Misr J. Ag. Eng., 30 (2): 309 - 326 IRRIGATION AND DRAINAGE

IMPROVEMENT CONSTRUCTED WETLAND PERFORMANCE FOR REDUCING CONTAMINATION LEVELS IN BAHR EL-BAQAR DRAIN, NORTH EAST OF EGYPT

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ABSTRACT

Nowadays, drainage water is being reused to overcome the gap between the amounts of available and water required. Constructed wetlands, whether of free surface flow or subsurface flow, aim among several purposes, at improving the quality of wastewater. However, the recommended discharge of these wetlands which is 2500 m^3/day, although could decrease the levels of pollutants in wastewater, yet it might be of interest to increase this discharge to meet the increased demands for water. Also, since the efficiency of the wetland to remove pollutants is dependent, among other factors, on the type of the plant cultivated in the surface flow cells, then trying some different types of plants might be fruitful. Therefore, the current study conducted aims at: (1) Assessing the efficiency of the constructed wetland under lower (1250 m^3/day) and higher (5000 m^3/day) discharges than the usual (2500 m^3/day). (2)Investigating the use of cattail and papyrus plants in the surface flow cell, compared with the commonly used reed plant..

KW: FWS, Free Water Surface, SFW, Sub- Surface Flow Wetland

1. INTRODUCTION

Reuse of agricultural drainage water is already practiced on a large scale in several countries. In Egypt, due to scarcity of water resources, drainage water is being reused. Currently, about a total of 5.5 Billion Cubic Meters (BCM) of drainage water is being reused after mixing with fresh water. This amount is expected to increase up to 9.6 BCM by the year 2017 **(NAWQAM, 1999)**. Drainage water is actually a combination of agricultural drainage water, industrial effluents, and sewage water with different ratios.

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The Egyptian agricultural drains receive discharges of untreated or poorly treated domestic wastewaters, in addition to agricultural drainage water. Therefore, they contain high concentrations of various pollutants such as organic matter, suspended solids, heavy metals and fecal bacteria. Uncontrolled discharge of untreated wastewater to agricultural drains and water resources is a major problem facing the rural areas of Egypt. A major concern when considering drainage water reuse is whether the drainage water quality is within the allowable limits for different uses as outlined by water quality standards and laws or not.

The wetland has water table at or near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, and various kinds of biological activity which are adapted to the wet environment. **(Mitsch and Gosselink, 2000).**

Wetlands are engineered and constructed for four principal reasons as indicated by specific descriptive terminology:

(1) To compensate for and help offset the rate of conservation of natural wetland resulting from agriculture and urban development (constructed habitat wetlands).

(2) To improve water quality (constructed treatment wetlands).

(3) To provide flood control (constructed flood control wetlands).

(4) To be used for production of food and fiber (constructed aquaculture wetlands) **(Kaseva, 2004).**

Constructed wetlands have been classified into two types. Free water surface **(FWS)** wetlands (also known as surface flow wetlands) closely resemble natural wetlands in appearance because they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland and water flows among the leaves and stems of plants. Subsurface flow **(SFS)** wetlands systems (also known as vegetated submerged bed (VSB)) which do not resemble natural wetlands because they have no standing water. They contain a bed of media (such as crushed rock, small stones, gravel, sand or soil) which have been planted with aquatic plants **(EPA, 2000).**

The main objectives of this paper are:

1. Assessing feasibility of constructed wetland system to improve the water quality so that it becomes suitable for different uses.

2. Decreasing time of treating the discharged water
3. Decreasing the level of pollutants flowing into Lake Manzala (بحيرة المنزلة) and the Mediterranean Sea.
4. Increasing quantity of the treated discharged water.

2.Materials And Methods

The study area is located at the southern edge of Lake Manzala as shown in figure (1). According to sedimentomorphic soil maps (MacLaren, 1982) and the soil study of Lake Manzala by the Japanese International Cooperation Agency (JICA), Bahr El- Baqar drainage (مصرف بحر البقر) water constructed wetland is located in the Coastal Plain and the soil type is Fluviomarine Deposits. These types of soils are covered by a thin, fluffy layer of clay, and often a thin salt crust is found on the surface. The groundwater table ranges from 0.5 to 1.5 m below the soil surface. The annual rainfall is approximately 67 mm. The highest absolute recorded temperature is 46 C°, occurring in June, while the lowest temperature of 0 C° is recorded in February. The average annual temperature in the area is 28 C°.

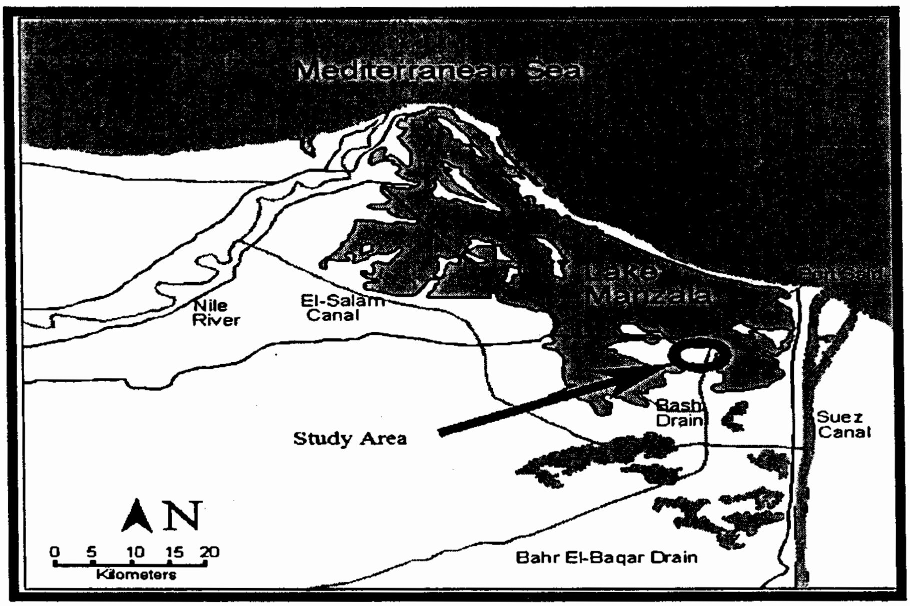


Figure (1) Bahr El-Baqar drain water constructed wetland (study area site),

2b.Components of Bahr El-Baqar Constructed Wetland (BCW)
BCW contains: intake structure, pump station, sedimentation basin, 10 free water surface wetland cells, reciprocating cells (two subsurface flow wetland cells), fishery facility and fish farm as shown in Figure (2).

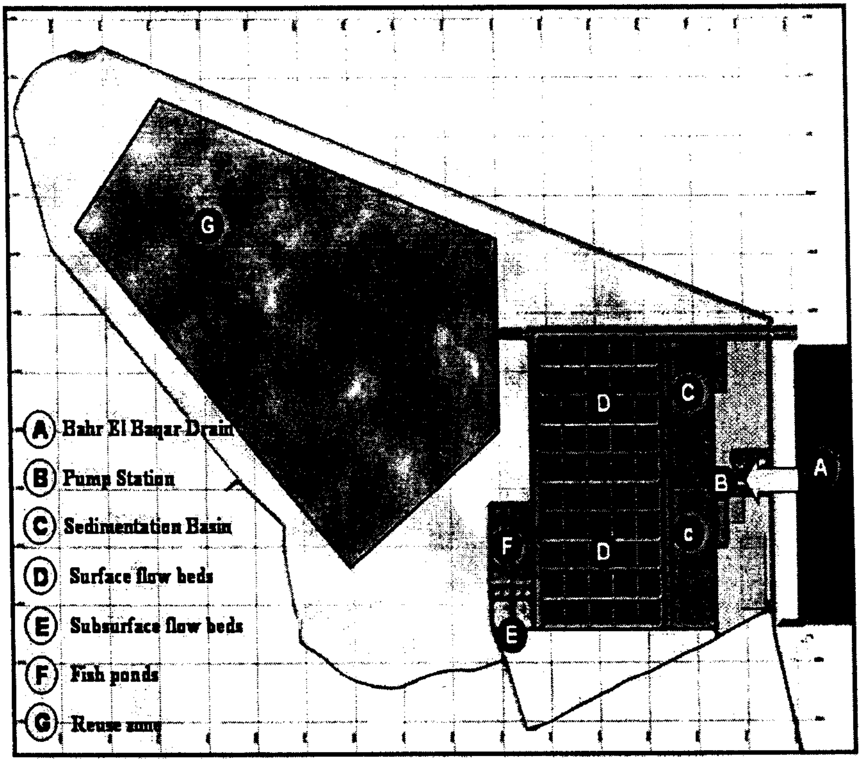


Figure (2) Major Components of (BCW)

2c.Water Intake and Pumping Station
The total study area is about 240 feddan and the total wetland system area is about 80 feddans. The intake channel selectively withdraws water from the upper half of Bahr El Baqar drain (A). Two course bar screens and a floating baffle prevent larger materials from entering the treatment system. Two 12,500 cubic meter per day (522 m^3/h) screw pumps lift the intake water approximately 3 meters into the sediment basins and provide hydraulic gradient for gravity flow through the remainder of the system. The station is operated by means of two diesel generators (B).

2d.Sediment Basins

Two sedimentation basins (C) of approximately 250 * 90 m and 1.5 m depth are provided with gravel media for the receiving of sediments accumulated in the sedimentation ponds with time and provide primary treatment. Sludge is periodically removed to conventional drying beds and disposed in accordance with environmental regulations. A majority of the metals will be removed by this part of the treatment process.

Flow is equally distributed between the two ponds as shown in Table (3).

Table (2) Design parameters for sedimentation basin

Parameter	Units	Value
Average flow rate	m^3/d	12500
Detention time	Days	2
Total depth	m	2.5
Operating depth	M	1.5
Volume of water	m^3.	25000
Area	m^2.	22500
Length	M	250
Width	M	90
Side slope	non	3:1
Bottom Slope	%	0

2e.Surface Flow Treatment Cells

Effluent from the sedimentation basins flows to ten surface flow cells through distribution canal (D). Each cell is divided into five compartments by open water trenches designed to redistribute lateral flow and reduce short circuiting. In order to test removal efficiencies at different flow rates, three low flow cells (approximately 1250 cubic meters per day)), medium flow cells (approximately 2500 cubic meters per day), have loading rate similar to conventional wetland systems),and high flow (approximately 5000 cubic meters per day) .

The cells were planted with common reed, cattail and papyrus emergent plants. Each treatment was replicated three times as shown in Table (3).

Planting started at a density of four plants (rhizomes) per square meter and was transplanted manually. After one year, plant density was increased to 20 plants (rhizomes) per square meter.

The parameters characterizing each cell are listed in table (4). Flow of water was controlled in the surface flow (SFW) cells at inlet and outlet with control valves and measured by Ultra Sonic meters.

Table (3): Design parameters for low, med., and high flow cells with (Reed – Cattail - Papyrus) plants.

Parameter	Unit	Low flow	Med. flow	High flow
Average flow rate	m^3/d	1250	2500	5000
Detention time	Days	4	2	1
Hydraulic loading rate	m/day	0.1	0.2	0.4
Operating depth	m	0.4	0.4	0.4

2. f. Reciprocating Subsurface Flow Treatment Cells

In this system the cells have a design capacity of 500 cubic meters per day and will initially treat effluent from the sediment basins. Alternatively, effluent from the surface flow cells can be used to supply the reciprocating cells. Two pumps 47 l/s each with 3 m head operating at 1500 rpm are used to reciprocate water between the two cells. The cells are filled with graded gravel and produce an effluent water suitable for supplying inflow to the fish-rearing facility.

2g. Design Criteria

Table (4) Design inflow characteristics based on available data (P. Lane 1992b; 1993a; Drain. Res. Inst. 1998; 2000).

Table (4): Design Criteria for Influent Water Quality

Parameter	Units	Value
Daily flow	m^3	25,000
Total BOD	mg/L	40
Total COD	mg/L	100
Total suspended solids	mg/L	160
Total phosphorus	mg/L	5
Total nitrogen	mg/L	12
pH	-----	7.5
Conductivity	dS/m	4

2h. Performance Calculation of Surface Flow Cells

The hydraulic loading rate is defined as

$$q = \left(\frac{Q}{A}\right), \quad (1)$$

where,

q = Hydraulic loading rate, m/d

Q = Water flow, m^3/d

A = Wetland area, m^2

2i. Performance Calculation of the Sedimentation Basin

The main function of the sedimentation basin is to hold and bake suspended sediment, phosphorus and heavy metals adsorbed to the sediment.

The basic formula to calculate the sedimentation in the basin is Stoke's law and the retention time, as follows:

$V = (2gr^2)(d-D)/9u$, (2)

where,

V = velocity

g = acceleration due to gravity (981cm/sec^2)

r = radius of particle (cm)

d = density of particle (g / cm^3)

D = density of water (1 g / cm^3)

u = dynamic viscosity of water (g/cm/day)

Retention time is calculated as:

$T = S / E(Q)$ (3)

Where,

T = retention time (sec)

S = Volume of sedimentation basin (m^3)

E (Q) = Average discharge (m^3 /sec)

2j. Removal Efficiency

The amount of pollution removed from receiving water can be quantatively expressed in terms of the removal efficiency (RE), between 0 and 100 percent. RE is defined as:

$$RE = \left(\frac{C_i - C_e}{C_i}\right) x100 \qquad (4)$$

Where,

C_i =inflow pollutant concentration

C_e = outflow pollutant concentration

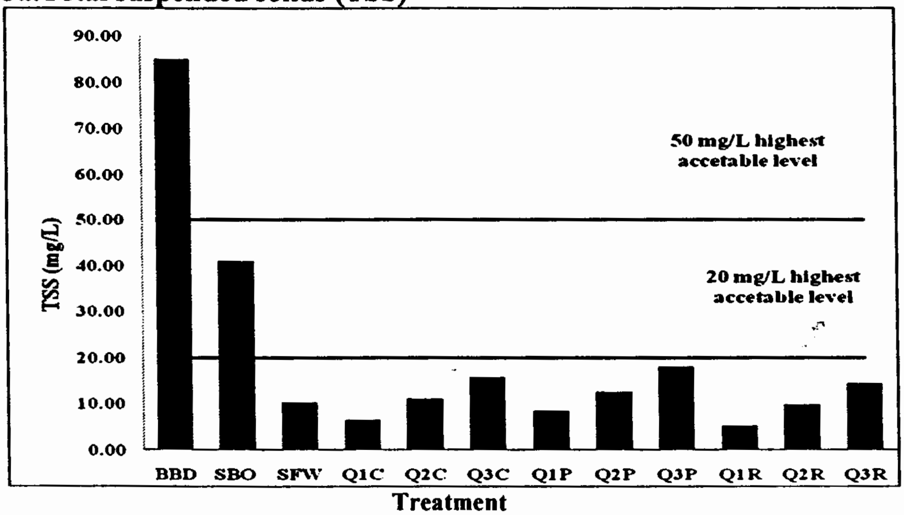
2k. Monitoring and Sampling Locations

Water sampling was scheduled on a biweekly monitoring. There are two types of measurements for the collected water samples, first field measurements for some parameters such as second lab analysis for the

water quality. All sampling procedures and analyses were carried out according to EPA standard methods.
Water samples were collected from the designed monitoring locations and delivered to the central environmental laboratories of the National Water Research Center for water quality analysis. These analyses were to determine water quality parameters, including total suspended solids (TSS), biochemical oxygen demand (**BOD**), total nitrogen (**TN**), total phosphorus (**TP**), heavy metals such as; iron (**Fe**) manganese (**Mn**), zinc (**Zn**),lead (**Pb**), copper (**Cu**) and nickel (**Ni**), beside the fecal coliform bacteria (**FC**) and total coliform bacteria (**TC**).

3.RESULTS AND DISCUSSION

3a.Total suspended solids (TSS)

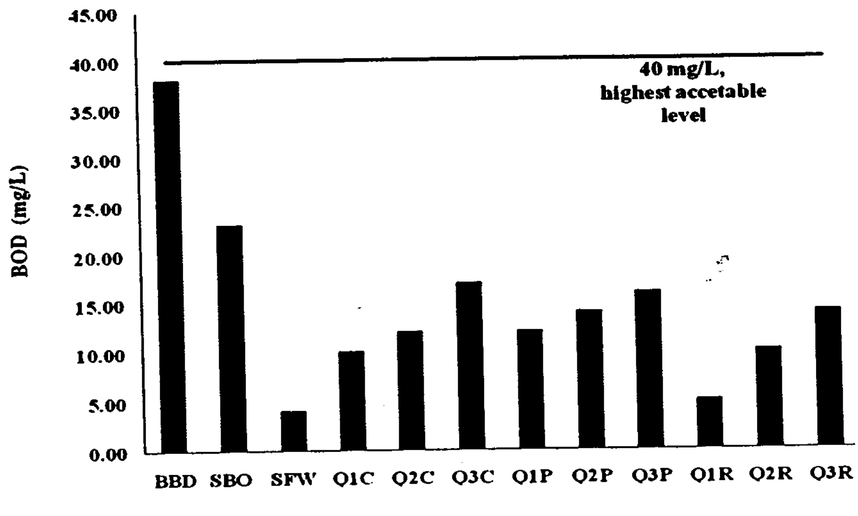


BBD Bahr El Baqar Drain. **SBO** Sedimentation Basin Outlet. **SFW** Subsurface Free Wetland , **Q1C** Discharge (1250 m^3/day), Cattail., **Q2C** Discharge (2500 m^3/day), Cattail., **Q3C** Discharge (5000 m^3/day), Cattail., **Q1P** Discharge (1250 m^3/day), Papyrus.,**Q2P** Discharge (2500 m^3/day), Papyrus., **Q3P** Discharge (5000 m^3/day), Papyrus., **Q1R** Discharge (1250 m^3/day), Reed., **Q2R** Discharge (2500 m^3/day), Reed and **Q3R** Discharge (5000 m^3/day), Reed.

Fig (3) TSS concentrations under different treatments.

Results in Figure (3) show values of TSS concentration under the different wetland systems, i.e. free water surface (FWS) and the subsurface wetland (SFW) as well as the different studied discharges Q1,Q2 and Q3.(i.e. 1250,2500 and 5000 m3/day)beside the different cultivated plants C, P, and R (i.e. cattail, papyrus and reed) . The maximum values of removal of TSS were attained due to (Q1C andQ1R), , while the corresponding minimum ones were achieved due to (Q3P and Q3C).However, all of these values were under the permissible limits, while those of water of BBD are obviously higher than the permissible ones i.e. 20 – 50 mg/L according to NAWQAM (2007). At sedimentation basin outlet (SBO), values of TSS, although were reduced as compared with those of BBD, yet these values remained somewhat higher than the permissible ones.

3b. Biological oxygen demand (BOD)



See footnote of Fig. (3)

Fig. (4): BOD concentration under different treatments.

Results in Figure (4) show concentrations of **BOD** under the studied treatments. The maximum removal values of **BOD** were due to (**SFW andQ1R**) treatments, On the other hand, the minimum values of **BOD** removal were achieved due to **Q3C, Q3P, Q3R and Q2P** treatments

.However, all of these values were under limit of TSS as reported in **NAWQAM 2007.** Also, values of **BOD** of water of BBD were lower than the permissible one i.e. 40 mg/L. Likewise, at the sedimentation basin outlet (SBO), values of **BOD** seemed to be lower than the permissible one.

3c. Total nitrogen (TN)

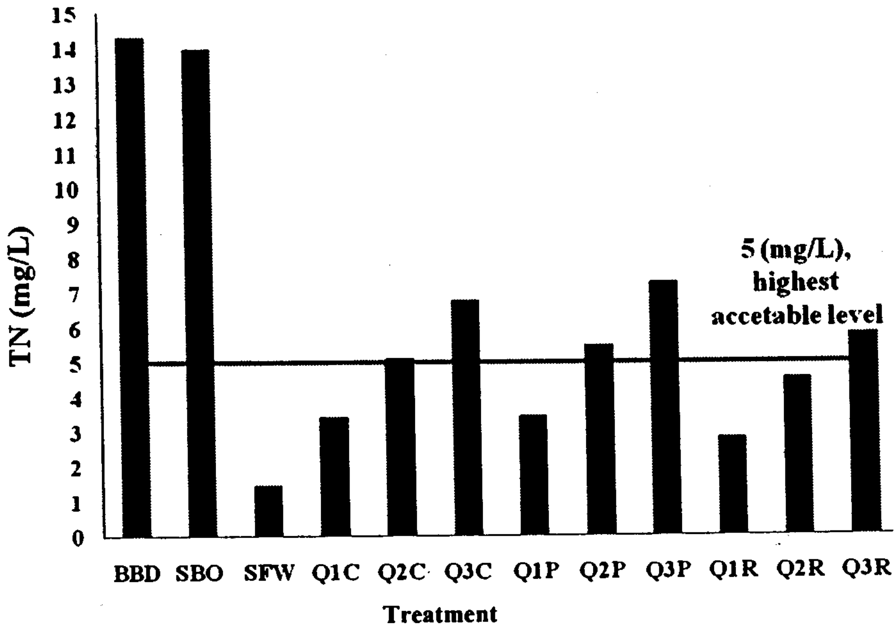


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Fig (5): TN concentration under different treatments.

Figure (5) shows concentration of TN attained under the studied treatments. Removal of TN was highest owing to the treatments (SFW). However, as well as all the concentrations achieved by Q1R, Q1C, Q1P and Q2R treatments, were lower than permissible limit proposed by FAO (1985). On the other hand, the lowest removal of TN occurred due to the treatments, Q3C, Q3P and Q3R where values of TN achieved due to these treatments as well as those of water of BBD, were obviously higher than the permissible one. At the sedimentation basin outlet (SBO), values of TN, although were very slightly lower than those of BBD, yet these values remained somewhat higher than the permissible ones.

3d. Total phosphorus (TP)

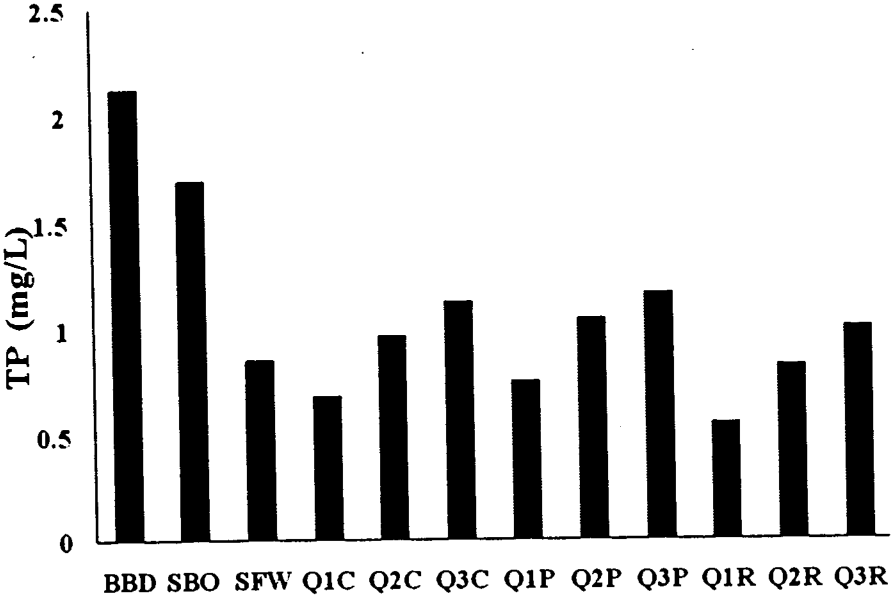

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Fig (6) TP concentration under different treatments.

Figure (6) shows concentration of **TP** under the studied treatments. The maximum removal of **TP** was attained due to the treatments Q1R while the minimum removal values of **TP** were achieved due to the treatments Q2P, Q3P and Q3C.However, all of these values were under permissible limit of TP 9.7 mg/L (= 30 mg PO_4 /L) as reported by **(FAO, 1992 and National Academy of Science-National Academy of Engineering 1973). TP** values of BBD water were higher than those of the wetland treated ones. Also TP of water at sedimentation basin outlet (SBO), were reduced as compared with those of BBD water .However, TP values of all the studied waters i.e. at BBD, SBO and the other treatments were obviously lower than TP values reported as highest acceptable limit

3e. Heavy Metals:

Table (5): Heavy Metals Concentration in mg/L

Parameter	Concentration of heavy metals in mg/L						
	Fe	Pb	Zn	Cu	Mn	Ni	Cd
BBD	**0.892**	**0.021**	**0.0460**	**0.0304**	**0.164**	**0.019**	**0.004**
SBO	**0.788**	**0.017**	**0.0460**	**0.0298**	**0.146**	**0.019**	**0.004**
SFW	**0.156**	**0.006**	**0.0113**	**0.0039**	**0.043**	**0.006**	**0.0004**
Q1C	0.139	0.007	0.0107	0.0068	0.035	0.0062	0.0005
Q2C	0.215	0.009	0.0128	0.0104	0.044	0.0079	0.0005
Q3C	0.26	0.009	0.0174	0.0136	0.051	0.0088	0.0008
Q1P	0.108	0.007	0.0089	0.0044	0.039	0.0057	0.0005
Q2P	0.193	0.008	0.0121	0.0076	0.052	0.0075	0.0005
Q3P	0.253	0.009	0.0154	0.0107	0.063	0.0085	0.0008
Q1R	0.092	0.007	0.0073	0.0035	0.032	0.0056	0.0005
Q2R	0.177	0.007	0.0089	0.0056	0.04	0.0062	0.0005
Q3R	0.216	0.008	0.0124	0.0087	0.044	0.0068	0.0006

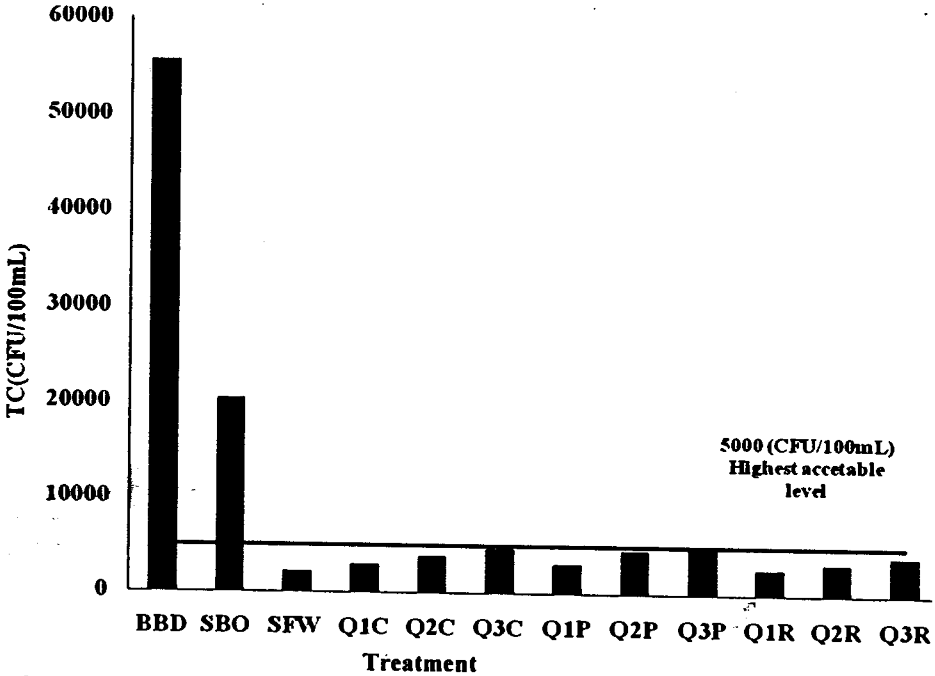
See footnote of Fig. (3)

Table (5) heavy metals concentration under different treatments.

Data illustrated in Table (5) reveal that concentrations of the studied heavy elements i.e. Fe, Mn, Zn, Pb, Cu, Ni, and Cd were less than the corresponding permissible limits i.e. 5, 0.2, 5, 5, 0.2, 0.2 and 0.2 mg/L as reported by **(FAO, 1992 and National Academy of Science-National Academy of Engineering, 1973)**. This was true even for the BBD water and the water of the sedimentation basin outlet. However, the secondary treatments contributed to more reduction in concentrations of these heavy metals.

Table (5) show concentrations of Fe , Mn ,Zn ,Pb ,Cu , Ni, and Cd under the different wetland systems i.e. free water surface (FWS) at the different studied discharges i.e. 1250,2500 and 5000 m^3/day beside the different cultivated plants i.e. cattail, papyrus and reed plant . The maximum values of removal were attained due to the treatments Q1R, for Fe , Mn ,Zn ,Pb ,Cu , Ni, and Cd , while the minimum ones were achieved due to the treatments Q3C . For, Zn, Pb, Cu, Ni, and Cd while the minimum value of removal of the Mn was attained due to the treatment Q3P.

3f. Total Coliform (TC)



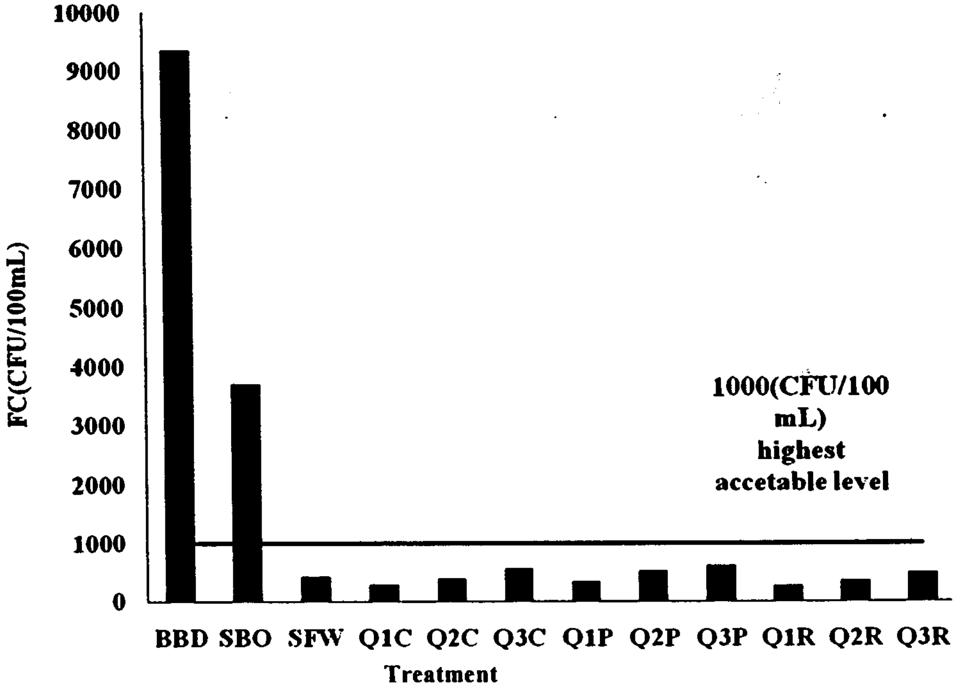
See footnote of Fig. (3)

Fig (14) TC concentration under different treatments.

Fig. (14) reveals that the sedimentation basin could reduce values of TC at BBD water effectively. However, those values remained far higher than the permissible limit which is 5000 CFU/100mL. **(FAO, 1992 and National Academy of Science-National Academy of Engineering , 1973).**

The different wetland systems regardless of the water discharge and type of the cultivated plant could reduce concentrations of TC to values less than the above mentioned highest permissible level.

3g. Fecal Coliform (FC)



See footnote of Fig. (3)

Fig (15): FC concentration under different treatment systems.

Fig.(15) illustrates that count of FC of BBD water exceeded highly the highest permissible count of FC in water to be used for irrigation which is 1000 CUF/100mL according to **NAWQAM (2007)** .The sedimentation basin could reduce this count but to levels still higher than the permissible one . Regardless of the wetland system or the water discharge and type of the cultivated plant, all the studied treatments succeeded to reduce count of the FC to less the 1000 CFU/100mL. However, very few differences could be observed among the different treatments.

4.CONCOLUSION

The results showed that the highest removal efficiencies for TSS were achieved owing to the treatment Q1R, however, all the other treatments could reduce level of TSS to less than the acceptable one. BOD was reduced and the effects seemed to be highest with the SFW and Q1R treatments. The treatments SFW and Q1R showed also the highest removal values of TN and TP, respectively.

However, it is worthy to indicate that the initial concentration of TP at the intake of BBD water was lower than the permissible level. Also, the heavy metals contents at the intake of BBD were less than the permissible ones. However, all the treatments could reduce these metal concentrations to lower values.

Regardless of the wetland system, water discharge or cultivated plant, all the treatments were efficient in reducing the count of FC to values less than highest permissible level.

Finally it can be concluded that using either of the studied discharge is dependent on the required levels of the pollutants present in the treated wastewater, which means it would be preferred to use the lowest discharge if the required concentration of a contaminant is low. On the other hand , the highest discharge would be preferable if high amounts of wastewater are available, and at the same time, this discharge provides concentrations of the different pollutants below the highest permissible ones.

Regarding to the different studied plants, it was proved that the reed plant showed the highest removal efficiency of all the pollutants.

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الملخص العربى

تحسين آداء الأراضي الرطبة المشيدة لخفض مستويات التلوث في مصرف بحر البقر، شمال شرق مصر

يعاد استخدام مياه الصرف هذه الايام لسد الفجوة بين كمية المياه المتاحة و الكمية المطلوبة. وتهدف الأراضى الرطبة المشيدة (سواء السطحية أو تحت السطحية) من بين العديد من الأهداف الى تحسين نوعية المياه العادمة . و بالرغم من أن تصرف المياه الخارجة من هذه الأراضى الرطبة المشيدة و الموصى بها ٢٥٠٠ م٣ / يوم قد استطاع تخفيض الملوثات فى المياه العادمة، الا أنه قد يكون من الضرورة زيادة هذا التصرف لسد المتطلبات الزائدة على المياه . وحيث أن كفاءة الأراضى الرطبة المشيدة فى ازالة الملوثات تعتمد (ضمن العديد من العوامل الأخرى)

على نوع النبات المستخدم فى الخلايا السطحية للأراضى الرطبة المشيدة فان تجربة أنواع أخرى من النباتات بخلاف نبات البوص المعتاد استخدامه قد يكون أكثر أثرا.

ولذلك أجرى هذا البحث بهدف تقييم أداء الأراضى الرطبة المشيدة سواء سطحية أو تحت سطحية فى ظل معدل تصرف أقل (١٢٥٠ م^{٣}/يوم) و أعلى (٥٠٠٠م^{٣}/يوم) من المعدل المعتاد استخدامه (٢٥٠٠ م^{٣}/ يوم) لتوفير مستويات أكثر قبولا من الملوثات أو كميات أكثر من المياه المعالجة بجانب استخدام نباتى ذيل القط و البردى فى الخلايا السطحية للمقارنة مع نبات البوص المعتاد استخدامه.

وقد بينت النتائج أن المواد الصلبة العالقة أمكن خفضها الى أدنى مستوى لها نتيجة استخدام الأراضى الرطبة المشيدة التحت سطحية و مع ذلك فان جميع المعاملات الأخرى نجحت فى خفض نسبة المواد الصلبة العالقة الى ما دون المستوى المسموح به . أيضا فان الأراضى الرطبة المشيدة كانت الأكثر أثرا فى خفض كمية الأكسجين المستهلك الحيوى و النتروجين الكلى و الفسفور الكلى، و مع ذلك يجدر ذكر أن تركيز الفوسفور الكلى فى المياه العادمه عند مأخذ بحر البقر كان أقل من الحدود المسموح بها .

ونفس الشىء صحيح بالنسبة للعناصر الثقيلة التى كان مستوى كل منها فى المياه العادمة أقل من الحدود القصوى المسموح بها لكل منها و مع ذلك فان كل المعاملات قد ساهمت الى حد كبير فى تخفيض مستويات هذه العناصر .

أوضحت النتائج أيضا أنه بغض النظر عن نوع الأرضى الرطبة المشيدة أو نوع النبات المزروع فى خلاياها فان كل المعاملات تحت الدراسة استطاعت تقليص عدد البكتريا البرازية الى مستويات أقل من تلك المسموح بها .

وفى النهاية يمكن استنتاج أن أستخدام أى من التصرفات فى الأراضى الرطبة المشيدة يعتمد على المستوى المطلوب من الملوثات فى هذه المياه، بمعنى أنه قد يكون من الأفضل استخدام الحد الأدنى من التصرف اذا كان المستوى المطلوب من الملوثات صغير جدا. أو على الجانب الآخر قد يكون من المفضل استخدام الحد الأقصى من التصرف فى حالة تيسر كميه كبيرة من المياه العادمه فى نفس الوقت يسمح هذا التصرف بخفض مستويات التلوث فى هذه المياه الى ما دون الحدود القصوى المسموح بها وفيما يخص نباتات الخلايا السطحية فقد أمكن أثبات أفضلية البوص عن النباتين الأخرين .