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Steps for rehabilitation of a Lake suffering from intensive pollution; Lake Mariut as a case study

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ABSTRACT

Due to the acute water scarcity facing many urban areas, the water resource management, and lake rehabilitation become a global interest. Before applying the appropriate approach in the rehabilitation (restoration) of a hypereutrophic lake, the assessing of the point sources of pollution and their effects are A MUST. Lake Mariut is an example of lentic polymictic closed coastal Egyptian lake. The economic and recreational values of Lake Mariut were deteriorated since 1960s, as a result of using its Main Basin as a sink of wastewaters discharged from the agricultural Umum Drain and the heavily polluted Qalaa Drain mixed with primary treated sewage waters from Alexandria East Wastewater Treatment Plant. The aim of the current study is to find the suitable solution/s for the Lake Mariut Main Basin restoration, by (1) studying the general characteristics of its drainage water system (Umum and Qalaa Drains) at their downstream parts before reaching the lake at its southern side as well as the adjacent non-polluted Lake Mariut Fishery Basin. (2) Discussing (by calculation) the applicability of two proposed improvement solutions. The results reveal that, in the first the water quality of the anoxic Qalaa Drain must be improved by diluting its waters with oxic Umum Drain waters via Lake Mariut Fishery Basin prior discharging. This solution is found not sounding as it difficult to attain from practical point of view. The other alternative is by diverting the polluted Qalaa Drain point source itself away from Lake Mariut Main Basin water body which is sounding and highly recommended.

INTRODUCTION

Many lentic water bodies in the world are threatened by cultural eutrophication resulted from the extremely high nutrient inputs through agricultural, industrial and untreated domestic sewage discharges (Zaragüeta and Acebes, 2017).

As a result of increasing the awareness of environmental degradation, the lake rehabilitation is becoming a priority in many countries for those lakes that are suffering from different stress factors, (González Del Tánago *et al*., 2012).

Lake restoration methods include either preventive (direct) method or ameliorative (indirect) methods (Singh, 1982; Zamparas and Zacharias, 2014). The curative techniques comprise both in-lake treatment and watershed techniques. The later techniques are usually the key in serving a lake recover its long-range vitality.

It is worthy to mention that, lake can never be totally restored to its initial complex physical, chemical, and biological status. However, lake conditions can be improved.

Before choosing and applying the appropriate lake improvement program, a ‘diagnostic-feasibility’ or ‘feasibility’ studies should be performed to diagnoses the lakes problems and causes. Accordingly, the lake and its watershed should be studied in detail. This study characterizes the chemical, biological and hydrological properties of the lake as well as determines the quality and amount of runoff from its watershed.

Lake Mariut is a closed coastal lake dislikes other five coastal lagoons laying north Egypt on the SE-Mediterranean Sea. These open lagoons are called Alamein Marina (on the west of the lake) and Edku, Burollus, Manzalah and Bardawil Lagoons (on the east), (Fig. 1).

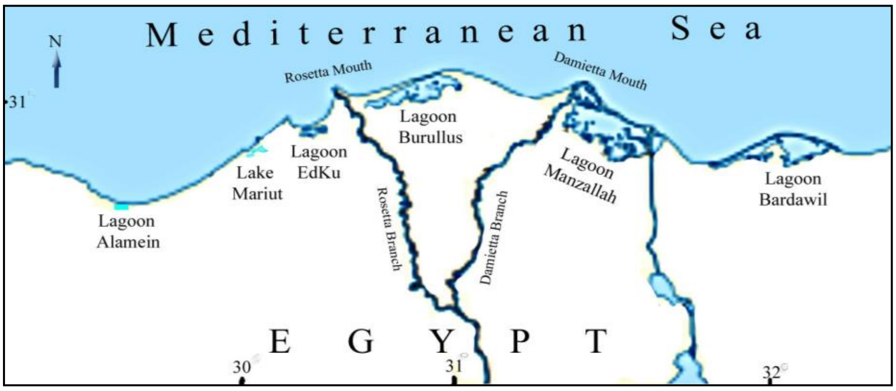

Fig. 1. A map showing the positions of Lake Mariut and the five coastal lagoons of Egypt

Lake Mariut lays south Alexandria City and extends for about 20 km (between longitudes 31° 01′48″ and 31° 10′ 30″ N and latitudes 29° 49′48″ and 29° 57′00″ S, Mateo, 2009). It is of depths ranging between 4.0 and 3.4 m below sea level and separated from the sea by a ridge called Abuser Hill. Its area diminished considerably with time from 60.000 (in 1950s) to 16.000 feddan (at present). This is mainly due to silting and land reclamation projects for agriculture.

It is an important resource of popular Tilapia fish species and is one of the nesting wild birds in Egypt. It is a depression receives both agricultural drainage waters (from the agricultural lands of neighbouring Bohaira and Alexandria Provinces) besides discharges of Alexandria sewage and industrial wastewaters, with respective rates 6 and 1 x 10^6 m^3/day (the lake volume is 23 x 10^6 m^3). The lake is artificially divided into four sub-basins, its main basin (area about 5500 acres) referring to it as Lake Mariut Main Basin, is main source of the fish catch and is of lowest salinity as it is the only one directly receiving the Alexandria sewage and industrial wastewaters (total rate as mentioned above 1 x 10^6 m^3/day). Therefore, it is the one suffering from an intensive pollution (El-Rayis, 2005) led to its general (cultural) eutrophication and subsequent deterioration accompanied with depletion in dissolved oxygen (DO) concentrations and intermittently replacement of the DO with noxious hydrogen sulphide (H_2S). The presence and evolution of the malodorous H_2S gas occur, especially in the area near the hot point of the land-based sources (sewage contaminated Qalaa Drain at its south east part and at its north west part where the discharge of the industrial wastewater). This has led to a noticeable drastic deterioration in its recreational and economic value reflected in the conversion of the lake from best productive and fertile aquatic habitat in Egypt in 1960s to the most polluted one. In addition to a remarkable drastic decrease in the quality and the quantity of the fish catchment (from 13,000 ton/y in the sixties of the last century i.e. before polluting the lake, to a less than 6,000 ton/y at present), (Abaza, 2008). Consequently, this has led to a great social and economic problem to the fishermen and their families (Abdelmeguid *et al*., 2007; Abaza *et al*., 2009; Shaaban, 2010).

As a result of that disaster condition of Lake Mariut, reflected in stating it as "a black spot'' by National Environmental Action Plan of Egypt (1992) and in urgent need for a rehabilitation plan to restore that vital basin.

Regarding the best management practices of lake improvement is to prevent the pollution rather than treating symptoms of pollution; i.e. prevention instead of correction. The suggested rehabilitation solutions are essentially based on improving the water quality of polluted point source before entering the lake body by either/ or both dilution and in-stream aeration depending on the expenditure.

The prim cause of the lake eutrophication and the subsequent depletion of DO and evolution of H_2S are generally depending on input load of nutrient (N and P) salts as well as of oxygen-consuming (mainly) organic matter. Thus, the objective of the present work is to cover three-folds. First, is studying the general characteristics of the water of drainage water system at their downstream parts of [i.e. the sewage contaminated Qalaa Drain and Umum Drain mainly agricultural drain (that brings the wash water of Bohaira and Alexandria Provinces farms that is lining the Lake Mariut Main Basin at its west side] i.e. before reaching the lake at its southern side. The characteristics include determination of their organic matter load (as a primary pollutant) beside their level of the plant nutrients (P and N) (as a secondary pollutant). The second fold is discussing the applicability of the proposed either or the two above mentioned improvement solutions. The last is to recommend which/or both the appropriate solution(s) to apply by the decision makers of Alexandria City Governors.

MATERIALS AND METHODS

Study area

Lake Mariut as mentioned above is formed from four sub-basins (Fig. 2), namely Lake Mariut Main Basin (area 5,500 acre), Lake Mariut North West Basin (3,000 acre), Lake Mariut South East Basin (> 6,000 acre) and Lake Mariut Fishery Basin (1,000 acre).

In the present work water samples were collected from nine stations from Lake Mariut Main Basin, representing four areas, Fig. 2. The first, (called area 3) which is at its south, it is a belt of water that directly receives input of the polluted Qalaa Drain [as it is mainly wastewater discharged from Alexandria East Waste Water Treatment Plant at the east side and its west side receives the input of mainly agricultural drainage water from Umum Drain. The second and third are the downstream areas of the two water sources [Umum Drain (area 1) and Qalaa Drain (area 2)]. Lastly, the part 4 is the neighbouring Lake Mariut Fishery Basin (the fourth Lake Mariut basin that is lying south of the current Lake Mariut Main Basin as a reference water occupying the 1,000 acres). From the first area, the Umum Drain-downstream, a station (No. I) was sampled. From the area 2, Qalaa Drain, three stations VI, VII and VIII (the last was at a site in front of three dykes or weirs that separate Lake Mariut Fishery Basin from the Qalaa Drain main stem) were conducted. In the southern part of Lake Mariut Main Basin itself (area 3), four stations II, III, IV and V, were there. Finally, station IX was at the reference area 4 (Lake Mariut Fishery Basin). The water samples were collected from these 9 stations every 2 successive months over a year from August 2006 to August 2007.

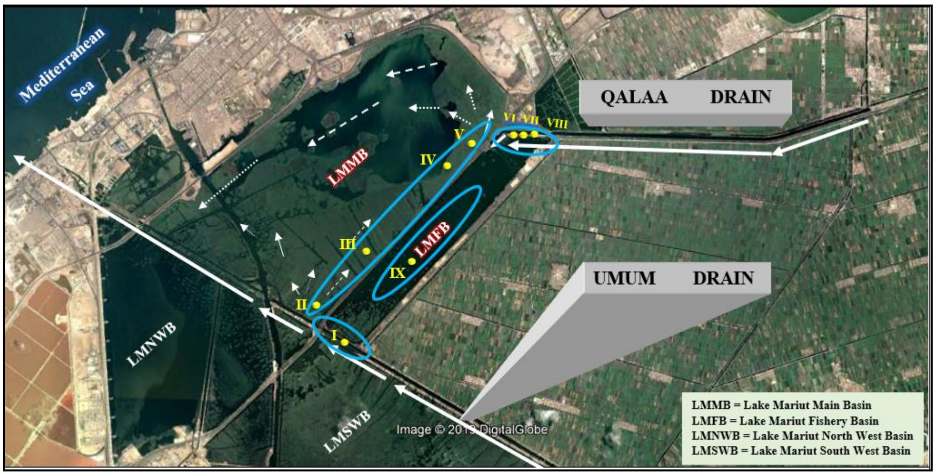

Fig. 2. A satellite image showing Lake Mariut basins and location of the sampling stations in Umum and Qalaa Drains and in south side of Lake Mariut Main Basin belt and in Lake Mariut Fishery Basin.

Water sampling and analyses

In each water sample physico-chemical parameters pH (using a portable Cyberscan[10] pH-meter), DO (according to the azide modification of the conventional Winkler's Method, (APHA, 1995) /or H_2S (using the back-titration technique according to (Andersen and Főyen, 1969), Cl_v and TSM contents (using the conventional Mohr's titration method and gravimetry APHA, 1995, respectively) were measured. For the purpose of the present paper the nutrients as Total N (TN) and Total P (TP) concentrations were colorimetrically measured (according to Strickland and Parsons, 1972; Valderrama, 1981). Shimatzu UV- VIS spectrophotometer was used. More details about the measured nutrient species in this study area will be published in a forthcoming paper.

The obtained results were analysed statistically using the STATISTICA 10.0 (Stat Soft. Inc., 2011). A Pearson's correlation analysis and the cluster analysis were applied to recognize interrelationships between studied parameters and to organize the observed data into meaningful structures and general categories. These statistical methods were performed at a 95% confidence interval (significance $p < 0.05$).

RESULTS AND DISCUSSION

Figure 3 shows an application of the statistical cluster analysis test for the studied parameters in the study area. It reveals presence of two distinct main water types (differs from each other by 100 %). One includes the group of water of both Umum Drain downstream and the west part of the South-Lake Mariut Main Basin belt (Group A) while the other (Group B) includes both waters of the downstream part of Qalaa Drain and the east part of the South-Lake Mariut Main Basin belt. It worth to mention that Lake Mariut Fishery Basin water (has characteristics more or less related to that of the Group A of Umum Drain water rather than that of the Group B of Qalaa Drain.

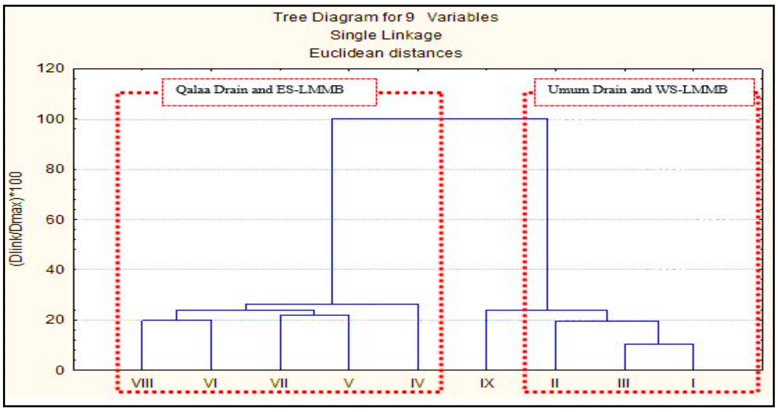

Fig. 3. The cluster analysis test of the studied variables at the nine stations sampled in Umum and Qalaa Drains and their downstream in South-Lake Mariut Main Basin (S-LMMB) besides to Lake Mariut Fishery Basin

The results obtained are represented here as distribution for the nine sampled stations shown in Figs. 4, 5 and 6.

Physico-chemical parameters

Figure 4a, shows that the water of the first group (A) is slightly alkaline (7.40±0.13) than that of the other (Group B) 6.98 ±0.11. The water of Lake Mariut Fishery Basin exhibited higher pH values (the local average value is 8.33±0.19) reflecting the role played by noticeable presence of intensive aquatic plants mainly hydrophytes) there in removal of CO_2 during photosynthetic activities, and thence to raising pH. This is in agreement with that obtained by (Abbas *et al*., 2001; Saad, 2003; Radwan, 2005). It is worth mentioning that the recorded pH values, however, were generally lying in the recommended level range for the normal fish productivity between 5 and 8.5, (Phang, 1991; Mateo, 2009). Thus, the water of this basin is within the pH values suitable for aquaculture purposes.

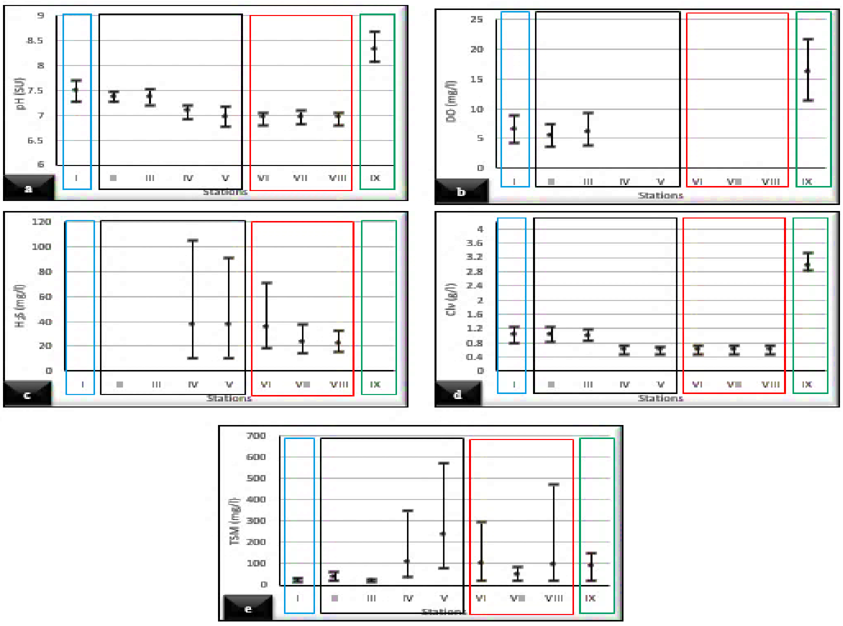

Fig. 4. Distribution of the concentration values of the studied parameters (from a-e) in the water of the nine sampled stations of Umum Drain downstream (St I), at the west side of the South-Lake Mariut Main Basin (Stations II and III) belt, at the east side of the South-Lake Mariut Main Basin (Stations IV and V) belt and Qalaa Drain downstream (Stations VI-VIII) as well as Lake Mariut Fishery Basin (Station IX).

Regarding distribution of DO and H_2S in the water of the study area (Fig.4b), one can see presence of two general phenomena, presence of oxygenated water in Group A and in Lake Mariut Fishery Basin area and the other is presence of water devoid in DO and containing H_2S in Group B. i.e. the water is in euxinic condition.

In the oxygenated water, (Fig 4b) the DO concentration general local average was 6.0 mg O_2/l (the saturation value is 8.7 mg/l). While in Lake Mariut Fishery Basin oxic water has general local average value exceeding the value 8.7 and reaches values as high as 16.2 mg/l which according to Mateo (2009) is suitable for aquaculture purposes and confirming the role of the condensed hydrophytes present there. On the contrary, the anoxic water in Group B has H_2S with a local average concentration value reach 22 mg/l (Fig. 4c), this certainly is not suitable for any aerobic organisms including fish to live there.

This anoxic water despite its movement but the oxygen-demand for oxygen-consuming matter seems to overcome available DO. i.e. reflecting high load of oxygen-consuming matter (like degradable and hard-degradable organic compounds beside reducing inorganic materials). All these in this case have led to not only the consumption of all available DO but also part of the oxygen in dissolved SO_4 ions in the ambient water and producing reduced sulphur forms (including H_2S gas) and CO_2 in presence of the reducing anaerobic (including) sulphur bacteria. The presence of both the acidic H_2S and soluble CO_2 in the anoxic water (Group B) are mostly responsible for the noticeable lower values of pH compared with that in the oxic water of the other group. The presence of an inverse and significant relationships between pH and each of H_2S and COD [(n= 36, $p < 0.05$), r = -0.66, and -0.64, respectively, Table 1] in the anoxic water is well illustrated.

Table 1: Correlation matrix between the studied parameters in surface water of study waters (Marked correlations are significant at p < .05000 N=36, using the absolute values).

	pH	**Clv**	**DO**	**H_2S**	**TSM**	**TN**	**TP**	**COD**	**POC**
pH	1.00								
Clv	**0.94**	1.00							
DO	**0.96**	**0.90**	1.00						
H_2S	**-0.66**	**-0.51**	**-0.68**	1.00					
TSM	-0.10	-0.05	-0.12	0.26	1.00				
TN	**-0.63**	**-0.58**	**-0.67**	**0.76**	**0.39**	1.00			
TP	**-0.63**	**-0.56**	**-0.71**	**0.81**	**0.36**	**0.75**	1.00		
COD	**-0.64**	**-0.52**	**-0.69**	**0.83**	0.32	**0.69**	**0.84**	1.00	
POC	-0.24	-0.18	-0.27	**0.40**	**0.53**	**0.49**	**0.43**	0.27	1.00

The anoxic water of Group B is also characterized by its freshness (Clv local average is 0.61 ±0.08 g/l while the other oxic water is relatively saltier of 1.02 ± 0.15 g/l, Fig 4b. The oxic water of Lake Mariut Fishery Basin is the saltiest as its local average Clv value is almost doubled (2.98 ±0.22 g/l, Fig 2b). This reflects the role of the municipality water in the sewage waste effluent during mixing with the agricultural drainage water of Qalaa Drain in lowering its salinity before discharging into the lake. The sewage wastewater part (from Alexandria East-Waste Water Treatment Plant, amounts to793, 000 m^3/d) in this drain constituting about 88 % of its total water.

The noticeable high Clv value in the oxic Lake Mariut Fishery Basin water despite its source is water pumped from the main stem of Umum Drain but as its residence time in the shallower Lake Mariut Fishery Basin is longer and more subjected to evaporation processes as a consequent it became more saline than the original one at Umum Drain main stem.

Examining distribution of TSM concentration values (Fig 4e), one can see that the concentration increases in the order Lake Mariut Fishery Basin > anoxic water of Group B > oxic water of Group A. The high values of TSM observed in the water of the oxic water of Lake Mariut Fishery Basin could be due mostly to occurrence of erosion processes due to presence of several earth islets there and to activities of fishermen in this relatively clean and less polluted fishery basin.

The anoxic water of low pH and lesser saline is on the contrary of high TSM content and therefore is more turbid not only that but also it is dark in colour (mostly due to presence of black H_2S and humic substance used to accompanying the discharged wastewater). It seems likely that considerable portion of the TSM is of organic matter (of both allochthonous and autochthonous origins) that is verified here by presence of a positive relationship between POC and TSM [$n = 36$, $p < 0.05$, $r = 0.53$, Table 1].

According to the Egyptian Environment (EEAA) Law number 92 of 2013 concerning the protection of the River Nile and its executive regulations, it stated that the allowable maximum suspended materials concentration value is 60 mg/l. Accordingly, the water of Group A is lying under the permissible limits for TSM, while that in the anoxic water of Group B exceeds by about 3 times. So, the last water source needs treatment through execution processes for example of more advanced treatment for the wastewater discharged from the current Alexandria East-Waste Water Treatment Plant.

Level of oxygen-consuming matter (BOD_5 and COD), Fig. 5

The COD is a measure of all reducing oxygen-consuming matter, including [degradable, simple BOD_5 and hard degradable (i.e. polymeric)] organic compounds and reducing inorganic matter. It is estimated as mg O_2/l.

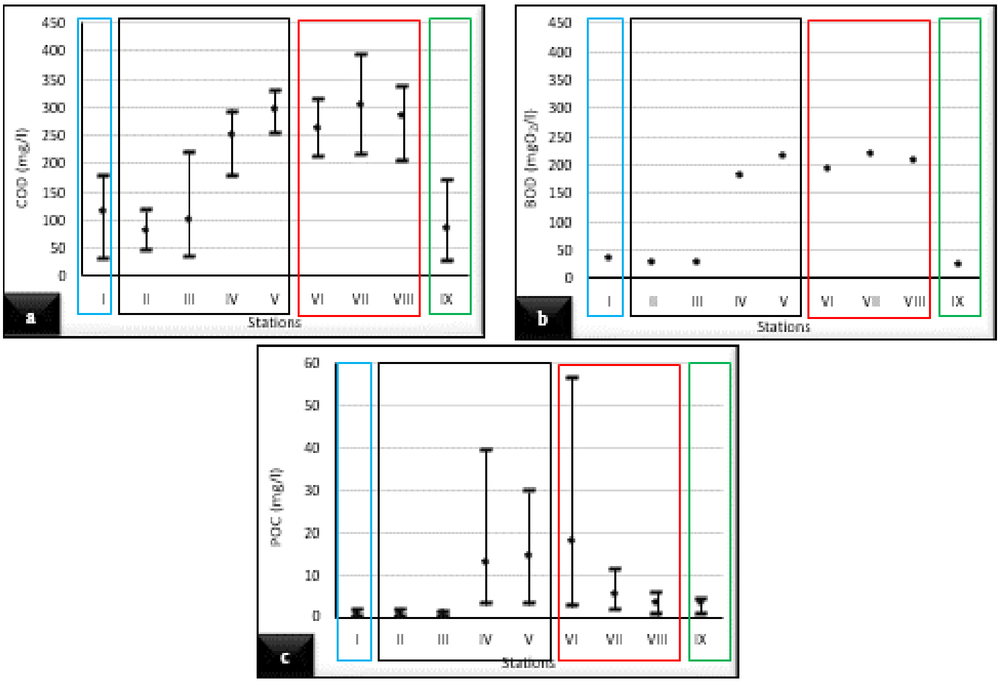

Fig. 5. Distribution of the concentration values of the studied parameters (a – COD, b-BOD and c-POC) in the water of the nine sampled stations of Umum Drain downstream (St I), at the W side of the South-Lake Mariut Main Basin (Stations II and III) belt, at the E side of the South-Lake Mariut Main Basin (Stations IV and V) belt, and Qalaa Drain (Stations VI-VIII) as well as Lake Mariut Fishery Basin (Station IX).

Examining the COD values (Fig. 5a), it shows the far enrichment of the anoxic water of Group B (local averages > 250 mg O_2/l) compared to that < 100 mg O_2/l of the oxic one of Group A. The oxic water of Lake Mariut Fishery Basin is remarkably the least (local average 86 mg O_2/l). This refers to the high organic load at the former anoxic one due to the contamination with the wastewater discharge from the Alexandria East-Waste Water Treatment Plant. Obviously, the Lake Mariut Fishery Basin water is almost the one free from contamination with the discharge of the sewage effluent.

According to permissible COD discharge limits (of the Environmental Egyptian law number 92/2013, 100 mg O_2/l), it is found that the current COD level in the water of the anoxic Qalaa Drain exceeds 2.7 times that limit. Reduction by dilution by three times for the Qalaa Drain water prior discharging to Lake Mariut Main Basin is necessary.

Regarding the BOD_5 values, the anoxic water of Group B was high (the general local average is ≈ 200 mg O_2/l) compared with that of the oxic one with average values < 37 mg O_2/l. The oxic water of Lake Mariut Fishery Basin has the least general local average value only 22 mg O_2/l, (Fig. 5b).

The primary treated domestic sewage effluent and the bypass from the Alexandria East-Waste Water Treatment Plant is mostly responsible for the high BOD concentration values in the anoxic water of Qalaa Drain and subsequently in the receiving water at the east side of the South-Lake Mariut Main Basin belt. This is in agreement with the finding of Chapman and Kimstach (1997) that the raw sewage usually has BOD values of about 600 mg O_2/l, whereas the treated is of values ranging from 20 to 100 mg O_2/l depending on both the level of the treatment applied and the ratio of the bypass to the treated effluents.

In a calculation of the percentage values of BOD_5 to COD, the oxic water of Group A in addition to that of Lake Mariut Fishery Basin are of ratios < 30 while that in the anoxic water of Group B is > 70. This reflects how aerobic bacteria in the oxic water have polished the oxygen-consuming biodegradable matter at a rate greater than that happened by anaerobic one in the anoxic water of Group B. This finding however may show how the kinetic mechanism and the thermodynamic processes of degradation are more efficient in the oxic water as mentioned by Stumm and Morgan (1996).

However, the current BOD level in the oxic water (with general local average < 37 mg O_2/l) is laying under the permissible limit (60 mg O_2/l) recommended for a discharge to surface waters in Egypt (EEAA Law number 92/2013). While that of the anoxic water is exceeding about 3.3 times than the limit. So, either dilution by at least 3 times or application of an advanced treatment process like secondary one for the discharged wastewater of the Alexandria East-Waste Water Treatment Plant is needed.

In order to assess more the condition of the wastewater of Qalaa Drain, the interrelationship between BOD and COD or their ratio is studied. Its BOD/COD ratio at is about 0.73, [which is in the typical range of untreated municipal wastewater (from 0.3 to 0.8)]. This ratio refers to a fact that the Qalaa Drain water in its present state can be treated by biological means (Metcalf and Eddy, 2007). On the other hand, this ratio (about 72) in the oxic waters of Group A as well as in the Lake Mariut Fishery Basin water refers to a fact that the majority of their organic matter is mainly non-biodegradable while that of the anoxic water is mainly biodegradable constituting about 73% of the total. This last matched that of Walker *et al.* (2006) who stated that domestic sewage contains about 300 to 400 mg/l of organic compound, 60 % of this is readily degradable by anaerobic bacteria commonly found in the milieu.

Particulate organic carbon (POC), is used as suitable alternatives for biological indicators since they often represent total biomass (Thomas *et al*., 1996) in natural environments. Because of that the carbon is an essential element in organic compounds, so the most analytical measurements of OM in water [either in dissolved OM (DOM) or POM forms] are based on determining the carbon content (Libes, 2009).

Qalaa Drain and the water at the east side of the South-Lake Mariut Main Basin has high general local average of POM exceeding 7 mg/l compared with that in the oxic water (< 0.8 mg/l) of Umum Drain and in the water of the other side the South-Lake Mariut Main Basin belt. However, Lake Mariut Fishery Basin (with longer residence time and less flushing time) showed an intermediate level of POC concentration between those two extremes, with general local average 2.8 mg/l, (Fig 5c). Such distribution pattern more or less mimics that for TSM, reflecting the association of POC with particulate matter.

Regarding the POC content is higher in the anoxic water of Qalaa Drain and at the east of the South-Lake Mariut Main Basin belt than in the other studied oxic water. The high load of allochthonous OM, due to the wastewater of Alexandria East-Waste Water Treatment Plant is mostly responsible. Visionally, Qalaa Drain water contained dark brown colour matter, mostly humic substances, as it gives high fluorescence when it subjected to UV-radiation.

Based on the degradation of sulphur-bearing OM [as those contain thiol (HS) group (as in S-containing amino acids)] or sulfate (SO_4) group [as in polysaccharide sulfates and aromatic sulfates] via hydrolytic reactions that carried out by several microorganisms (Goel 2008), which results mainly in the formation of H_2S (responsible for some of the disagreeable odors produced in putrefaction). This can explain the recorded pronounced positive significant relationship between POC and H_2S [$n = 36$, $p < 0.05$, $r = 0.40$] in the water of Group B.

On other hand, the presence of a noticeable strong positive relationship between POC and TSM [$n = 36$, $p < 0.05$, $r = 0.53$] confirms the co-association between them.

Nutrients

Total-N (TN)

The TN concentration values in the studied areas showed wide variation between the relatively low values at Lake Mariut Fishery Basin (general local average 292 μM) and in the oxic water of Group A (general local average < 530 μM) and those of extremely high ones in the anoxic water of Group B (general local average > 1,360 μM), which is about 2.5 times higher (Fig. 6a). This variation is deduced to the quality of the waters where Umum Drain and Lake Mariut Fishery Basin their water is mainly agricultural drainage water, while that of Qalaa Drain is mainly a sewage contaminated agricultural drainage water.

The anoxic water of Group B exhibited high TN values to reach high TN loading level at the Qalaa Drain outlet (station V) to 279.5 g m^{-2} yr^{-1} which exceeds the provisional dangerous permissible loading rate of TN [estimated by Vollenwieder (1968) for such shallow lake, to maintain its steady state is 2.0 g m^{-2} yr^{-1}, (Wetzel, 2001)] by 139.7 times.

Total-P (TP)

The oxic Lake Mariut Fishery Basin water as expected it contained least values of TP (local average of 6.7 ±2.7 μM). Followed by the oxic water of Group A where slightly higher level of TP content (about two times higher) with local average of 12.7 ±3.6µM, (Fig 6b). Regarding the polluted anoxic water Group B exhibited extremely high TP concentration values, > 60 µM. The TP elevation led to a higher TP loading at Qalaa Drain outlet to the lake (station V) by 63.1 g m^{-2} yr^{-1} that exceeds the provisional dangerous permissible loading rate of TP [of Vollenwieder (1968), to maintain this shallow lake in steady state (0.13 g m^{-2} yr^{-1})] by 485.3 times.

From the aforementioned results and discussions, it is clear that the polluted Qalaa Drain is responsible for the drastic increase in the level of the pollutants (N- and P) and oxygen-consuming matter as well as H_2S in Lake Mariut Main Basin. Therefore, in order to regain the healthy condition of the vital Lake Mariut Main Basin we must reduce the level of the nutrient N and P as well as the COD in this polluted drain (before discharging) to a level at least that recommended by Vollenweider and the EEAA Law No. 92/2013.

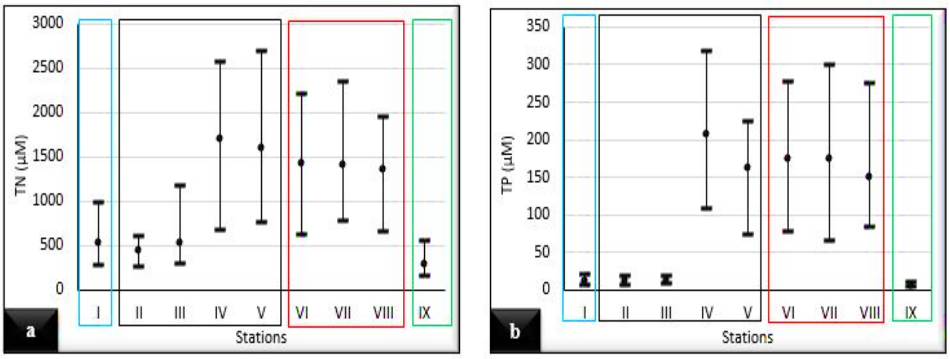

Fig. 6. Distribution of the concentration values of the studied parameters (a – TN and b-TP) in the water of the nine sampled stations of Umum Drain downstream (St I), at the west side of the South-Lake Mariut Main Basin (Stations II and III) belt, at the east side of the South-Lake Mariut Main Basin (Stations IV and V) belt, and Qalaa Drain (Stations VI-VIII) as well as Lake Mariut Fishery Basin (Station IX).

The Suggested practical solutions for the pollution of Qalaa Drain water

The current primary treatment occurs at Alexandria-Waste Water Treatment Plants is clearly not efficient to reduce the primary (oxygen consuming matter) and secondary (plant nutrients) pollutants to the recommended level in the Qalaa Drain before discharging. In order to rehabilitate or restore the lake to regain its fame as good productive natural lake and as a touristic area we must improve the quality of the Qalaa Drain waters itself before reaching to Lake Mariut Main Basin.

Till the completeness of the construction and the operating of the costly next stage secondary treatment plant processes [which according to Hocking (2005) will aerate and remove about 90 % of BOD, TSM, about 80 % of COD, 50 % of TN and 30 % of TP], a fast and not much costly solution is needed to solve this critical pollution problem.

The following is two fast solutions suggested and are assessed to help the decision-Makers of the Alexandria Governor to take proper action. These are: (1) Dilution, and/or (2) Diversion of Qalaa Drain itself.

By Dilution:

It is one of the suggested solutions, it is simply by allowing surplus of the well oxygenated water from the Lake Mariut Fishery Basin [(at its west side) to flow over the weir at station VIII to mix with and dilute the polluted water of Qalaa Drain. The surplus water obviously will be substituted by more pumping from the Umum Drain stem. The amount of this oxic water sufficient in order to overcome the anoxicity and to re-aerate the Qalaa Drain water must be calculated.

The necessary amount of water for the dilution process is calculated (and illustrated in Fig. 7) as follows:

The local average DO content at station VII at Umum Drain stem is 7.2 O_2 mg/l. The flowing rate at this point is about 6.315 x 10^6 m^3/d.

On the other hand, the daily water rate of Qalaa Drain water at the stations near the dykes (the suggested place for mixing) 0.793 x10^6 m^3, where there the average BOD content 204.9 mg O_2/l and the average H_2S concentration is 26.8 mg H_2S/l. Thus, the total amount of H_2S in this water is about 21,252 kg H_2S, equivalent 21.252 ton H_2S/d.

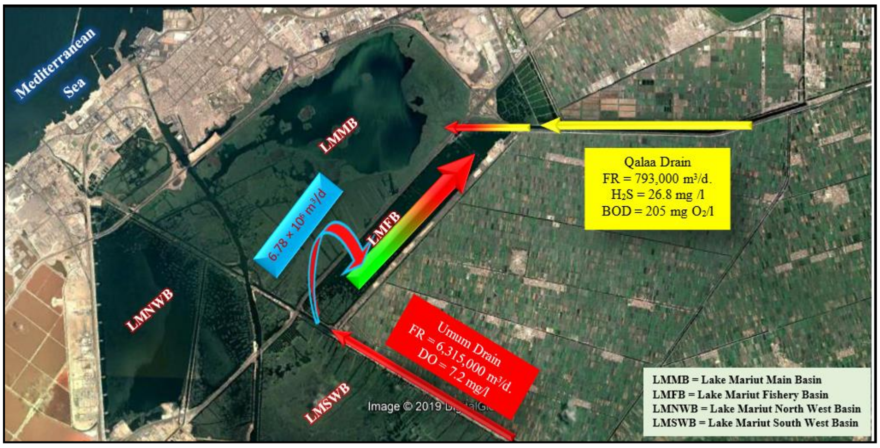

Fig. 7. Illustrates the dilution solution to improve the water quality of Qalaa Drain prior entering Lake Mariut Main Basin.

The DO needed for oxidation of H_2S can be calculated according the equation given by Camp (1963):

$$H_2S_{aq} + 2\,O_{2\,aq} = 2\,H^+ + SO_4^{-2} \text{……………………………. (1)}$$

$$34 \quad + \quad 64 \quad = \quad 2 \quad + 96$$

From the equation, about 34 mg of H_2S consume about 64 mg O_2 (about double amount) for the oxidation process to SO_4^{-2}. So, the load of 21.252 tons of H_2S needs [21.252 × (64/34)] 40,005 tons of DO.

Based on the previous information, one can conclude that the daily volume of Umum Drain water (have 7.2 mg O_2/l) required for oxidation of all sulphide content in Qalaa Drain (at the suggested site) is about 5.56 million m^3/d (this equivalent about 7 times that at the Qalaa Drain 793,000 m^3/d). These need a daily volume 5.56 million m^3 which is about 88 % of the current total discharge of Umum Drain. It is worthy to mention that the resulting mixed water in Qalaa Drain will contains Nil DO value. So, in order to raise the DO content in the Qalaa Drain water before discharging into the Lake Mariut Main Basin to a level for example 1 mg DO/l, additional volume of 1.22 million m^3/d of water from Umum Drain is needed. So, the total water needed will be 6.78 × 10^6 m^3/d. This solution is unrealistic. Theoretically if this happens it is true it reaches with the pollutant levels in the Qalaa Drain to a value (Table 2) lower than that of the permissible limits stated by EEAA Law No. 92/ 2013. But this solution however, from the practical point of view is difficult to attain due to technical difficulties because the voluminous water needed beside if this happened the level of water in

Lake Mariut Fishery Basin will rise to a level leading to submerge its banks (including the vital Alexandria-Cairo Desert Road lay at its north).

Table 2: The average concentration values of some parameters in the waters at the suggested mixing site in Qalaa Drain waters after dilution with (5.56 and 2.70 million m^3/d) of Umum Drain water across Lake Mariut Fishery Basin.

Parameter	Unit	Using 5.56 million m^3/d		Using 2.70 million m^3/d	Environmental Egyptian Law No 92 of 2013
		The average concentration values at stations VI, VII, and VIII			
		Before dilution	After dilution	After aeration followed by dilution	
***H_2S*/DO**	*mg S/l*	*26.8*	-	-	-
	mg O_2/l	-	Nil	2 mg/l	-
BOD	mg O_2/l	204.94	29.25	60.00	60
COD	mg O_2/l	282.00	40.25	82.94	100
TSM	mg/l	82.80	11.82	24.35	60
TN-N	mg/l	19.74	2.82	0.83	-
TP-P	mg/l	5.14	0.73	0.22	-

Dilution with in-stream aeration together could be another alternative. Abstract two volumes of that oxygenated water simultaneously with aerating the Qalaa Drain water; using artificial aerators to remove the H_2S from the water (Camp 1963) before discharging is investigated.

The In-Stream aeration (Camp 1963)

This application is utilized to increase the DO which will improve the drain conditions and thus self-purification. Camp (1963) reported that, about 1 to 1.5 mg oxygen are required for the removal of 1 mg organic matter (carbonaceous mainly) and 4.6 mg oxygen are needed for stabilization of 1 mg nitrogenous organic matter. Metcalf and Eddy (1991) stated that, the amount of oxygen required for stabilization of BOD_5 vary from 0.7 to 1.4 times the amount of BOD_5 removed. They also pointed out that the carbonaceous BOD is oxidized first, followed by nitrogenous BOD oxidation. Both carbonaceous and nitrogenous BOD oxidation are first-order processes, with the rate of oxidation equal to the rate of BOD exertion and is proportional to the amount of BOD present.

The sufficient oxygen requirements for oxidation of organic matter and removal of H_2S does not enter water through normal surface air water interfaces due to low solubility of oxygen and the consequent low rate of oxygen transfer. Thence, additional interfaces must be formed. Either air or oxygen can be introduced into the liquid, or the liquid in the form of droplets can be exposed to the atmosphere (Metcalf and Eddy, 2007).

That aeration may be operated by either mechanical aerators or by weir and cascade aeration (the least costly method to raise DO level).

After the aeration of Qalaa Drain that concerned with removal of H_2S, the decreasing of organic pollution loading (BOD of concentration 204 mg/l to the permissible limit (60 mg/l) is essential to improve the water quality. That is means that we have to dilute Qalaa Drain waters by 3.4 times. Hence the needed volume from Umum Drain waters is about 2,7 million m^3/d. It is worthy to mention that volume of required water will raise the surface level of Lake Mariut Fishery Basin (through which the Umum Drain water will transfer) by 64 cm in order to avoid the flooding of Lake Mariut Fishery Basin water, dredging of about 64 cm of the bottom is necessary (Fig. 8). Consequently, the decline in level of the other different parameters will take place (Table 2).

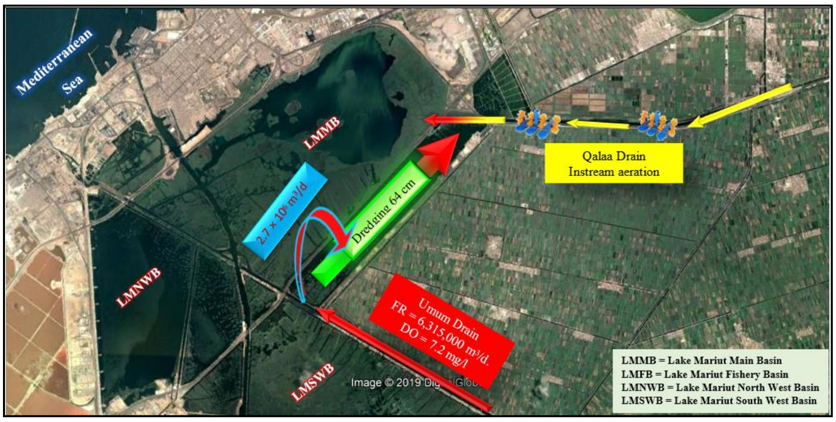

Fig. 8. Illustrate the instream aeration before the dilution of Qalaa Drain waters with Umum Drain waters to improve the water quality of Qalaa Drain.

By Diversion of Qalaa Drain

This attained by diversion of the polluted Qalaa Drain itself away from Lake Mariut Main Basin, by insulation. This can be achieved by extending the Qalaa Drain itself in Lake Mariut Main Basin by erection of a new dyke parallel to the Lake Mariut Main Basin east side before turning west to east at the north side of Lake Mariut Main Basin till it meets the most lower point of Umum Drain before pumping into the sea via El-Mex Pumping Station on the top of the separating hill (Abuser). This new extended canal or channel will also collect the discharged wastewater of the second Alexandria West-Waste Water Treatment Plant that is lying at the NW side of the Lake Mariut Main Basin before directly adjoining Umum Drain (Fig. 9). So, in this case the almost solely source of the water to Lake Mariut Main Basin will be then the inflowing relatively clear oxygenated water from Umum Drain. This will lead to an increase in salinity of the Lake Mariut Main Basin water to a level higher than that of Lake Mariut Fishery Basin because the increase of evaporation as this basin is of bigger surface area. This may lead to change in the biological diversities in the basin especially to the stenohaline species.

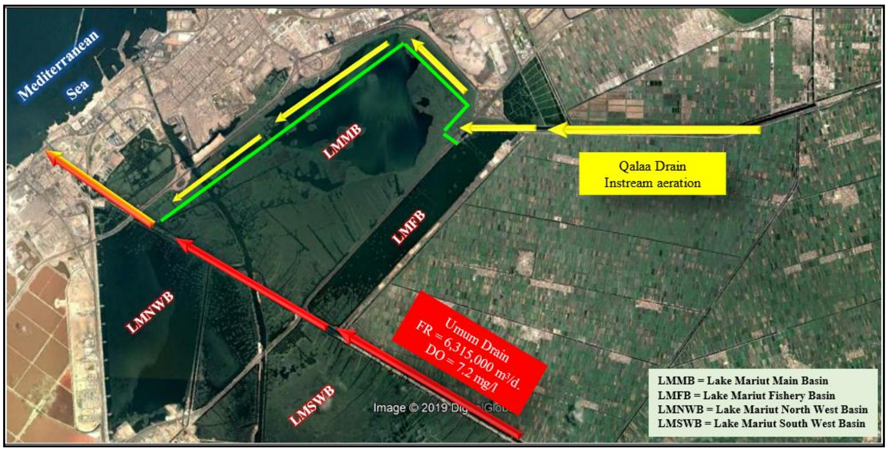

Fig. 9. Illustrate the solution by diversion of polluted Qalaa Drain waters from Lake Mariut Main Basin to improve the water quality of the basin.

CONCLUSION

From the aforementioned one can conclude:

Lake Mariut Main Basin is still suffering from the current discharge from the polluted Qalaa Drain (anoxic and with high loaded of nutrients and organic matter).

The solely solution of the Lake Mariut Main Basin-pollution problem- depends upon the improving of the water condition of Qalaa Drain.

In the light of shortage of the Nile water and water poverty in Egypt, there is direction to cover the water shortage by reusing other water sources like those from the agricultural drainage waters and from sewage wastewater.

In this respect, the wastewater of both East-Waste Water Treatment Plant and West-Waste Water Treatment Plant (total rate about one million m^3/d) can be reused for irrigation but after efficient treatment using advanced secondary treatment processes. If this happen then the water in Qalaa Drain will be restricted to the agricultural drainage water less loaded with BOD or COD from the neighbouring Alexandria farmlands.

If none of the projects of water reuse were implemented or delayed, then the suggested safe and fast solution to solve the current lake pollution problem is the insulation of the polluted Qalaa Drain from the water body of Lake Mariut Main Basin becomes a must.

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