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Calculations and solutions for heavy metals pollution load from Umum and Qalaa drains to Lake Mariut, Egypt

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In Egypt, after the construction of High Dam and the controlling of the River Nile, the water flow of Umum Drain has become one of the main land-based sources regularly discharging its waters directly into the Mediterranean Sea at El-Mex Bay, west of Alexandria. On the other hand, Qalaa Drain is the polluted source, having over 70% of its water as wastewater from eastern wastewater treatment plant, (EWTP). The present work is an assessment of a seasonal study of heavy metals' discharge from some pump stations into Umum and Qalaa Drains to control the heavy metals pollution load from each Umum and Qalaa to Lake Mariut Main Basin (LMMB). The results indicated that Lake Mariut is still suffering from the massive polluted loads from Qalaa Drain with high concentration of dissolved metals mostly in the sulphide forms. The present study highly recommends the insulation of anoxic water from Qalaa Drain.

[**Keyword**: Heavy metals Load; agricultural drainage waters; UmumDrain; Qalaa Drain; Lake Mariut; Egypt].

Introduction

During 1965, a plan was designed to improve the drainage system of El-Bohaira province by lowering the water level of the Umum Drain by about 40 cm. Hence some underground pipes were constructed between the drain and the lake at a level of 2.5 m below the sea level (BSL) in order to discharge the lake's water exceeding that level. Consequently, the original water supply to the main basin from Umum Drain was replaced by water discharging from the Qalaa Drain. Over the time, the Qalaa Drain became highly polluted with industrial wastes and sewage effluents specially after connecting it to Smouha Drain. The latter carries most of the sewage and industrial wastes of the Eastern District of Alexandria City[1&2]. Meanwhile, all the four basins of the lake are hydraulically connected by numerous breaches in the dykes of Umum Drain and Nubaria Canal[3].

Many literatures studied the concentration of heavy metals in both Qalaa and Umum Drains, among which[4,5&6], who studied the distribution and the concentration of Cu, Cd, Zn. Co, Ni, Pb, Mn and Fe in Qalaa and Umum Drains as well as LMMB, using the Chelex-100 resin for determination of both particulate and dissolved metals. The aim of this work is to make an estimation of some heavy metals discharge from drainage water of some pump stations into Umum and Qalaa Drains. Moreover, to calculate and control the heavy metals' load from each drain to Lake Mariut Main Basin (LMMB). Furthermore, this work is considered as one of the first studies that calculate the total metals contribution from each pump station into the two studied drains, beside it gives suitable and practical solutions to solve the Qalaa Drain pollution problems as a good step towards rehabilitation of Lake Mariut.

Materials and Methods

Sampling stations were selected in the Umum Drain course; [Stations St(I), St(II) and St(III)] were the flowing waters from the three pump stations (PSs), Dishudi, Haris and Abis, respectively. The last one in the main stem of the downstream of the drain before entering to the southwestern basin of LMMB (SW-LMMB), as shown in (figure 1). Station (St IQ) was at the inflowing water from Qalaa PS, while station (St IIQ) was along the drain course downstream at the end of Qalaa Drain, towards the opening onto the southeastern part of LMMB (SE-LMMB), (figure 1).

From all the selected stations, surface water samples were collected. The water samples were obtained using 5-liters heavy duty polyethylene sampling bottle, at least 4 liters of each water sample

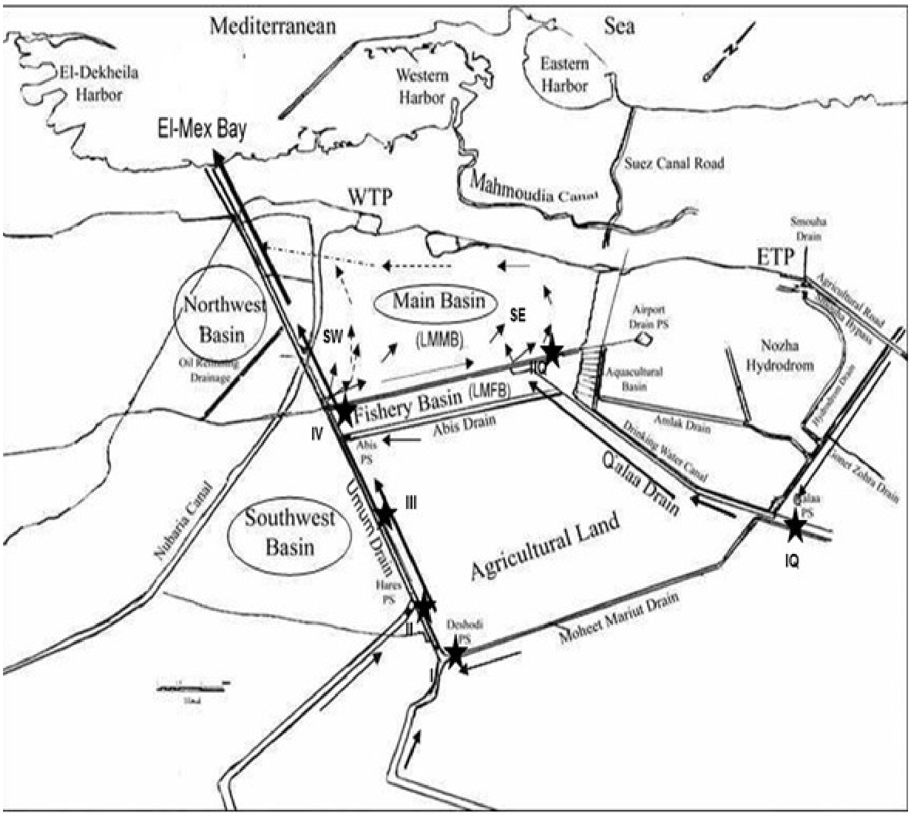

Fig. 1 — A map shows the sampling stations locations in the four studied waters, (Umum and Qalaa Drains).

was used for metals analysis. These were kept in a pre-acid washed and rinsed well with de-ionized water (DIW) polyethylene Jerry-cans, with polyethylene caps. The sampling of the water from the study areas has been performed seasonally [spring, summer, autumn, 2007 and lastly winter 2008].

Many methods of metal analysis, such as neutron activation and atomic absorption, depend on the prior separation and concentration of the metals from such samples as air, soil, industrial waste waters, and biological extracts. Trace metals can be concentrated by adsorption to Chelex chelating resin. The use of Chelex resin to preconcentrate samples for analysis has been extensively reviewed. Chelex 100 resin is also effective in concentrating traces of Cd, Co, Cu, Mn, Ni, Pb, and Zn with Average recoveries about 98.1% determined with standards[7].

The water samples for metal analysis were filtered using 0.45 um Millipore filters. The filtrate was passing through Chelex-100 resin in the ammonia form for preconcentration[8], and the eluted metals were collected. Particulate metals were also determined by digestion of the TSM retained on the filters[8]. The metals in the acid extract of both dissolved and particulate metals were measured using flame-Atomic Absorption Spectrophotometry [(AAS) Model Perkins-Elemer 2380]. The sum of both dissolved and particulate metals was represented as Total Metals. Solutions with known different metal concentrations were passed through columns containing Chelex-100 and the concentrations of metals after passing through the columns were measured. The results were compared with the actual standard values and the efficiency for the studied metals was calculated and it was within (97±5%).

Results and Discussion

Current agriculutral drains and canals discharging into the lake:

(A) Umum Drain

The Umum Drain is a huge agriculture drain that opens directly into the Mediterranean Sea at El-Max Bay, west of Alexandria (figure 1). It is the largest drain discharging into Lake Mariut[2&3]. Its average flow rate is ~ 6.6 million m^3/day ($2547.7x10^6$ m^3/year) all year round[9].

The drain is about 40 to 50 m wide. Upstream, off the Desert Road, the drain has an average depth of 3.5

m, and from there to 500 meters after its intersection with the Nubaria Canal, the average depth decreases to 2 m then it increases gradually until it reaches 5 m at its downstream part at El-Max PS[10]. This drain bears agricultural drainage water from both El-Bohaira governorate and the south part of Alexandria[11].

The Umum Drain system consisted of one rease and seven drainage PSs presented in (Table 1). In the Umum Drain system, only Abu Humus area is drained by gravity. The reuse of PS Mariut Khalt pumps the water from Umum Drain into Nubaria Canal. Afterwards, there is an input of drainage water from sheshera PS and Truga PS. Downstream, the PSs Dishudi, Hares and Abis discharge into the Umum Drain, which flows into Lake Mariut and then to El-Max Bay before entering the sea. The amount and position of the water flowing from the seven subsidiary drains via the drainage PSs are shown in (figure 2 and Table 1).

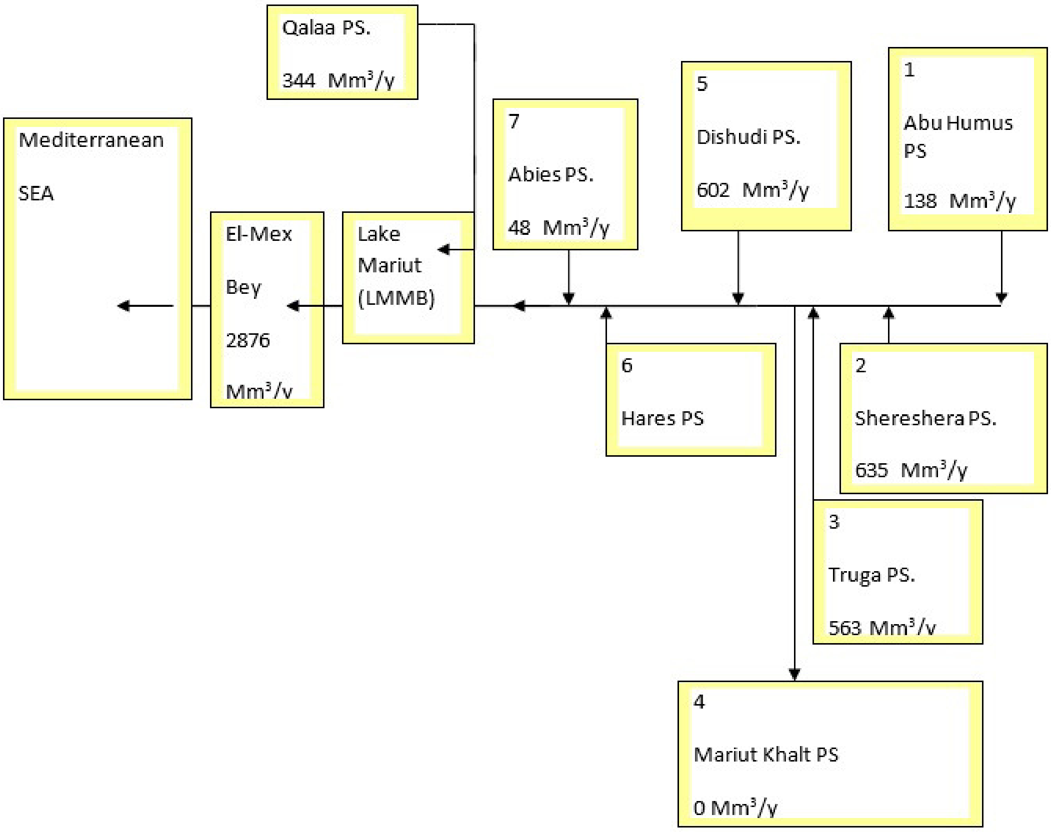

Fig. 2 — Scheme of Umum Drain system

Table 1 — Some characteristics of the eight drainage pump station (PSs) of Umum Drain and that Of Qalaa Drain, after[10].

Number PS No.	Name of Pumping Station (PS)	Date of construction	Discharge rate 10^6 m^3/y	Catchment area 10^3 feddan	Reuse 10^6 m^3/s
1	Abu Hummus	1990	138	50	-
2	Sheshera	1976	635	150	-
3	Truga	1967	563	103	-
4	Mariut Khalt	-	0	0	63
5	Dishudi	1959	602	63	-
6	Hares	1968	546	62	-
7	Abies	1989	48	8	-
Sum			2532		
Qalaa PS		1978	344	14	-
El-Mex PS		1987	2876	627	-

(B) Qalaa Drain

This drain begins at the north of the Alexandria/Cairo Agriculture Road at the point of intersection between the Hydrodrome Drain and the Qalaa PS[10]. For a long time, the drain received raw domestic, agriculture and industrial wastes from the eastern region of Alexandria through Smouha Drain. These wastes were subjected to natural self-purification processes along the drain (about 7 km long) before it reaches the lake basin[11]. Since 1993 (after the EWTP was built), the Qalaa Drain received water from the EWTP via the Hydrodrome Drain (371,000 m^3/day of primary treated effluent) to carry it to Lake Mariut.

Additional resources of its water come from Smouha Drain (primary source of untreated wastewater), Gonat Zohra Drain (agriculture drainage waters, its rate is about 50,000 m^3/day), Amlak Drain (72,300 m^3/day), airport drainage and agriculture runoff, in addition to some untreated sewage from villages located along the drain[2&10].

Since 2007, Qalaa Drain receives high amount of water than before according to[12]. Qalaa Drain brings 915,790 m^3 daily of primary treated sewage from the EWTP. The discharge from the EWTP is 607,000 m^3 daily, bringing 55 tons per day of Total suspended solid (TSS). It also receives 200,000 m^3/day of untreated sewage from Amlak, Smouha and Gonat Zohra Drains as shown in (figure 3). Finally, the agricultural drainage water contributes to the organic pollution of the lake and brings most of the P and N. The water travels 7 km from the EWTP discharge point to the entry into LMMB. Natural digestion of the effluent, oxygen-consuming matter, led the dissolved oxygen (DO) reaching 0 mg/L and anaerobic bacterial decay of organic substances creates emission of H_2S in the Qalaa Drain water before reaching LMMB[13,14&15].

In Umum Drain, The total average load of Cu, Ni and Mn were higher in Dishudi PS, where the total average load of Cd, Zn and Fe were higher in the water of Hares PS. Moreover, it was clear to thatthe total load of all heavy metals from Abis PS was lower than other PSs. While at station (St IV) at the end of Umum Drain, before entering the SW-LMMB, the total average load of the seven studied metals was higher than the rest of the selected stations at Umum Drain, and this might be due to the high flow rate at

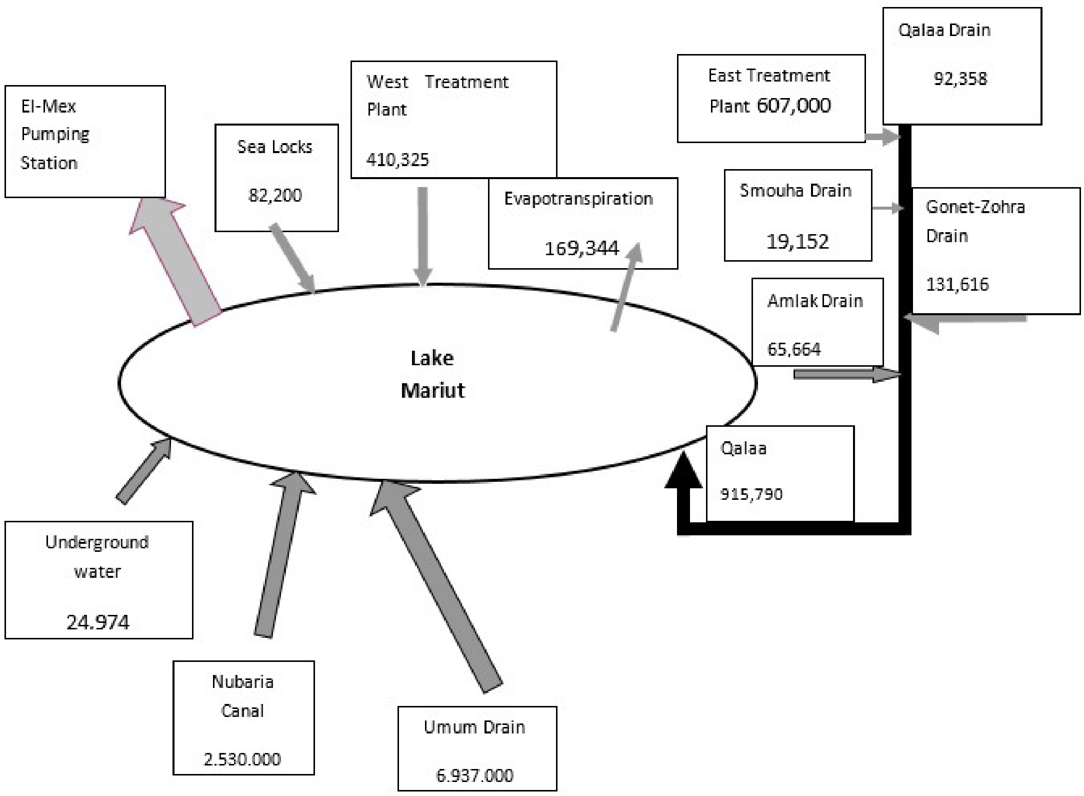

Fig. 3 — Schematic water balance in Lake Mariut Main Basin (LMMB) (m^3/day)[7]

Table 2 — Concentration level (ug/L) and total average load (kg /d) of metals from the subsidiary PSs to Umum and Qalaa Drains to LMMB (spring 2007-summer 2008). a- Total metals (ug/L)

Parameter		Umum Drain					Qalaa Drain	
		Dishudi PS St I	Hares PS St II	Abis PS St III	St IV	To SW-LMMB	Qalaa PS St I	St VIIQ* To SE-LMMB
Flowing water (m^3/d)		1,649,315	1,495,890	131,507	6,937,000	1,500,000	942,466	915,790
Cu	ug/L	15.6	6.1	9	8.1	8.1	7.7	13.6
	Load	25.73+	9.12	1.18	56.19	12.15	7.26	12.45
Cd	ug/L	0.5	1.6	1.1	1.3	1.3	0.6	2
	Load	.82	2.39+	0.14	9.02	1.95	0.57	1.83
Zn	ug/L	53.3	60.3	51.64	53.37	53.37	46.8	55
	Load	87.91	90.20+	6.79	370.23	80.6	44.11	50.37
Co	ug/L	1.3	2.0	1.7	2.6	2.6	1.1	2.7
	Load	2.14	2.99	0.22	18.04+	3.90	1.04	2.47
Ni	ug/L	5.4	3.7	4.9	5.0	5.0	5	6.5
	Load	8.91+	5.53	0.64	34.69	7.50	4.71	5.95
Mn	ug/L	48.9	42.5	81.8	52.9	52.9	38.6	46
	Load	80.65+	63.58	10.76	366.97	79.35	36.38	42.12
Fe	ug/L	82.3	111.9	67.9	74.6	74.6	25.3	95.5
	Load	135.74 +	167.39+	8.93	517.50	111.90	23.8	87.46 +

this particular station compared to the other stations' flow rates, (Table 2). The level of concentrations of T-Zn and T-Fe are slightly higher in Umum Drain than in Qalaa Drain. The elevation in the T-Zn concentration in the mainly agricultural drainage water could be due to the use of Zn fertilizer chemicals in the farm lands[13,14&15]. In addition, due to the dilution of Qalaa Drain water with wastewater less contaminated with Zn.

On the other hand, from (Table 3), we can see that the load from Qalaa Drain to SE-LMMB is higher in Cu and is in equal load level in Cd with Umum Drain. While the total load from Umum Drain for the rest of the studied metals is higher than that from Qalaa Drain. This reflects contamination of the wastewater from ETP at least with respect to Cu. The enrichment with Mn is due to the solublization of Mn from the bottom sediments of Qalaa Drain.

The evolution of the H2S reflects that the oxygen consuming matter (mainly organic matter [16]) is overcoming the supply of dissolved oxygen (DO) from the overlying O_2 gas supply from the atmosphere. In otherwords, the rate of the diffused O_2 gas from the atmosphere is much less than the required DO necessary for oxidizing the available organic matter via aerobic bacterial action. The current condition has led to the disappearance of aerobic bacteria and the replacement with anaerobic bacteria in the sequence of (1) denitrifying bacteria [reducing the high oxidant state of N] (NO_3 and NO_2) to either N_2O and /or N_2 molecule[17&18].

Table 3 — Surface water loading mg/m^2 in LMMB* from Qalaa Drain and Umum Drain (1.5 milion m^3/d).

	Cu	Cd	Zn	Co	Ni	Mn	Fe
	Umum Drain						
To SW-LMMB	0.53	.08	3.47	0.17	0.32	3.44	4.84
	Qalaa Drain						
St VIIIQ To SE-LMMB	0.54	.08	2.18	0.11	0.26	1.82	3.79
Sum	1.06	.16	5.65	0.28	0.58	5.26	8.63

**LMMB = 5500 feddan. (Feddan =4200 m^2) surface area 5500 X 4200 = 32 km^2. * It lies at 7km downstream of Qalaa PS.*

Inspite of these high loads,the foregoing results showed that the concentration level of each of the studied dissolved metals in the waters according to USEPA is at acceptable safe levels. i.e. they are still far below the maximum permissible limitsthat causes health hazards to life of biota and subsequently to human. Not only that but they are at levels compared to those suitable for drinking water[13,14&20].

The waters of Umum Drain, is always aerated (8.3 mg O_2/L) compared with that of Qalaa Drain which is consistently bearing H_2S, reflecting that the oxygen-consuming matter in this water is exceeding the available DO, thus leading to the euxinic condition of this Qalaa Drain[13&14].

In order to solve the pollution problem of Qalaa Drainage water, the wastewater from the EWTP needs further or secondary treatment. This is an advanced treatment that requires the construction of suitable secondary treatment facilities, which takes time and money. Until then, a fast and urgent solution is needed to reduce the pollutants levels in Qalaa Drain water. To rehabilitate the euxinic Qalaa Drain water this can be achieved by turning it from the anoxic to the oxic condition. Hence, three suggestions were proposed and evaluated.

Solution/s for Qalaa Drain pollution problem

In this section, an evaluation for the suggested solution/s to solve the pollution problem of Qalaa Drain is presented. These are dilution, aeration and dilution, and diversion or insulation methods.

1-By dilution method

The dilution method is described as mixing the polluted (H_2S) bearing water at the downstream part of Qalaa Drain with aerated and less polluted water from Umum Drain. The Umum Drain water contains DO concentration with an average of (8.3 mg O_2 /L,) [13&14].

The discharge rate in this Drain is about 4.200.000 m^3/d. Since the daily volume of water reaching Qalaa Drain at station IIQ is 915,790 m^3/d, with an average H_2S 79.8 mg H_2S /L[13&14], then the total amount of H_2S concentration is about (915.790 x 79.8 = 73.080 x10^9 mg H_2S). This is equivalent to about 73.080 tons

H_2S/d. = 73.080 X 10^6 g H_2S /d = 73.080 / 34 X10^6 mole H_2S /d.

The amount of DO needed for oxidation of H_2S can be calculated according to the equation given by[12];

$$H_2S + 2O_2 = 2H^+ + SO_4^{--} \quad \dots (1)$$

$$34 + 64 = 2 + 96 \quad \dots (1)$$

From the equation, about 34 mg H_2S consume almost double of O_2 (64 mg O_2) for the oxidation processes to the sulphate (SO_4^{--}), i.e. the load of 73.080 tons of sulphide need 73.080 x 64/34 = 137.39 tons of DO. Accordingly, the daily volume of water from Umum Drain (8.3 mg O_2/L) required for oxidation of sulphide is about 16.57 million m^3 (equivalent to 18 times of discharge rate 915.790 m^3/d) and this will lead to the dilution of metals' concentrations.

Apparently, this solution might be considered impractical, as in this case it is required to pump the whole Umum agriculture drainage waters via the Lake Mariut Fishery Basin (LMFB), before mixing with the polluted waters at the downstream part of Qalaa Drain.

2-By both aeration and dilution method

The removal of H_2S from the polluted water of Qalaa Drain using forced aeration technique, is a partial solution. It suggests to remove the malodorous odour gas from the Qalaa Drain water. According to[12], oxygen gas doesn't react with H_2S gas except at elevated temperature. Also the aeration of water containing H_2S will lead to expel the gas out of water.

The same author stated that, the portions of HS^- and H_2S in water, as computed from equation (2).

$$H_2S = HS^- + H^+ \quad \dots (2)$$

The condition prevailing at Qalaa Drain of average 6.93 (~ 7) was computed to be about 47.7 % of the total sulphide existing in the form of H_2S gas.

As the dissolved gas is oxidized, hydrogen ions combine with the hydrogen ions of water to form more H_2S gas[21]. This means that the entire load at St IIQ can be considered as free H_2S gas.

Since the atmosphere is normally free of H_2S, this gas may be removed readily from water by aeration, which accomplishes the double function of H_2S release and to furnish DO for the oxidation of H_2S in the water. In the presence of DO, H_2S is oxidized according to the following equations:

$$2H_2S + O_2\,aq = 2H_2O + 2S \quad \dots (3)$$

$$H_2S\,aq + 2O_2\,aq = 2H^+ + SO_4^- \quad \dots (4)$$

The aeration of Qalaa Drain water is advisable to be at stages of the oxic water or slightly oxic condition. However the mixing of Qalaa Drain water with LMMB and the exchange between air and drain water will lead to further oxidation of water at St IIQ and hence to an expected minimization or disappearance of the odour of H_2S. After the aeration of Qalaa Drain water, the H_2S concentration in the Qalaa Drain water will be (Nil). Then, it will be required to calculate the amount of the water to be abstracted from Umum Drain to rise the level of O_2 in Qalaa Drain.

The water volume in Umum Drain, is about (4.200.000 m^3/d) containing about (8.3 mg O_2 /L, table 11), so by pumping about (2,000,000 m3/d) each day to Qalaa Drain through LMFB, the content of O_2 in Qalaa Drain will rise to a level of (~ 4.00 mg O_2/L). This will convert the anoxic condition to the oxic condition in Qalaa Drain.

Unfortunately, this aeration and dilution technique remains impracticable due to the following reasons:

Pumping about 2 million m^3/d of Umum Drain to LMFB will raise the water level in LMFB, to at least 0.5 m [(1000 feddan X 4200 m^2 = (4,200,000 m^2) and if the abstracted water about 2,000,000 m^3/d, this means that the water level in this basin will rise to about = 2,000,000 / 4,200,000 = 0.48 m (~ 0.5 m)]. This will submerge the surrounding lands including the Alexandria- Cairo Desret Road. To solve this problem we need to dig the bottom of LMFB to at least 0.5 m more than the current depth.

3-By the diversion or insulation of Qalaa Drain

This method aims at diverting the polluted Qalaa Drain itself away from LMMB, by insulation. This can be attained by extending the current course of Qalaa Drain by erection of a new dyke parallel to the LMMB east coast and then westward until it meets the terminal downstream part of Umum Drain before pumping through El-Mex PSs and discharging to the sea. This new extended course channel will also collect in its way the wastewater discharge from El-Kabbary west treatment plant (WTP). This is lying at the northwestern side of LMMB. Therefore, in this case the only water source to LMMB will be from Umum Drain via the breaches. This will lead to an increase in the salinity of this basin and subsequently will have an impact on the diversity of biota living there.

Recently, there is an intention by the Ministry of Irrigation (near future plan) to reuse water from Umum Drain. Of course, this will lower the water level in the drain particularly in the downstream part that is neighboring LMMB. So the breaches on the drain at its east dyke will be blocked. This makes the water supply to LMMB restricted only by two sources, Nubaria Canal and Sea Locks [between this Canal and Alexandria Western Harbour (82,200 m^3/d)[7], besides salty water from benthic flux of underground water[22]. In the last case Abdallah, mentioned that the benthic flux is at a rate 2250 m^3/d, this will raise the salinity of LMMB with time to reach 30 g salt /kg within 20 years. Thus turning LMMB from exorheic to endorheic saline lake.

Conclusion

From the foregoing study, the following key points are concluded: LMMB is still suffering from the current discharge of anoxic water from Qalaa Drain loaded with high concentration of dissolved metals mostly in the sulphide forms because about 70% of Qalaa Drain water is a wastewater discharge from ETP. The other 30% is agriculture drainage water. Also the Qalaa Drain is loaded with high level of oxygen consuming wastes (organic matter) that overcomes the O_2 supply from the atmosphere. The only solution of the LMMB-pollution problem is depending on improving the water condition of Qalaa Drain and turning it from anoxic to oxygenated water. And this will be achieved through the insulation solution. Insulation of Qalaa Drain with its anoxic water away from the water body of LMMB is highly recommended and is a practicable solution and it is easy to implement. This solution will also simultaneously collect the current discharge from WTP. Evidently, if the secondary treatment processes become available, it would be the most practical solution to implement. The current Qalaa Drain discharge waters containg heavy metals in concentrations at level still safe for living organisms as they are at the permissible limits recommended by the EEAA Law 4/1994 and other world organization like USEPA.According to recommended maximum concentrations of trace elements in the irrigation waters by Irrigation resources 1972[23], the level of the studied metals is still below than these limits and therefore the waters of Umum and Qalaa Drains safely can be used for irrigation.

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