Water Quality and Trophic Status of a Lake (Mariut, Egypt) Eight Years After Diversion of Wastewater Effluents

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Research Article

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Abstract

Water resource management and lake rehabilitation is a global interest, to overcome the acute water scarcity facing most urban areas, especially in developing countries. Lake Mariut (LM) is an Egyptian lake that lies south of Mediterranean Sea, and its management had a great interest in Alexandria's future development and as a part of the environmental sustainability of the Mediterranean basin. LM consists of 4 major basins namely, main basin MB, NWB, SWB, and FB. The MB has deteriorated as it consistently received (sewage and industrial) wastewaters till 2010. This was the date of diversion of the polluting sources as a rehabilitation step. The present work is made after elapsing 8 years from the diversion and aims at monitoring and assessing the status of the water quality not only of MB but also for the other 3 basins too. This was carried out twice, one in cold winter and the other in warm summer. The parameters studied were physico-chemical ones including DO besides nutrient salts (N and P compounds). The results revealed that the waters of both MB and SW basin were depleted in DO to a level difficult to sustain fish life. Tropically, all the studied basins were in eutrophic-hypereutrophic condition. The depletion in the vital DO is catastrophic and needs urgent solution/s. One of the proposed solutions is the dredging of bottom spoiled organic-rich sediments. This and other suggested solutions are, however, discussed, evaluated, and presented.

1. Introduction

The recent growth in population and urbanization, have a substantial effect on the local environment and cause water quality degradation. This is due to the increase in industrial, agricultural, and sewage effluents that are discharged into the aquatic environment (Lin et al. 2020).

Lake eutrophication (due to natural, cultural, or both) is a water environment challenge in the world. Cultural eutrophication arises due to the excessive nutrients (N and P) loading from anthropogenic origins, leading to considerable growth of aquatic flora, especially harmful algal blooms. Changes in algal community structure usually coincided with water quality deterioration, (Nikolai and Dzialowski 2014). Continuous depletion in dissolved oxygen (DO) of the water column of such environment as a result of aerobic decomposition can result in loss of biodiversity and death of aquatic life (Song et al. 2017).

The management of the lake is essential for generating and restoring an aquatic environment suitable for growing healthy life. Water quality plays a vital role in keeping both the indigenous biota and the surrounding ecosystem healthy and productive. There are two broad approaches concerning the water quality management of lakes: 1) the reduction of external loading (remediation, preventive, or indirect), and 2) the lake-internal (restoration, ameliorating, curative, or direct), noting that the former approach has the priority over the later one (Zamparas and Zacharias 2014). It is worthy to mention that the remediation approach of the drainage basin is convenient for shallow, polymictic lakes with short-lasting water residence time. This approach is based on identifying the pollutants, decreasing their generation rate, and/or preventing them from entering the lake (Kasprzak et al. 2018). Lake rehabilitation strategies not only aim to restore the water and sediments qualities of the lake but also to maintain sustainable improvement.

Egypt is characterized by its northern coastal lake and lagoons (six water bodies), which represent about 25% of the Mediterranean total wetlands. However, these water bodies are the ones of the most valuable they are also the vulnerable ecosystem as they receive the wastewater discharged from the watershed (El-Naggar and Rifaat 2019).

Lake Mariut (LM) is the focus of this research as an example of a recently rehabilitated lake on the northern Egyptian Coast. This lake since the late sixties of the last century and along 50 years ahead, was a victim of uncontrolled urbanization (El-Rayis and Abdallah 2006; El Kafrawy et al. 2017), and its water quality showed a downward trend that accompanied by a remarkable decline in its importance as a source for the popular Tilapia fish for the Egyptian people and as a place for recreation and nesting wild birds (El Kafrawy and Ahmed 2020). Where it was converted from the most productive and fertile aquatic habitat in the 1960s (produced about 60% of the total fish production from the coastal lakes) to the most polluted one and least productive in the 1990s (El-Rayis et al., 1997; Abaza et al., 2009; Shaaban et al., 2021).

This lake (LM) is artificially subdivided into four principal basins by Desert Road and Umum Drain (UD). The four basins are, shown in Fig. 1, called Main Basin (MB), Fishery Basin (FB), North-Western Basin (NWB), and South-Western Basin (SWB). The last

is split into two subbasins; SWB_{2000} and SWB_{5000} due to crossing of UD through, (Fig. 1). As a result, there was a semi-restricted movement of water, fish, and fishermen, causing each basin to function independently and has unique characteristics.

Historically, the lake deterioration was due to the decline of its MB (where most of the fish catch comes) ecosystem as a consequence of contaminating it as it was the receptor (in 1960) of raw civilian sewage and industrial wastewater discharges (till 1995) and of the primary treated wastewaters effluents (after 1995) after the erection of east and west wastewater treatment plants (EWTP and WWTP, respectively) of Alexandria City (El-Rayis 2005; Donia et al. 2016; Shreadah et al. 2020).

However, there was a noticeable water quality improvement (for a while), the organic matter and nutrients load discharged were not sufficiently reduced (Abdallah 2003). Consequently, the water quality got worse again and MB became hypereutrophic, accompanied by a complete depletion in DO and intermittent evasion of toxic hydrogen sulfide (H_2S) gas, especially in front of two defined hot points land-based sources. One at the southeastern part of MB [where the outlet of the agricultural polluted Qalaa Drain, QD contaminated with the discharge of the EWTP effluent (El-Rayis et al. 2019). The other was in front of WWTP mainly industrial discharge at a site laying at the NW side of this basin.

Because of this severe water pollution and its consequences, it attracted the attention and promote researchers and decision-makers to adopt some countermeasures to combat the situation. To control nutrients and organic matter supply, several rehabilitation programs were suggested to solve the severe lake pollution problem (Shaaban 2010; El-Rayis et al. 2019). The diversion of the pollution point sources is adopted in 2010 as the cheapest and fastest solution for the problem to alleviate or reduce water pollution. This diversion was attained by discharging directly into the lower reach of the huge agricultural drain, (namely Umum Drain, UD), before pumping to pour into the sea at El-Mex Bay (SE Mediterranean Sea).

The water quality of MB and its two lately diverted polluted drains, was monitored 3 years after the diversion by (Shaaban 2015; Shreadah et al. 2020). They showed that the water of the MB was improved again, aerated, and became in oxic condition instead of DO depletion. Not only that but also the annual fish production remarkably increased and the fish-flesh quality has been improved and becomes safe for human consumption (Shaaban et al. 2021).

The continuous monitoring of MB water quality is important for evaluating not only the efficiency of the recently implemented rehabilitation step (the diversion of the wastewater effluents) but also to examine its sustainability.

Thus, the present work is the second monitoring for the water quality for MB after elapsing 8 years of the diversion of the wastewater effluents besides that of the other 3 basins too in addition to the drainage system of the lake. This study can be considered as a complementary one to examine if the adopted rehabilitation program was efficient enough or requires modification(s) and/or suggesting another solution(s). To achieve the objective, the current spatiotemporal changes of selected water quality parameters and the trophic status were examined.

2. Material And Methods

Study area

Lake Mariut (LM) is an inland closed shallow lake Mean depth of 1 m) lies south of Alexandria City. It is a depression extends for about 20 km between 31° 01′48″ and 31° 10′ 30″ N and 29° 49′48″ and 29° 57′00″ E. Its bottom is below the sea level by values ranging between 4.0 and 3.4 m and separated from the neighboring Mediterranean Sea by a ridge called Abuser (Shaaban et al. 2021). The lake as mentioned formed from four basins, the main basin MB, (the recently restored basin), North-West Basin (NWB), South-West Basin (SWB), and Fishery Basin (FB). Their areas ranged between 5500 and 1000 acres (Fig. 1).

Before 2010, MB was used to be filled with water from three main resources; 1) partly from UD (the huge agricultural drain its course is lining westside of MB and at the same time is lining NWB (at its eastside) and go through SWBs). 2) Qalaa Drain (QD, is also an agricultural one but mixed with the effluent of Alexandria EWTP, and was discharged at the southeast side of MB) and 3) the industrial effluent of the WWTP that was pouring directly at NW-side of MB. After 2010, as mentioned before, where the last two polluted wastewaters have been diverted to pour into $UD_{downstream}$ (Shaaban 2015; El-Rayis et al. 2019; Shreadah et al. 2020).

The following Table 1 summarizes the current discharge rate of the different water sources related to LM:

Table 1 The current discharge rate of different water sources of Lake Mariut

Source	Rate m^3/day	Type
QD		
EWTP	650,000 plus 309,000	Secondary treated sewage wastewater plus from subsidiary agriculture drains.
WWTP drain	405,000	Primary treated industrial wastewater.
UD UD $_{upstream}$	4.20 x 10^6	Agricultural drainage water
UD $_{downstream}$	about 8.0 x 10^6	Polluted Agricultural drainage water discharging into the SE Mediterranean Sea via El-Mex Bay
NC **(before joining the MB)**	2.53 x 10^6	Freshwater Canal

Sampling sites

Surface water sampling was collected two times, July and November, from 15 selected locations shown in Fig. 1, representing the different basins and the drains.

Methods of analysis

Environmental parameters including water temperature, transparency, hydrogen ion concentration (pH), in addition to conductivity and salinity were determined in-situ using thermometer, Secchi-disc, portable pH-meter (Cyberscan^{10}pH), and portable conductivity-meter (CRISON CM-35, Spain), respectively. Concentrations of DO/H_2S were measured according to the Winkler method (APHA,1995). Nutrient salts, including $NO^-{}_{3}$-N, NO_2^- N, NH_4^+ N, PO4 -P (DIP), and SiO_4-Si, total N (TN), and P (TP). Chlorophyll a (Chl a) content was measured according to Strickland and Parsons (1972) and Valderrama (1981). All spectrophotometric analyses were done using the Shimadzu UV-VIS spectrophotometer (model UV-1201). The values of dissolved inorganic nitrogen (DIN) and organic nitrogen (ON) concentrations were calculated.

Data analysis

The water quality was evaluated via the 12 studied standard parameters and by applying the trophic status criteria (TS). Water sample data were statistically analyzed using cluster analysis, principal component analysis (PCA), and paired samples t-test, using the software of STATISTICA 10, and IBM SPSS statistics 22.0. To organize data into meaningful structure and categories, and to reduce data and extract a small number of latent factors for analyzing relationships among the observed variables, and finally, to compare and evaluate the water quality situation at MB after three and eight years of wastewater diversions.

3. Results And Discussion

3.1 Environmental parameters

To represent, classify, and discuss the current situation of different Lake Mariut Basins (LMBs) and their drainage water system (drains and canal), the cluster analysis was employed using the obtained data of water quality parameters and nutrients at the monitoring locations covering the study area. The cluster analysis showed that stations I and III (center and northwest corner of MB, respectively) had their unique characteristics with the dissimilarity of 100, and 60 %, respectively, from the study area (Fig. 2). The feeding UD and NC are grouped in one cluster, while LMBs and the diverted drains are to some extent close to each other with

a similarity (> 60 %). Consequently, the present results can be illustrated in terms of three categories as follow LMBs, diverted drains, and feeding UD, and NC.

LMBs were characterized by their shallowness with an average of 1 m, in addition to the diverted drains from MB (QD and WWTP effluent). While the LM drainage system UD and NC were deeper (with about 3 m depth), Fig. 3a. It worth mention that during the present study the surface water in UD was about 1 m lower than that recorded earlier in 2013 (Shreadah et al., 2020). Reflecting shortage of the agricultural drainage water by amount reaching about 3 mcm/d to be reused after treatment for plantation of about a half-million acre at west desert (Ministry of the Water Resource and Irrigation, personal communication). This has led some parts of the lake to get dry.

The obtained results show that the water temperature of LMBs was generally varied between a minimum of 18.8°C in winter and a maximum of 30.1°C in summer. This range was coincided with those obtained by (Farouk et al. 2020), and was within the desirable optimum condition for fish culturing (Bhatnagar and Devi 2013; El Zokm et al. 2018).

Also, the water of LMBs was nearly transparent at both FB and SWB (with STD/TD of > 90%) while in MB water the STD/TD % was less, average about 50, Fig. 3b. On other hand, the drainage water of the deep UD and NC and each of the polluted shallow QD and WWTP drain were even lower 23 ± 14 %. The last was in agreement with that recorded by (Shreadah et al. 2020).

Regarding DO, extremely wide fluctuation in the concentrations over the study area happen, from nil in the effluent polluted waters of QD and WWTP beside that in the $UD_{downstream\ part}$ and NC to 12.9 ± 4.5 mg O_2/l (oversaturation, of average % oxygen saturation 169) only in FB, Fig. 3c. Therefore, the order of abundance in DO in the study lake was: FB (13.0 mg O_2/l), > NWB (10.5 mg O_2/l) > SWB (6.0 mg O_2/l) > MB (2.6 mg O_2/l). This is in agreement with that mentioned by (Abd El-Alkhoris et al. 2020). The standard guideline suitable for aquaculture purposes (Rachman and Adi, 2005) is > 3 mg/l. Therefore, MB water is in a critical stage particularly at the zones of stations I and II, where H_2S gas was detected in summer. It seems likely that relatively high temperature accelerates the aerobic decomposition rate of organic matter. Also reflects the existence of remnant oxygen-consuming matter mostly those impeded with the old bottom spoiled organic-rich sediments (El-Rayis et al, 1994). The sluggishness of the water in this basin could be another reason. Further the current basin is slightly feeded with less oxygenated water at its lonely opening SW from UD. Certainly, a solution for such a critical problem is urgently needed to regain the health condition of this important basin and therefore for the fish catch.

Focusing drainage system, the adverse effect of the high organic matter load, not only restricted on DO depletion and appearance of malodorous H_2S gas at each of QD and WWTP drain (average 7.4 ml H_2S/l) but also responsible for converting the oxic water of the proper NC and $UD_{downstream}$ into anoxic one, Fig. 3d.

By highlighting the DO content of UD water before joining MB (station IX), in the present work there was a remarkable decline to about one third (2.0 mg O_2/l equivalent 25 % of O_2 saturation) relative to the previously recorded in 2007 and 2013, where the respective mean values were 6.5 and 8.8 mg O_2/l (equivalent to 75, and 102 % oxygen saturation (Shaaban, 2010; Shreadah et al., 2020, respectively). This drastic decrease often coincided with the latest strategy of the Egyptian Ministry of Water Resources and Irrigation in abstracting about 3 mcm/d from UD which in turn has led to lowering the water level to -325 cm (below the sea level) in this drain. This situation consequently has led part of the DO depleted water of SWB_{5000} to drain into the upper reach of UD. These often are the causes of the general decline of DO content noticed in the water of this essential drain.

The pH values fluctuated from 6.95, slightly acidic, in the industrial WWTP to 8.70 at FB, Fig. 3e. The change in the basins was not much and they were in the order: MB (7.48) ≤SWB_{5000} (7.49) < SWB_{2000} (7.83) < NWB (8.13) < FB (8.53). This distribution is more or less in agreement with that obtained by (Farouk et al. 2020). The relatively high values in FB reflects the role played by the presence of condensed aquatic plants there in the removal of ambient CO_2 during photosynthetic activities, and thence in raising pH. This observation was previously noticed by (El-Rayis et al. 2019). It is worthy to mention, the current pH levels were within the recommended range (5.5–9.5) suggested by the Central Pollution Control Board for the inland waters (CPCB, 1995), and the proposed range (6.0–9.0) by the European Union (EU) for fisheries and aquatic life.

The lower values (7.05), noticed in QD could be due to the liberation of H_2S and CO_2 resulted from anaerobic decomposition processes of organic matter occurring there. It is worthy to mention that QD water always attained slightly acidic and neutral due to its anoxic sewage wastewater, which verified by an inverse significant relationship between pH and H_2S ($r = -0.61$, $p < 0.05$), especially in high temperature (summer; July) coincided with increasing the decomposition (oxidation) rate of organic matter.

Seasonally, summer (July) generally exhibited the lowest pH compared with winter (November) ones. This could be a result of an increase in water temperature that accelerates the rate of decomposition of organic matter. It worthy to mention the distribution pattern pH values at waters of LMBs were previously recorded on the alkali side (Abd El-Alkhoris et al. 2020).

The salinity values of LMBs waters varied between 2.31 and 7.10 g/l and show the following decreasing order: the FB_{1000} > $NWB_{3000} \geq SWB_{2000} > MB_{6000} = SWB_{5000}$, Fig. 3f. It coincided with the previous observation by (Farouk et al. 2020), where FB (6.7 ± 0.6 g/l) is a closed basin with a high evaporation rate and no source of direct freshwater discharge and its water source is from Abis PS (with relatively high salinity about 4 g/l (Shaaban 2010). The horizontal distribution of salinity over the study area confirms the fact that the source of water of both MB (2.78 ± 0.27g/l) and SWB_{5000} (2.89 ± 0.06 g/l), are from UD (2.70 ± 0.04 g/l) water. Meanwhile, the waters of diverted drains, QD and WWTP, were concurrent with the freshwater salinity (1.35 ± 0.48 g/l) reflecting the role of municipal sewage water (> 88%) in decreasing the salinity of the drains water. In contrast the water of navigational canal (NC) and the agricultural drain (UD), attained high salinities.

with a relatively high residence time of LMBs The Chl a, the indicator of phytoplankton abundance and biomass (Ahmed 2020)is of values ranged between higher levels in the waters of the four basins (average 43 mg/m^3) to lower levels (< 8 mg/m^3) of anoxic QD, and WWTP drain. This notice agrees with that observed by Abd El-Alkhoris et al., (2020), The low Chl a content in QD and WWWTP drain reflect unfavorable conditions for algal plants due to evasion of toxic H2S. The order of Chl a abundance between LM basins is: MB > NWB > LMFB = $SWB_{5000 \text{ and } 2000}$, Fig. 3g. Generally, the maximum Chl a content was recorded in the summer season, coincided with low transparency and high DO concentration, reflecting the role of photosynthetic activities.

Monitoring of nutrients (N and P) levels has a significant response on the water quality and food webs at the lake (Somura et al. 2018). As well as the nutrients content determines the amount of phytoplankton and algal biomass, reflected in eutrophication status and related to total fish production (El Zokm et al. 2018).

In the current study (Fig. 4a), the TN content (with an average value > 1 mM) of the drainage water system (drains and canal) sustained at least 3 times higher than those recorded at different LMBs (with an average value < 0.4 mM). Moreover, most of the TN was in ON form in the study area, particularly, in the warm season (July). The order of TN abundance was: SWB_{5000} (7.2 mg/l, 0.51 mM) > MB (6.8 mg/l, 0.49 mM) > NWB (3.3 mg/l, 0.24 mM) ≥ FB (3.1 mg/l, 0.22 mM) > SWB_{2000} (2.6 mg/l, 0.19 mM), which reflect the declining in the TN content regarding to previous studies (Abd El-Alkhoris et al. 2020) by at least 25%.

The distribution pattern of DIN levels revealed that the least DIN values were at FB (0.02 mM) followed by NWB (0.07 mM), SWB (0.13 mM), and MB (the relatively high DIN content with an average of 0.19 mM). Moreover, July (hot season) attained the lowest values of DIN (< 0.1 mM) compared with relatively higher ones in November (cold season). Most anoxic waters of the diverted drains (QD and WWTP), downstream waters of UD and NC were characterized by the elevated DIN content relative to aerated stagnant waters of LMBs. On other hand, the downstream of the running water of both UD and NC were, always, exhibited an elevated DIN content than their upstream waters.

The NH_4 has constituted a considerable part of DIN, particularly in the anoxic waters (> 90%) as illustrated in Fig. 4a. revealing the reducing conditions. This was an indication of the ammonification and/or deamination processes, which concurrent with a decline in the NO_3^- concentration.

Like TP, the current TP concentrations of LMBs were generally lower (by about three times of magnitude) compared with those of the drainage water system (Fig. 4b). Regarding LMBs, the order of abundance of TP was MB (0.92 mg/l, 0.030 mM) > FB (0.75 mg/l, 0.024 mM) > NWB = SWB_{5000} (0.49 mg/l, 0.016 mM) > SWB_{2000} (0.29 mg/l, 0.009 mM). However, MB showed a relative decrease in TP levels when compared with the previous studies (Abd El-Alkhoris et al. 2020), this situation was reversed for the other basins.

The extremely elevated levels of TP (> 0.07 mM) were observed at the diverted polluted drains QD and WWTP, beside the downstream part of UD (Fig. 4b). The high TP levels in the diverted drains are due to the massive amount of sewage discharge usually loaded with P.

The percentage of DIP to TP was higher in summer (July) relative to that in winter (November), this could be attributed to the increasing of domestic discharge that enriched with polyphosphates (in commercial soaps and detergents) which are quickly hydrolyzed and yield to the production of orthophosphate species in aqueous solution.

Comparing the present study results with the guidelines of the Egyptian Ministry of Water Resources and Irrigation "law 48/1982," for protection of the Nile River and waterways from pollution, i.e., decree No. 49 in the amended executive regulations of the law by Minister Decision No. 92/2013 (Table 2) revealed that MB and SWB showed elevated levels of most nutrient salts (NH_4^+, ON, TN, and TP) than those recommended by EEAA, however average DO concentrations of MB was lower than permissible limits the pH values were within the recommended range. On other hand, the other two lake basins' waters (NWB, and FB) were within the allowable boundaries for most parameters excluding ON content.

3.2 Trophic Status

The trophic state can be used for evaluating the efficiency of the restoration program, and for lake categorization. This can be accomplished by applying three definite approaches, namely (1) trophic state criteria (TSC); (2) trophic state index (TSI); and finally, the nutrient loading criteria (Premazzi and Chiaudani, 1992).

1. Based upon the TSC (first approach), some proposed parameters were used for evaluating changes in the ecological conditions of lakes and for qualitative description of the trophic status. The TSC includes abiotic; STD, DO, TP, TN, organic- and inorganic-N; in addition to biotic parameters as Chl-a, (Premazzi and Chiaudani 1992; Thomas et al. 1996; Wetzel 2001b).

The trophic statuses of the studied lake waters relative to standards were presented in Fig. 5. It reveals that although waters of both NWB and FB were supersaturated with DO and contained relatively low concentrations of inorganic-N forms, their waters were identified as hyper-eutrophic relative to other standard parameters. While MB water was categorized as hyper-eutrophic regarding suggested parameters. Additionally, the diverted drain and effluent of QD and WWTP were recognized as dystrophic, with poly-humus, refractory dissolved organic and brown water which decrease the attenuation of light, causing the decline in Chlo-a concentration, (Carpenter and Pace 1997)

1. The calculated TSI using these formulas developed by Carlson (1977) that are based on STD, TP, and Chl-a are presented in Fig. 5. The results indicated that the TSIs, according to STD and Chlor-a, most of the study areas were grouped as eutrophic waters. On contrary, the TSIs (TP) were classified the study area as hyper-eutrophic. Moreover, the order of TSI values: TSI (TP) > TSI (Chl-a) = TSI (STD), proposed zooplankton grazing or/and N- content, are growth limiting factors of algal biomass production (Brown and Simpson, 2001).
2. The nutrient loading criteria according to the Vollenweider model (Vollenweider 1968, 1976) were applied to compare the present study TN and TP loading levels of UD at its upstream and downstream (UD_{us} and UD_{ds},) respectively with those corresponding permissible and dangerous loading levels (Wetzel, 2001) that required to maintain lake in a steady state as a function of its mean depth (Table 3). The results revealed that UD_{us} (the feeding water source of MB after the diversion of QD and WWTP effluent) loads TP lower than the permissible and dangerous loading levels to MB. However, TN loading was exceeding the permissible levels it was lower the dangerous loading values. Moreover, levels of TN and TP entering Mex Bay through UD_{ds} were slightly higher than the permissible limit and lower than dangerous loading.

Table 2 A comparison between present study data of MB and its drains with those ones recommended according to Egyptian Law (92/2013).

Parameters	Unit	Egyptian Law (92/2013)				LMBs				Drainage system (drains and canal)			
		FW	Agri. D	TWW						Diverted		Feeding	
				Domestic	Industrial	MB	NWB	FB	SWB	QD	WWTP	UD	NC
DO	mg/l	> 6	> 5	> 4	> 4	**2.6**	10.5	12.9	6.0	**ND**	**ND**	**1.9**	**3.4**
pH	SU	6.5–8.5	6.5–8.5	6.0–9.0	6.0–9.0	7.5	8.1	8.5	7.7	7.4	7.1	7.5	7.6
ON	mg/l	< 1	-	-	-	**4.2**	**2.3**	**2.8**	**3.1**	9.8	12.0	8.9	9.1
NH_3	mg/l	< 0.5	-	-	-	**2.0**	0.2	0.3	**1.2**	6.3	7.8	2.4	3.0
NO_3	mg/l	< 2	-	-	-	0.5	0.8	0.1	0.4	ND	0.3	0.7	0.6
TN	mg/l	< 3.5	15	-	-	**6.8**	3.3	3.1	**4.9**	16.1	20.1	12.3	12.8
TP	mg/l	< 0.5	3	-	-	**0.9**	0.5	**0.8**	0.4	2.3	2.1	0.9	1.0

FW = guideline for fresh waters subjected to industrial wastewater discharge Agri. D = guideline for agricultural drains ND= not detected

– = not mentioned criterion TWW = Treated wastewater before discharge into non–freshwater aquatic environment

MB= Main Basin NWB = North West Basin FB= Fishery Basin SWB = South West Basin QD = Qalaa Drain

WWTP = West Wastewater Plant effluent UD = Umum Drain NC = Nubaria Canal

Bold numbers represent the higher values than recommended guidelines

Table 3 Values of the permissible loading levels for TN and TP in g/m ^{2} yr as well as those values of Umum Drain upstream and downstream (UD_{us} and UD_{ds}, respectively) in the present study.

Mean depth	Wetzel, (2001)				Present study			
	Permissible loading		Dangerous loading		MB from UD_{us}		Mex Bay from UD_{ds}	
	N	P	N	P	N	P	N	P
< 5 m	< 1.0	< 0.07	> 2.0	> 0.13	1.1	0.06	-	
10 m	< 1.5	< 0.10	> 3.0	> 0.20	-		1.6	0.15

The trophic status according to Wetzel (2001) * according to Thomas et al (1996)

MB= Main Basin NWB = North West Basin FB= Fishery Basin SWB = South West Basin QD = Qalaa Drain WWTP = West Wastewater Plant effluent

UD = Umum Drain NC = Nubaria Cana

TSI = trophic state index (Wetzel, 2001) TSI (STD) = 60 − 14.41 ln (STD) TSI (CHL) = 9.81 ln (Chl−a) + 30.6 TSI (TP) = 14.42 ln (TP) + 4.15

3.3 Principal component analysis (PCA)

The principal component analysis (PCA), the multivariate method, has been applied on 16 variables (measured parameters) and 15 sampling stations. The number of factors extracted from the variables was measured regarding Kaiser's rules. This criterion retains only factors with eigenvalues that exceed one. Based on eigenvalues and varimax rotation five factors explained 86.3 % of total variability explaining 24.58%, 21.29%, 16.91%, 12.32%, and 10.23% for PCF_1 (pH factor), PCF_2 (NH_4 factor), PCF_3 (NO_2 factor), PCF_4 (TD factor), and PCF_5 (Chl a factor), respectively, (Table 4). The loading of the variables on the five PC showed that

pH, salinity, DO, and DIP are the dominant variables on the PCF_1 (-0.90, -0.84, -0.80, and 0.73, respectively). The N-forms were the core variables controlling 2nd and 3rd components, where NH_4 (0.94), DIN (0.93), and TN (0.68) on PCF_2 and NO_2 (-0.91) and NO_3 (-0.74), on the PCF_3. Finally, the TD (0.87) and percentage of STD to TD (-0.84), in addition to STD (0.75) and Chl a (-0.87) were the dominant variables on PCF_4 and PCF_5, respectively.

However, most dominant variables of PCF_1 were negatively correlated with components and positively correlated to each other. Likely, high significant linear relationship between DO and pH at the meantime the inverse relationship between H_2S with both DO and pH, indicated the presence of liberated H_2S and CO_2 weak acids resulted from an occurrence of oxidation (decomposition) processes of organic matter and exhaustion of DO (El-Rayis et al. 2019).

Table 4 Varimax rotated component matrix of the studied parameters in Lake Mariut Basins and their drainage system

Rotated Component Matrix [a] 2018–2019					
	Component ($r = 0.46$, $p > 0.01$)				
	1	2	3	4	5
TD	-0.01	0.04	-0.22	**0.87**	0.10
STD	-0.31	-0.32	-0.21	-0.15	**0.75**
STD/TD	-0.17	-0.22	-0.02	**-0.84**	0.37
Water temperature	0.27	**-0.52**	**0.57**	0.41	0.09
pH	**-0.90**	-0.24	0.02	-0.16	0.12
Salinity	**-0.84**	-0.30	0.11	-0.10	0.21
DO	**-0.80**	-0.39	0.20	0.03	0.00
H_2S	**0.67**	-0.11	**0.55**	-0.09	0.07
Chlor-a	-0.06	-0.29	0.05	-0.02	**-0.87**
NH_4	0.28	**0.94**	0.16	0.04	-0.02
NO_2	0.12	0.03	**-0.91**	0.10	0.12
NO_3	0.04	-0.24	**-0.74**	0.33	0.23
DIN	0.30	**0.93**	-0.03	0.10	0.03
TN	0.36	**0.68**	0.00	**0.49**	0.12
DIP	**0.73**	0.15	**0.50**	0.20	0.07
TP	**0.51**	**0.54**	**0.54**	0.10	0.01
Variance %	24.58	21.29	16.91	13.32	10.23
Cumulative %	24.58	45.86	62.78	76.10	86.32
Extraction Method: Principal Component Analysis.					
Rotation Method: Varimax with Kaiser Normalization.					
a. Rotation converged in 18 iterations.					

3.4 Comparative evaluation of water quality of MB

To evaluate the efficiency of wastewater effluents diversion process on the water quality of MB with time (as MB-rehabilitation

 present study, 2018) with the older ones in 2013 (Shaaban 2015;

Shreadah et al. 2020), with five years interval. The average concentration values of selected parameters during 2013 and 2018 are presented in Table (5). However, the observable decreasing trend in the concentrations of H_2S, TN, NO_2, DIP, and TP by approximately 87, 44, 40, 25, and 20%, respectively, could be an improvement indicator. Those were combined with decreasing in DO concentration (by 84%), and a moderate decline in TD, transparency, and pH by 19, 11, and 2 %, respectively, and a slight increase in water salinity by 2%.

Moreover, the previous notice was statistically confirmed by applying the paired t-test using the data of the environmental and nutrients parameters between the two successive periods after three years (Shaaban 2015; Shreadah et al. 2020) and eight years (present study) of diversion. The results revealed significant temporal variations in terms of total depth, DO, H_2S, and TN ($p < 0.05$), while the other parameters did not show significant differences, (Table 5).

Table 5 Results of the paired t-test of differences of the environmental and nutrients between the two successive periods after three and eight years of insulation of wastewater effluents away from MB.

Rotated Component Matrix [a] 2018–2019					
	Component (r = 0.46, p > 0.01)				
	1	2	3	4	5
TD	-0.01	0.04	-0.22	**0.87**	0.10
STD	-0.31	-0.32	-0.21	-0.15	**0.75**
STD/TD	-0.17	-0.22	-0.02	**-0.84**	0.37
Water temperature	0.27	**-0.52**	**0.57**	0.41	0.09
pH	**-0.90**	-0.24	0.02	-0.16	0.12
Salinity	**-0.84**	-0.30	0.11	-0.10	0.21
DO	**-0.80**	-0.39	0.20	0.03	0.00
H_2S	**0.67**	-0.11	**0.55**	-0.09	0.07
Chlor-a	-0.06	-0.29	0.05	-0.02	**-0.87**
NH_4	0.28	**0.94**	0.16	0.04	-0.02
NO_2	0.12	0.03	**-0.91**	0.10	0.12
NO_3	0.04	-0.24	**-0.74**	0.33	0.23
DIN	0.30	**0.93**	-0.03	0.10	0.03
TN	0.36	**0.68**	0.00	**0.49**	0.12
DIP	**0.73**	0.15	**0.50**	0.20	0.07
TP	**0.51**	**0.54**	**0.54**	0.10	0.01
Variance %	24.58	21.29	16.91	13.32	10.23
Cumulative %	24.58	45.86	62.78	76.10	86.32
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.					
a. Rotation converged in 18 iterations.					

Unfortunately, the current results reveal the subsequent improvement of MB water quality was temporary and fell short of expectations. The re-deterioration was fasted by lowering the water level of UD, the main LM-water source, with its negative impact

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not only on LMBs but also on the quality of the drain itself.

Accordingly, the implementation of further rehabilitation steps is highly recommended. Strengthen the east bank of UD separating it from MB is a must to keep the water surface level constant. Dredging the spoiled organic-rich sediments to lower any internal load of nutrients and deepening the basin too. As long as the wastewater of the EWTP (about half mcm/d) becomes now secondary treated it is better to allow it to flow again directly into MB. The excessive water is therefore allowed to flow over the bank into UD and not the reverse. This will replenish water loss by evaporation and/or evapotranspiration and seepage from this basin besides overcoming elevation in its water salinity.

4. Conclusion And Recommendations

The present study describes and evaluates the lake Mariut (LM) state after 8 years of implementing the restoration program, the prevention of pollution point sources, of this formerly heavily polluted lake.

Although the major standards of the remediation and restoration of Lake Main Basin (MB) are well-characterized, the aftereffects of the implemented measure can be disappointing after a relatively short period (around 8 years). The deterioration in most water quality parameters was observed, again, which is often attributed to the continuous internal fertilization (nutrients loading) from nutrient-rich sediment. Thus, the applying of more efficient and applicable solution(s) is A MUST. The suggested solutions recommended are summarized as follows:

1- Mounting the MB particularly the UD east bank to make the elevation of the surface water inside MB independent of that in the drain itself, this is deadly requested.

The same is also needed for the other basins.

2- Dredging the spoiled nutrient and organic-rich sediments and deep-rooted plants.

3- Allow the EWTP effluent, which is now secondary treated (i.e, it becomes of low and acceptable organic matter and nutrients contents) to pour again directly into MB instead of discarding into the sea via $UD_{downstream}$.

Of course, it is better to adopt the three suggestions together and at once or in a sequent two main steps, one includes both suggestions no, 1 and 2 simultaneously, followed by the last one no. 3.

Lastly, it would be advisable to implement the previous recommendations accompanied by frequent continuous monitoring.

Declarations

-Ethical Approval

Not applicable

-Consent to Participate

Not applicable as the study did not include human subject.

-Consent to Publish

Author approves this submission.

-Author Contributions

Nashwa A. Shaaban: Conceptualization; Methodology; Formal analysis and investigation; Writing - original draft preparation; -review and editing; Funding acquisition; Resources; Supervision.

-Funding

Not applicable

-Competing Interests

The author declares that she has no competing interest.

-Availability of data and materials

Some of data generated or analysed during this study are included in this published article. The other datasets used and/or analysed during the current study are available from the author on reasonable request.

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Figures

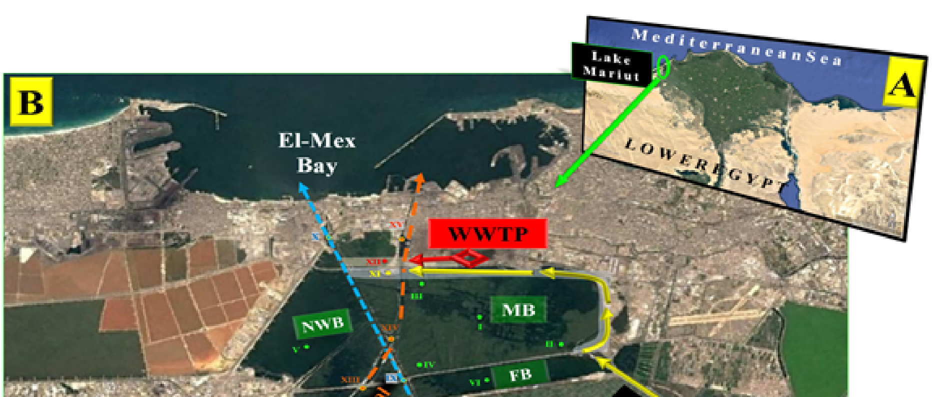

Figure 1

A satellite image of different Lake Mariut Basins (LMBs) and their drainage system showing the location of the sampling stations Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

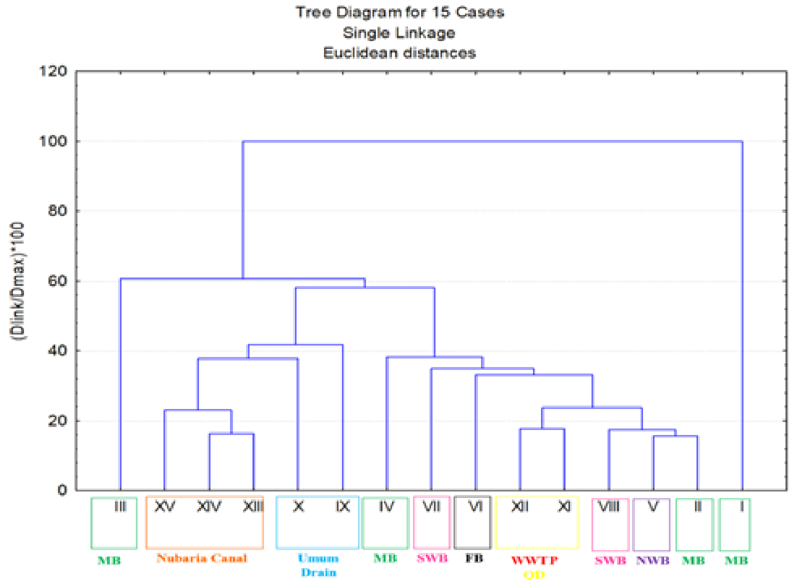

Figure 2

Cluster tree of Lake Mariut Basins (LMBs; Main Basin, MB; Southwest Basin, SWB; Northwest Basin, NWB; and Fishery Basin, FB) and their drainage water system Umum Drain (UD), the diverted Qalaa Drain (QD), West wastewater treatment plants (WWTP) effluent, and Nubaria Canal (NC) during the study period.

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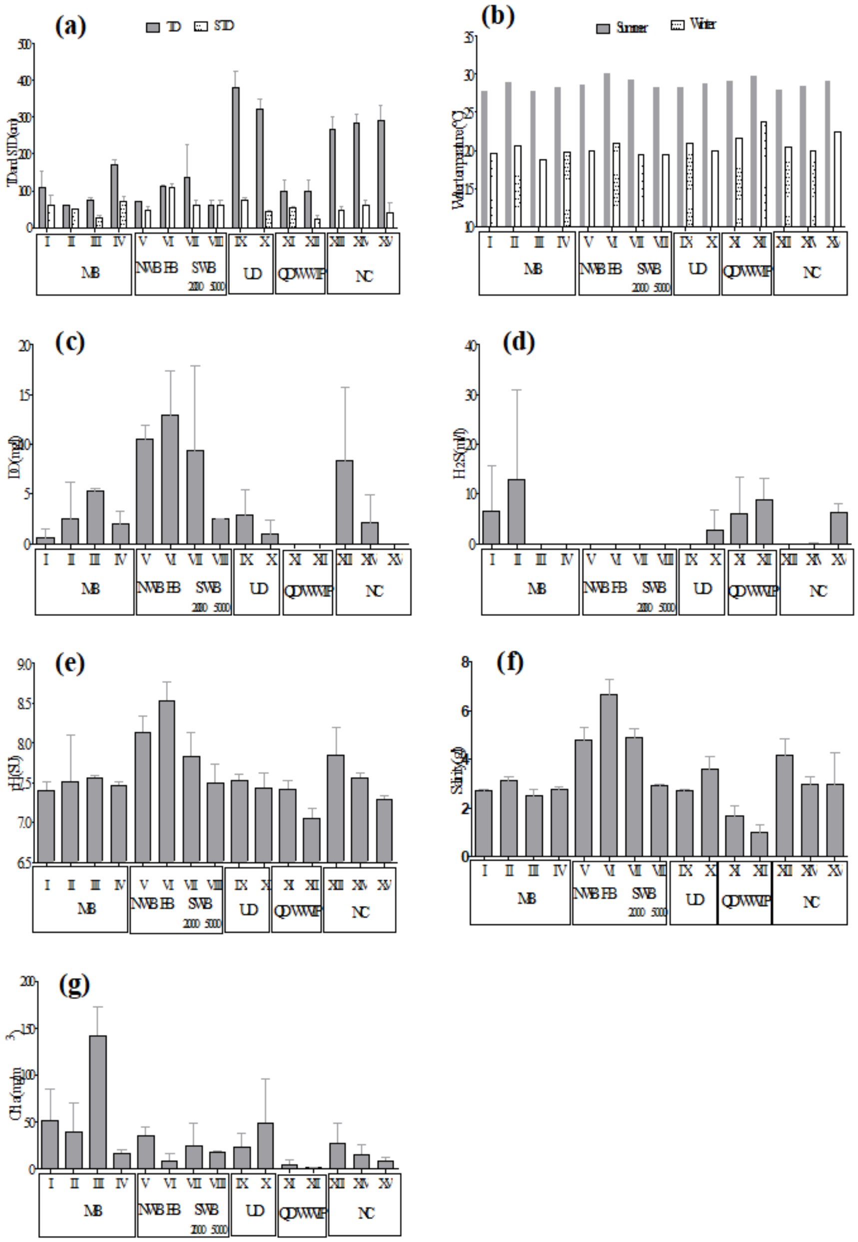

Figure 3

(a - g) Distribution of (a) total depth (TD) and Secchi Disc Transparency Depth (STD), (b) water temperature, (c) dissolved oxygen (DO), (d) hydrogen sulfide (H2S), (e) pH, (f) salinity, and (g) chlorophyll a, concentrations in the surface waters of Lake Mariut basins (LMBs) and their drainage water system.

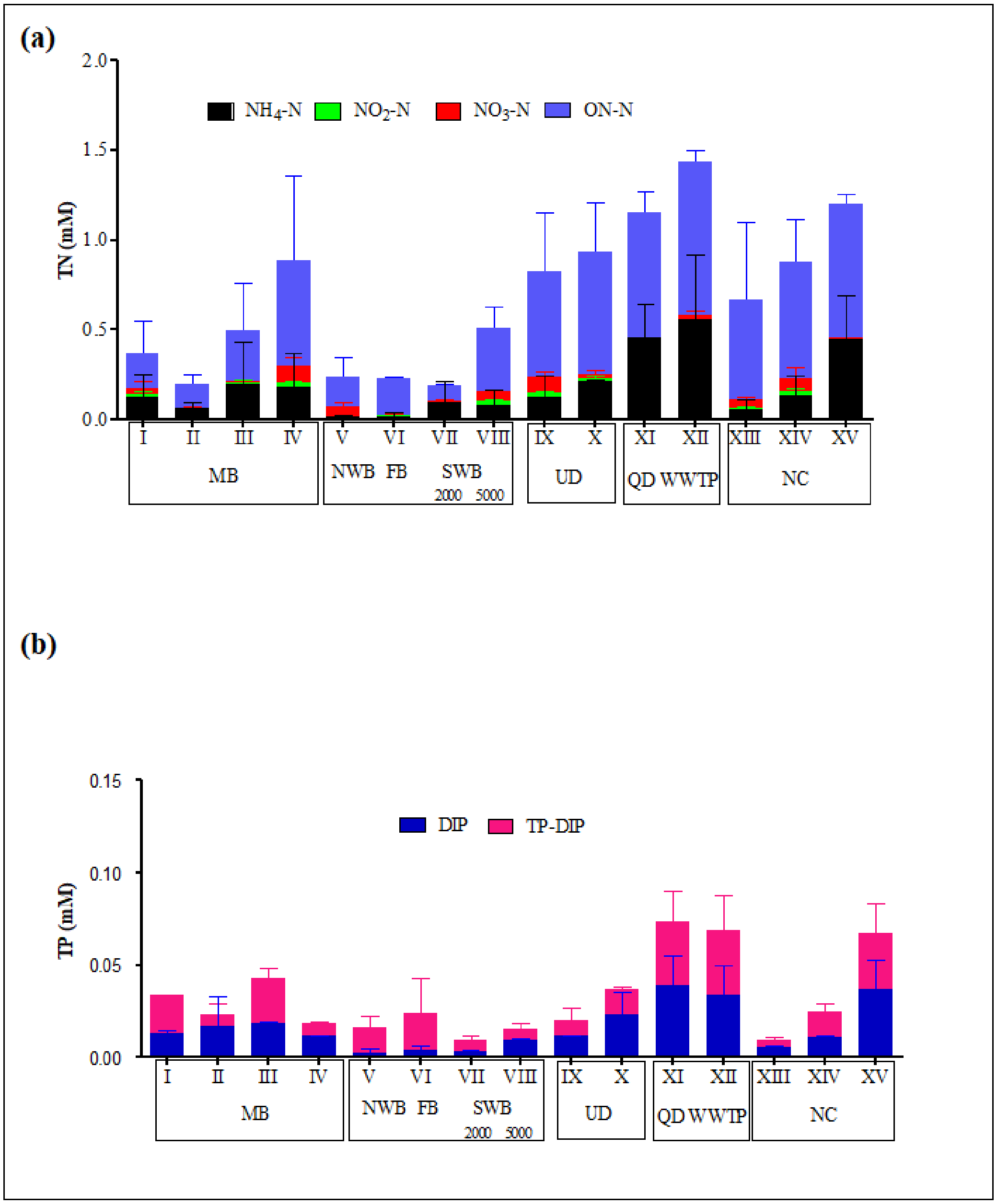

Figure 4

Distribution of (a) total nitrogen (TN) and (b) total phosphorus (TP) together with their different species (mM) in the surface waters of Lake Mariut basins (LMBs) and their drainage water system.

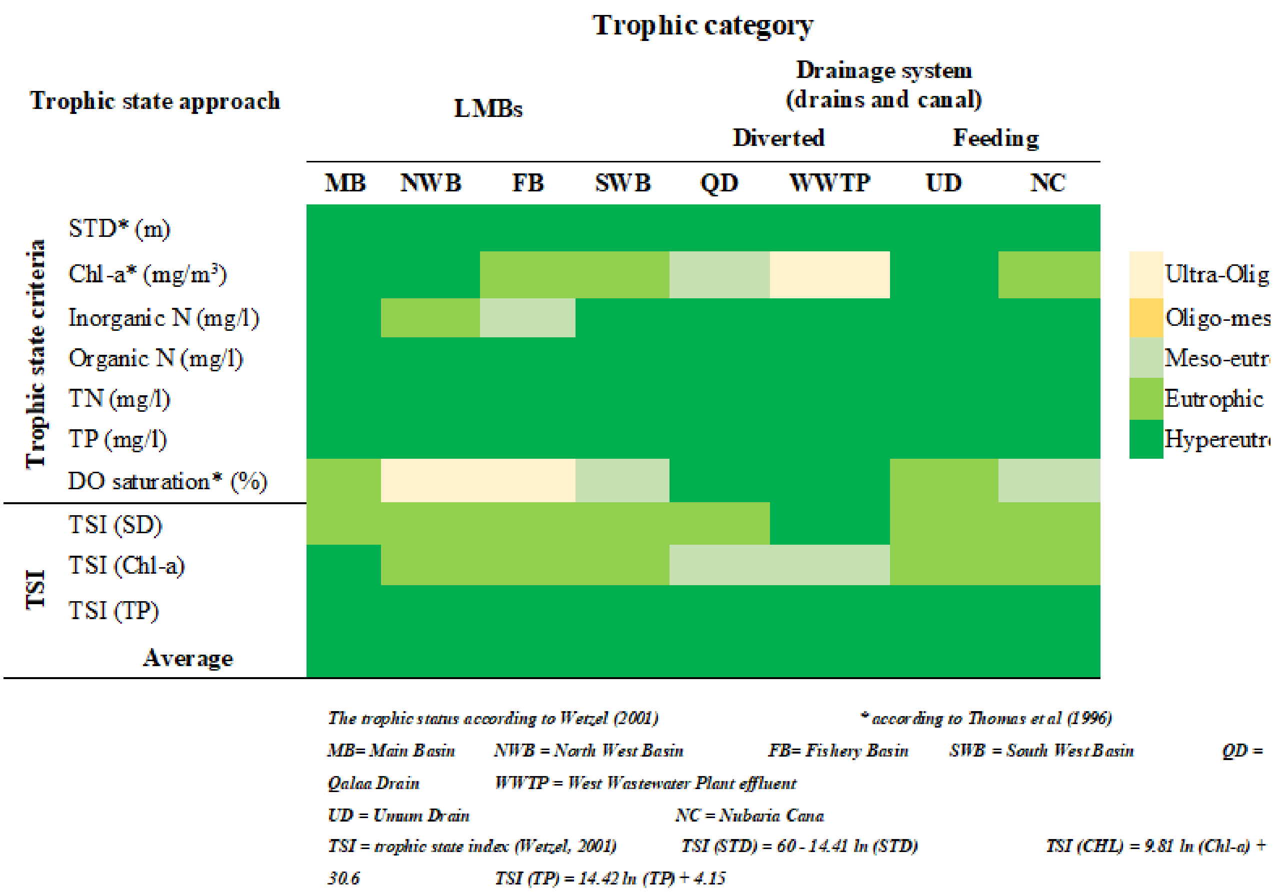

Figure 5

A heat map shows the classification of the study area water according to different trophic status criteria and trophic state index (TSI).