. In the present study, nitrate content comprises DIN about

24.5 and 36.0 % for El Umum Drain and El Mex Bay, respectively. The seasonal distributions of nitrate are reversed to that observed in ammonia where summer 2020 and autumn 2020 have the highest seasonal levels. Also, station 7 has high concentrations of nitrate, especially in these two seasons. With respect to a high annual average of nitrate, this met with allochthonous input by El Umum Drain, in addition to an autochthonous source resulting from decaying of organic matter. The decrease of nitrate in the El Mex Bay during winter 2021 could be attributed to two factors: the first is the assimilation by plants and the second is denitrification, that is the reduction of nitrate to nitrite before releasing N_2O (Hutchinson, 1957). The concentration increases eastward of El Umum Drain than the west, especially in the surface water. In the other seasons, the concentration increases mostly westward. Generally, the distribution of NO_3–N at the surface water is higher than that recorded in the near-bottom layer, except during the summer season. However, they showed the same pattern of distribution. Compared with the previous result (Table 6), the average concentration of NO_3 in the El Mex region increases with years, as it recorded a value of 4.7 μm/l during 2003–2004 (Mahmoud et al., 2005). During 2007–2008 (Nessim et al., 2010) it attained 13.3 μm/l. With respect to 2010–2011 (Shreadah et al., 2014), it recorded an average of 9.98 μm/l. In accordance with the present study, it reached 20.6 μm/l (2020–2021).

4.5.4. Reactive phosphate (PO_4–P)

Phosphorus is essential to the growth of organisms and can be the nutrient that limits the primary productivity of a body of water. In instances where phosphate is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of photosynthetic aquatic microorganism and macroorganisms in nuisance quantities (Vanloon and Duffy, 2000; Abdel-Rhman, 2013).

El Mex Bay water, influenced by land-based sources, is still too high in phosphorus content if compared with open seawater. The Drain water and El Mex water exhibit an annual average of phosphate concentration of 10.9 and 2.2 μm/l, respectively; which reflected a hyper-eutrophication condition (UNEP, 1988). The high enrichment of both Drain and Bay water with phosphate during winter 2020 is mainly attributed to the allochthonous huge amounts of industrial, domestic, and drainage effluent enriched with phosphate and other fertilizers discharged into this area. High consumption of phosphate ions by marine flora was observed in the waters of El Mex Bay during the summer (0.7 and 0.5 Drain and surface water of the Bay, respectively). The seasonal variety of PO_4–P concentrations in the study area was widely varied in the different seasons, which in the bottom water are lower than that the surface layer; this could be associated with the biological uptake and/or additional phosphate sources. The increasing reactive phosphate concentration in the El Mex Bay is due to the continuous discharge of water from the El Umum Drain. The concentration of reactive phosphate in the five seasons is in the order of winter 2020>spring 2021>autumn 2020>winter 2021>summer 2020. The summer season, which has lower concentrations than the other seasons, has a different distribution where reactive phosphate is concentrated mainly seaward than in front of the El Umum Drain, especially in the surface water. During this season, the reactive phosphate increases westward than compared with the east, particularly in the surface water in contrast to other season Compared with the previous result (Table 6), El Mex Bay, influenced by land-based sources, is still too high in phosphate content if compared with the open sea. The Drain and Bay waters exhibited an annual average phosphate concentration of 10.9 and 2.2 μm/l, respectively, which reflected an eutrophication condition (UNEP, 1988). The annual average of Drain water and El Mex Bay in this study is lower than the average measured by Mahmoud et al. (2005) (14.66 and 4.7 μm/l), Nessim et al. (2010) (14.0 and 2.9 μm/l), and Shreadah et al. (2014) (10.68 and 4.1 μm/l) at the same region of investigation.

4.6. Nitrogen and phosphorus ratio

The general assumption that nitrogen is a critical limiting factor for algal growth in coastal marine water (Nixon and Pilson, 1983) does not seem reliable in the case of the Mediterranean Sea (Bonin and Maestrini, 1981). The general agreement with the result obtained for algal growth, and enrichment assays undertaken at different levels confirms the role of phosphorous in the eutrophicated coastal area (Mingazzini et al., 1992; Zaghloul, 1994). The decisive role of phosphorus as a limiting factor for primary production suggested by many authors appears indisputable. The N: P ratio is considered a useful indicator for eutrophication in the Mediterranean, which is regarded as being oligotrophic.

The N/P ratio is 16 : 1 by atom (the so-called Redfield ratio, Fonselius, 1986) or above 19 : 1 (UNESCO Report, 1988). Highly eutrophic waters regardless of whether they are eutrophied by rivers or man-made effluents are constantly receiving phosphorous supplies at levels approaching the optimum values for the growth of the mixed phytoplankton standing crop, at an eutrophic level, that is, 0.3–0.5 μg/lat. PO_4–P (UNESCO Report, 1988). It appears logically that under such conditions, nitrogen might be the prevailing limiting factor, although this has never been experimentally proved in the Mediterranean coastal waters, while it is well known in other marine environments (Goldman, 1977).

Several studies report the importance of the N: P ratio from both ecological and biotechnological perspectives. The well-known Redfield's ratio (atomic or molar ratios of carbon, nitrogen, and phosphorus in phytoplankton (Redfield et al., 1963) can be considered a global average with significant variance for different phytoplankton species (Martiny et al., 2014). It is globally accepted that this ratio could be the optimal nutrient ratio required for growth, obviously with taxon-specific differences: the average optimum N: P ratios in the eukaryotic algae range from 16 to 23 N to 1 P, while the average optimum ratio for cyanobacteria is found to be 10–16 N: 1 P (Schreurs, 1992). Some experimental studies proved that the optimal N: P ratio for certain algal species is indeed around the ratio widely accepted in the literature (Mayers et al., 2014).

DIN and PO_4–P are the main forms of N and P that are readily bioavailable for the growth of phytoplankton. The average ratios of DIN/P showed higher values at the El Umum Drain in the summer season (300.77) and the lowest (7.44) in autumn. However, the average values in the surface water of El Mex Bay ranged from 12.29 in the winter of 2021 and 133.57 in summer. At the near-bottom layer, the ratio fluctuated between 14.04 in winter 2020 and 126.2 in summer. The average N/P for the whole period of investigations is 14.5 for the El Umum Drain, 26.6 in the surface water of El Mex Bay, and 27.8 at near the bottom layer of the Bay. This value is higher than that recorded previously in the same region during 2007/2008 (Nessim et al., 2010) and similar to that of 2010/2011 (Shreadah et al., 2014). It is higher than that reported by a Redfield ratio with a value of 16 : 1 revealing high nitrogen content in comparison with that of phosphorus, that is the N/P ratio of the coastal polluted areas is strongly deviated. The values of the N/P ratio could be related to allochthonous conditions (Zaghloul, 1996). Smith (1983) found a ratio higher than 15–17 indicated that phosphorus was the critical, controlling factor, and less than 9–10 : 1 indicated that the yield varied with nitrogen, and higher than 21 shows that phosphorus was the primary controlling factor.

4.7. Reactive silicate (SiO_4–Si)

Silica is an important element in animal and plant life. Specifically biogenic silica is extracted from water by plants, microorganisms, or invertebrates for building structural materials and growth. The silicate is one of the important parameters that control marine productivity. Diatoms are important phytoplankton groups with regard to the primary productivity and natural food for some fish species. When diatoms are eaten, the remains sink, then the silica dissolves slowly in water (Abdel-Rhman, 2013).

Seasonal variations of silicate in El Mex Bay water were observed during the period of study, which could be attributed to increases in sewage, agricultural, and industrial effluents from the El Umum Drain. There is an increase in silicate concentrations in winter 2020 and spring. This is attributed to low salinity values as a function of discharge waters and also to a decrease in the activity of diatoms, and other microorganisms (Bailey-Watts, 1976). On the other side, during autumn 2020 and winter 2021 the lower silicate concentrations were due to consumption by diatoms, bacteria, and fishes (Dickson, 1975).

Compared with the previous result (Table 6), El Mex Bay, influenced by land-based sources, the Drain, and Bay waters exhibited an annual average of silicate concentration of 130.4 and 26.9 μm/l, respectively. This is more or less similar to that measured by Mahmoud et al. (2005) (123.16 and 34.08 μm/l), Nessim et al. (2010) (152.4 and 36.3 μm/l), and Shreadah et al. (2014) (66.66 and 24.53 μm/l) at the same region of investigation.

4.8. Pollution index

The PI was calculated based on individual measured parameters with respect to its standard water quality marine environment. The obtained data revealed that all stations were seriously affected due to the higher concentrations of study parameters, particularly stations 1 and 2, which represented El Umum Drain water. This can be attributed to the fact that all discharged water to El Mex Bay contains high concentrations of different parameters that exceed their standard and acceptable limits.

4.9. Water budget

According to the annual water budget influx into the Mediterranean Sea at El Mex Bay through the El Mex Pumping Station (Table 5), it attained

Table 7. Annual salt Budget of El Mex Bay during different years (ton/year).

Parameters	1992/1993	2003/2004	2011/2012	2020/2021
DIN	248.95	531.54	321.07	176.96
NH_4	211.1	369.37	284.39	111.6
NO_2	7.05	31.79	9.84	22.05
NO_3	30.8	130.38	26.84	43.32
PO_4	23	43.26	307.3	12.14
SiO_4	69.9	362.6	112.86	145.79

2784.38×10^6 m^3/year (according to the Drainage Research Institute; DRI, 2020/2021). We can calculate from the present averages of the annual salt budget (metric ton/year) reflex into the Bay as follows: DIN176.96, ammonium 111.6, nitrite 22.03, nitrate 43.32, phosphate 12.14, and silicate 145.79 m^3/year. Compared with the previous result (Table 7), the water budget differs from 1 year to the other according to the amount of water discharged from the El Mex Pumping Station.

4.10. Residence times of El Mex Bay

Shreadah et al. (2014) calculated the residence time of El Mex Bay water during 2010–2011 (1.4 days in spring 2010, 5.62 days in autumn 2010, 5.33 days in winter 2011, and 12.48 days in summer 2011). Also, El Gindy et al. (1986) recorded a residence time value of 1.2 days; however, Shaltout (2008) recorded a residence time that ranged from 8.6 to 13.3 days. These variations may be attributed to physical barriers.

4.11. Conclusion

The investigation of the environment particularly the impact of wastewater discharged from El Umum Drain to El Mex Bay is one of the most important targets in the present study. Thus, the assessment of major sources of pollution caused by uncontrolled land-based discharge is done to estimate the impact of pollution on the water quality of marine environment particularly in some nutrient values to develop suitable treatment methods.

Regarding sustainable development, it involves improving the integrated management of water quality, enhancing agricultural efficiency, and preserving the environment. It is necessary to create a wastewater purification plant on the El Mex Pumping Station to benefit from it in many fields. The study recommends the discharge of treated anthropogenic wastes and the recycling of anthropogenic wastes to control eutrophication and pollution.

Conflicts of interest

There is no conflict of interest.

Acknowledgement

The authors acknowledge the Marine Environment Division, NIOF, for the continuity and financial support.

References

Abdel-Halim, A.M., 2004. Chemical Equilibria Studies of Some Phosphorus Compounds under Different Conditions. Alexandria University, Alexandria.

Abdel-Rhman, M.Kh, 2013. Distribution of Nutrient Salts in hot spot areas at El-Mex Bay (Egyptian Mediterranean Sea) In relation to physicochemical parameters. M.Sc. Thesis. Faculty of Science, Alexandria University.

Abou-Tahoun, H.A., 1999. Application of a mathematical model for estimating the pattern of pollutant dispersion at the coast of Alexandria. M.Sc. Thesis. Faculty of Science, Ain Shams University, p. 118.

Bailey-Watts, A.E., 1976. Planktonic diatoms and some diatom-silica relations in a shallow eutrophic Scottish loch. Freshw. Biol. 6, 69–80.

Bonin, D.J., Maestrini, S.Y., 1981. Importance of organic nutrients for phytoplankton growth in natural environmental: implications for algal species succession. Can. Bull. Fish. Aquat. Sci. 21, 279–291.

Bricker, S.B., Clement, C.G., Pirhalla, D.E., Orlando, S.P., Farrow, D.R.G., 1999. National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries. NOAA, national ocean service, special projects office and the national centers for coastal ocean science. In: Silver Spring. U.S. National Oceanographic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Center for Coastal Ocean Science.

de Jonge, V.N., Elliott, M., Orive, E., 2002. Causes, historical development, effects and future challenges of a common environmental problem: eutrophication. Nutr. Eutroph. Estuar. Coast Waters Hydrobiologia 475/476, 1–19.

Dickson, E.L., 1975. A silica budget for Lough Neagh 1970-1972. Freshw. Biol. 5, 1.

Dodds, W., Smith, V., 2016. Nitrogen, phosphorus, and eutrophication in streams. Inl. Waters 6, 155–164.

Dorgham, M.M., 1987. Occurrence of Tintinnids in two polluted areas of Alexandria coast. Papers presented at the FAO/UNEP meeting on the effect of pollution on marine ecosystems. FAO Fish. Rep. 352, 76–83.

Dorgham, M.M., 1997. Phytoplankton dynamics and ecology in a polluted area on the Alexandria Mediterranean coast. In: Proceedings of the 3rd international conference on Mediterranean coastal environment, 11–14 November 1997, Qawra, Malta, 1, pp. 151–160.

Egyptian Drainage Research Institute; DRI, Data Report 2020/2021 (http://www.dri.gov.eg/).

Duursma, E.K., 1961. Dissolved organic carbon, nitrogen and phosphorus in the sea. Netherlands J. Sea Res. 1, 1–141.

El Gindy, A., Aboul Dahab, O., Halim, Y., 1986. Preliminary estimates of water and trace metals balances in Mex Bay west of Alexandria (Egypt). Int. Expl. Sci. Mer. Mediterr. 30, 27.

Fahmy, M.A., Tayel, F.T., Shriadah, M.A., 1995. Effect of pollution on the water quality of El-Mex Bay and El-DeKhaila Harbour of Alexandria. In: Present and Future Technology of

Navigation and Marine Science of Mediterranean and Red Seas Conf., 29–31 Oct. Alexandria, Egypt.
Fahmy, M.A., Beltagy, Aly, Abbas, A.A., 1999. Nutrient salts and Chlorophyll-a in the Egyptian Mediterranean coastal waters. In: MEDCOAST 99 – EMECS 99 Joint Conference, Land-Ocean Interactions: Managing Coastal Ecosystems 9–13 November 1999; Antalya, Turkey.
FAO, 1976. Manual of methods in aquatic environment research part I: permanganate value (oxidability) of organic matter in natural waters. FAO Fish. Tech. Pap. 137, 169.
Farag, M.M., 1982. Circulation patterns and hydrographic structure of El-Mex and western harbour areas. M.Sc. Thesis. Faculty of Science, Alexandria University, p. 276.
Fathy, S.A.H., Abdel Hamid, F.F., Shreadah, M.A., Mohamed, L.A., El-Gazar, M.G., 2012. Application of principal component analysis for developing water quality index for selected coastal areas of Alexandria Egypt. Res. Environ. 2, 297–305.
Ferreira, J.G., Andersen, J.H., Borja, A., Bricker, S.B., Camp, J., Cardoso da Silva, M., 2011. Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuar. Coast Shelf Sci. 93, 117–131.
Foehrenbach, J., 1969. Pollution and eutrophication problems of great south bay, long Island, New York. Water Poll. Contr. Fed. 41, 1456–1466.
Fonselius, S.H., 1986. The hydrography of the Gulf of Bothnia. Report from the hydrography group. Publ. Water Res. Inst. Nat. Bd. Waters 68, 6–16.
Förstner, U., Wittmann, G.T.W., 1981. Metal Pollution in the Aquatic Environment, second ed. Springer Berlin Heidelberg, Berlin, Heidelberg.
Goldman, J.C., 1977. Biomass production in mass cultures of marine phytoplankton at varying temperatures. J. Exp. Mar. Biol. Ecol. 27, 161–169.
Grasshoff, K., Kremling, K., Ehrhardt, M., 1999. Methods of Seawater Analysis-Third Edition. Wiley-VCH Verlag GmbH, Weinheim, pp. 203–223. https://doi.org/10.1002/9783527613984.
Haas, P.M., 2002. Environment: pollution. In: Simmons, P.J., Oudraat, C.J. (Eds.), Managing Global Issues: Lessons Learned. Carnegie Endowment for International Peace, Washington, DC, pp. 310–353.
Hutchinson, G.E., 1957. A Treatise on Limnology, Geography, Physics and Chemistry. John Wiley and Sons, New York.
Ignatiades, L., Karydis, M., Vounatsou, P., 1992. A possible method for evaluating oligotrophy and eutrophication based on nutrient concentration scales. Mar. Pollut. Bull. 24, 238–243.
Kimmerer, W.J., 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Mar. Ecol. Prog. Ser. 243, 39–55.
Kress, N., Manca, B., Klein, B., Deponte, D., 2003. Continuing influence of the changed thermohaline circulation in the eastern Mediterranean on the distribution of dissolved oxygen and nutrients: physical and chemical characterization of the water masses. J. Geophys. Res. Oceans 108, 8109. https://doi.org/10.1029/2002JC001397.
Mahmoud, T.H., 1979. The Effect of Sewage Discharge on the Water Quality of the Coast of Alexandria. Alexandria University.
Mahmoud, T.H., 1985. Phosphorus and Nitrogen Dynamics in the Polluted Coastal Waters off Alexandria. Alexandria University.
Mahmoud, T.H., 1995. The effect of sewage discharge on water quality off the coast of Alexandria in spring and summer. Chem. Ecol. 11, 255–268.
Mahmoud, T.H., Deek, M.S., 1997. The relationship between iodine, chlorinity, Ph, reactive phosphate, nitrite and organic matter in the coastal water of Alexandria. Chem. Ecol. 14, 39–54.
Mahmoud, Th.H., Masoud, M.S., Shaltout, N.A., 2005. Physico-chemical characteristics of different water types in El-Mex Bay, Alexandria, Egypt. In: Conference MTS/IEEE Ocean 2005, Washington, D.C. USA.
Mahmoud, M.G., El-Khir, E.A., Ebeid, M.H., Mohamed, L.A., Fahmy, M.A., Shaban, K.S., 2020. An assessment on the coastal seawater quality of the Gulf of Suez, Egypt. J. Environ. Protect. 11, 34–47.
Martiny, A.C., Vrugt, J.A., Lomas, M.W., 2014. Concentrations and ratios of particulate organic carbon, nitrogen, and phosphorus in the global ocean. Sci. Data 1, 140048.
Masoud, M.S., Mahmoud, T.H., Abdel-Halim, A.M., 2001. Chemical studies of El-Mex bay, Alexandria. In: The Second Conference and Exhibition for Life and Environment, 3-5 April. Alexandria. International Center for Research and Consultation COMIBASSAL and National Institute of Oceanography and Fisheries, Alexandria NIOF, pp. 338–360.
Mayers, J.J., Flynn, K.J., Shields, R.J., 2014. Influence of the N:P supply ratio on biomass productivity and time-resolved changes in elemental and bulk biochemical composition of Nannochloropsis sp. Bioresour. Technol. 169, 588–595.
Mikhail, S.K., 1997. Ecological Studies of Phytoplankton in El-Mex Bay [PhD Thesis]. Faculty of Science, Alexandria University, Alexandria, Egypt, p. 266.
Mingazzini, M., Rinaldi, A., Montanari, G., 1992. Multi-level nutrient enrichment bioassays on Northern Adriatic coastal waters. Mar. Coast Eutroph. 115–131, 1992.
Munawar, M., 1970. Limnological studies on freshwater ponds of Hyderabad-India I. The Biotope. Hydrobiologia 35, 127.
Nemerow, N.L., Sumitomo, H., 1970. Benefits of water quality enhancement. Report No 16110 DAJ, Prepared for the US Protection Agency. Syracuse University, Syracuse, NY.
Nessim, R.B., Salem, D.M.S.A., Abou-Taleb, A.E.A., 2005. Investigation of some major ions anomalies in Alexandria coastal water, Egypt. J. Aquat. Res. 31, 38–44.
Nessim, R.B., Salem, D.M.S.A., Abdel Ghani, S.A.H., Abou-Taleb, A.E.A., 2010. Level of some major constituents of the Egyptian Mediterranean Coastal waters, Egypt. J. Aquat. Res. 36, 1–9.
Nixon, S.W., Pilson, M.E.Q., 1983. Nitrogen in estuarine and coastal marine ecosystems. Nitr. Mar. Environ. https://doi.org/10.1016/b978-0-12-160280-2.50024-9.
Okbah, M.A., Ibrahim, A.M.A., Gamal, M.N.M., 2013. Environmental monitoring of linear alkylbenzene sulfonates and physicochemical characteristics of seawater in El-Mex Bay (Alexandria, Egypt). Environ. Monit. Assess. 185, 3103–3115.
Okbah, M.A., Masoud, M.S., El Zokm, G.M., Abd El-Salam, A.A., 2017. Study of nutrient salts, chlorophyll-a and physico-chemical condition in El-Mex Bay Water, Alexandria, Egypt. Am. J. Biol. Environ. Stat. 3, 54–64.
OSPAR, 2003. Eutrophication Series OSPAR Integrated Report 2003 on the Eutrophication Status of the OSPAR Maritime Area Based upon the First Application of the Comprehensive Procedure OSPAR Commission.
Pujo-Pay, M., Conan, P., Oriol, L., Cornet-Barthaux, V., Falco, C., Ghiglione, J.-F., 2011. Integrated survey of elemental stoichiometry (C, N, P) from the western to eastern Mediterranean Sea. Biogeosciences 8, 883–899.

Redfield, A.C., Ketchum, B.H., Richards, F.A., 1963. The influence of organisms on the composition of seawater. In: Hill, M.N. (Ed.), In the Sea. Wiley Interscience, New York, pp. 26–79.
Riley, J.P., Skirrow, G., 1965. Chemical Oceanography. Academic Press, London.
Said, M.A., El-deek, M.S., Mahmoud, T.H., Shreadah, M.A., 1993. Effect of pollution on the hydrochemical characteristics of different water types in El-Max Bay area, west of Alexandria, Egypt. Acta Adriat. 34, 9–19.
Schreurs, H., 1992. Cyanobacterial Dominance. Relations to Eutrophication and Lake Morphology. University of Amsterdam, Amsterdam, the Netherlands.
Schuler, J.F., Diller, V.M., Kersten, H.J., 1953. Preferential assimilation of ammonium ion by Chlorella vulgaris. Plant Physiol. 28, 299–303.
Seike, Y., Kondo, K., Hashitani, H., Okumura, M., Fujinaga, K., Date, Y., 1990. Nitrogen metabolism in the brackish Lake Nakanoumi. IV. Seasonal variation of nitrate nitrogen. Jpn. J. Limnol. (Rikusuigaku Zasshi) 51, 137–147.
Shaltout, N.A., 2008. Inorganic Carbon Cycle of Alexandria Coastal Water [PhD Thesis]. Faculty of Science, Alexandria University, Alexandria, Egypt.
Shoukry, M., 1999. Monitoring and Assessing the Water Quality after the Construction of El-Dikhela New Harbour Using Remote Sensing Techniques. Alexandria University, Alexandria.
Shreadah, M.A., Masoud, M.S., Khattab, A.R.M., El-Zokm, G.M., 2014. Impacts of different drains on the seawater quality of El-Mex Bay (Alexandria, Egypt). J. Ecol. Nat. Environ. 6, 287–303.
Smith, V.H., 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in Lake Phytoplankton. Science 221, 669–671.
Soliman, A.M., Gharib, S.M., 1998. Water characteristics, phytoplankton and zooplankton population of Mex Bay region, Alexandria, Egypt. Bull. Fac. Sci. Alex. Univ. 38 (1–2), 45–66.
Tayel, F.R., Fahmy, M.A., Shriadah, M.A., 1996. Studies on the physicochemical characteristics of Mex bay and new Dekhaila harbor waters of Alexandria. Egypt Bull. Natl. Inst. Oceanogr. Fish. 22, 1–18.
UNEP, 1988. First Meeting of Scientific. Technical Committee, Athena, pp. 23–27.
UNESCO Report, 1988. Eutrophication in the Mediterranean Sea: receiving capacity and monitoring of long-term effects. In: Report and Proceedings of a Scientific Workshop Bologna, Italy, 2–6 March 1987. ISSN 0253-0112.
Vaalgamaa, S., 2004. The effect of urbanisation on Laajalahti Bay, Helsinki City, as reflected by sediment geochemistry. Mar. Pollut. Bull. 48, 650–662.
VanLoon, G.W., Duffy, S.J., 2000. Environmental Chemistry, a Global Perspective, first ed. Oxford University Press Inc., New York, pp. 25–92. 134–183.
WHO, 2002. Eutrophication and health. WHO European Commission Luxembourg: Office for Official Publications of the European Communities, 28 pp. ISBN 92-894-4413-4.
Zaghloul, F.A., 1994. Phytoplankton dynamics in the western Harbour of Alexandria. Bull. Natl. Inst. Oceanogr. Fish. 20, 107–117.
Zaghloul, F.A., 1996. Further studies on the assessment of eutrophication in Alexandria Harbours. Egypt Bull. Fac. Sci. Alex Univ. 36, 281–294.
Zaghloul, F.A.-R., Khairy, H.M., Hussein, N.R., 2020. Assessment of phytoplankton community structure and water quality in the Eastern Harbor of Alexandria, Egypt. Egypt J. Aquat. Res. 46, 145–151.