EFFECTIVE NATURAL WASTEWATER TREATMENT SYSTEMS IN RURAL AREAS OF EGYPT

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Abstract

The countries of the Middle East and North Africa region have 5% of the world's population but have less than 1% of the world's renewable fresh water. The region is the driest in the world and poorly endowed with natural freshwater supplies. The main source of water for Egypt is the Nile River, which represents 97% of the country's freshwater. The annual per-capita water availability in 1960 was about 1550 m^3 and has fallen by 40% to about 995 m^3 today and expected to be about 600 m^3 in 2025.

Wastewater treatment in the Egyptian rural areas lags far behind potable water supply. The vast majority of the Egyptian population receives piped potable water, however only urban centers and some larger rural villages possess wastewater treatment facilities. Economics of scale make conventional wastewater treatment cost prohibitive in smaller more dispersed rural settlements. Domestic wastewater is typically discharged directly or indirectly to drainage canals. This practice has contributed to widespread degradation of drainage water quality and, so, the reuse of drainage water plans in Egypt.

Several treatment alternatives that vary in efficiency and cost are available. The natural wastewater treatment requires relatively low capital investment when flat land is available at reasonable price. They are easily maintained, and they can adsorb shock loads. All these features plus the ability to markedly reduce BOD, nutrients, and pathogen concentrations, have made these alternatives very attractive for rural communities particularly in tropical countries.

One of the key elements impacting the in-stream wetland biological treatment efficiency is the used vegetation type. Pilot studies in the Nile Delta drain system were conducted to demonstrate the technical feasibility of the in-stream study and to define the most appropriate vegetation type for the Egyptian environment. Three vegetation species were tested including Cyperus Rotundus, Phragnites Australis and Eichhornia Crassipes (Water Hyacinth). Short-term intensive monitoring scheme was conducted covering three months of April to June 2003.

The study shows that the performance of the studied aquatic species varies in narrow range from 29% to 37% and within the expected treatment efficiency for hydraulic detention below one day. The overall efficiency of the in-stream wetland including sedimentation zone can reach up to 40%, 45% and 50% for Eichhornia Crassipes, Cyperus Rotundus and Phragnites Australis respectively. Those values can reach 75%, 80% and 85% for four days detention time. The performance of the in-steam wetland treatment system under Egyptian condition is expected to

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be equivalent to the primary to secondary conventional treatment and based on the designed detention time and aquatic species used.

1. Introduction

In Egypt, drainage water is actually a combination of agricultural drainage water, industrial effluents, and sewage water with different ratios. Agricultural land drainage is and will continue to be a vital and necessary component of agricultural production systems. Due to scarcity of water resources, drainage water is being reused. Currently about 5.5 Billion Cubic Meters (BCM) of drainage water are being reused after mixing with fresh water. This amount is expected to increase up to 9.6 BCM by the year 2017. Another form of reuse is being carried out where drainage water is reused without mixing with irrigation water. 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 the national and international water quality standards and guidelines.

Identifying appropriate treatment options for improving drainage water quality has a high priority since villages without sanitation facilities can be expected to continue discharging their sewage to near by agricultural drains. Contamination of drainage water by untreated domestic sewage negatively impacts human health of downstream users and limits drainage water reuse.

The objective of this paper is to investigate the potentiality of the in-stream wetland treatment system as the most appropriate natural treatment systems that can be used in rural areas of Egypt. The treatment process and governing equations simulating the treatment process and design criteria is presented as well.

2. Conventional Treatment versus Natural Treatment System

The ideal system should satisfy the following criteria as indicated USEPA, 1992:

- Health criteria: Pathogenic organisms should not be spread either by direct contact with sewage or indirectly via soil water or food. The treatment chosen should achieve a high degree of pathogen destruction.
- Reuse criteria: the treatment process should yield a safe product for reuse, preferably in aquaculture and agriculture.
- Ecological criteria: in those cases when the wastewater cannot be reused, the discharge of effluent into surface water should not exceed the self-purification capacity of the recipient water.
- Nuisance criteria: the degree of odor release must be below the nuisance threshold. No part of the system should become aesthetically offence.
- Cultural criteria: the methods chosen for wastewater collection, treatment and reuse should be compatible with local habits and social practice.
- Operational criteria: The skills required for the routine operation and maintenance of the system components must be available locally or are such that they can be acquired with only minimum training.
- Cost Criteria: Capital and running costs must not exceed the community's ability to pay. The financial return from reuse schemes is an important factor in this regard.

Feature of conventional treatment

The conventional treatment system is good for urban areas and big cities since it does not need large space to put the wastewater treatment units. The detention time needed to implement the treatment processes is short if compared with other non-conventional treatment systems. The main disadvantage of the conventional treatment is the design and construction high cost plus the following items:

- Operation and maintenance of conventional wastewater treatment relies heavily on electrical machinery pumps, sludge scrapers, aerators that require considerable skills in installation, operation and maintenance.
- Odor in hot climate sewage can quickly become smelly if sufficient oxygen is not made available to prevent the onset of anaerobic conditions.
- Fecal coliform reduction is relatively low comparing with natural systems because of the short detention time.

Features of the natural treatment systems

Using the Natural Treatment Systems for Wastewater has several advantages, among them:

- Treatment efficiency is high, especially biological load treatment.
- Required relatively low capital investment if flat land is available at reasonable price.
- Easy operation and maintenance
- Suitability for hot climate

If land is not available, especially if the site located inside an attraction area or administration zone inside large cities, the natural treatment system would be very expensive and infeasible. In addition, the detention time needed for complete treatment in natural system is relatively long if compared with the conventional treatment systems.

3. In-stream Wetland System

Performance expectation

Wetland system can reduce high levels of BOD, suspended solids and nitrogen as well as significant levels of metals; trace organic and pathogens [Wetzel, 1993]. The removal of settable organic is very rapid in all wetland systems and is due to the quiescent conditions in the free water surface types and to deposition and filtration in the vegetated submerged bed VSB systems. Similar results have been observed with the over flow OF systems where close to 50% of the applied BOD is removed in the first few meters of travel down the treatment slope, see Table (1) [Mitsch, 1993].

Table (1): The expected performance of the wetland systems [Mitsch, 1988]

Parameter	Inflow	Outflow	%Removal
TSS mg/l	130	21	84
BOD mg/l	40	17	57
COD mg/l	200	92	54
Total P mg/l	5	2.5	50
Total N mg/l	12	5	58
NH4-N mg/l	10	5	50
FC MPN/100ml	$3*10^5$	$3*10^4$	One order

Main Elements of a Typical In-stream Wetland Treatment System

Figure (2) illustrates a typical in-stream wetland treatment system which consists of the following elements [Harza, 2000]:

- Sedimentation zone to reduce suspended matter load
- Two aquatic plant zones to enhance biological treatment process
- Number of submerged berms (two to three) to mange the detention time required for treatment
- Floating vegetation barriers (two to three) to avoid weed and vegetation spreading
- Control weir to manage the treated effluent discharge

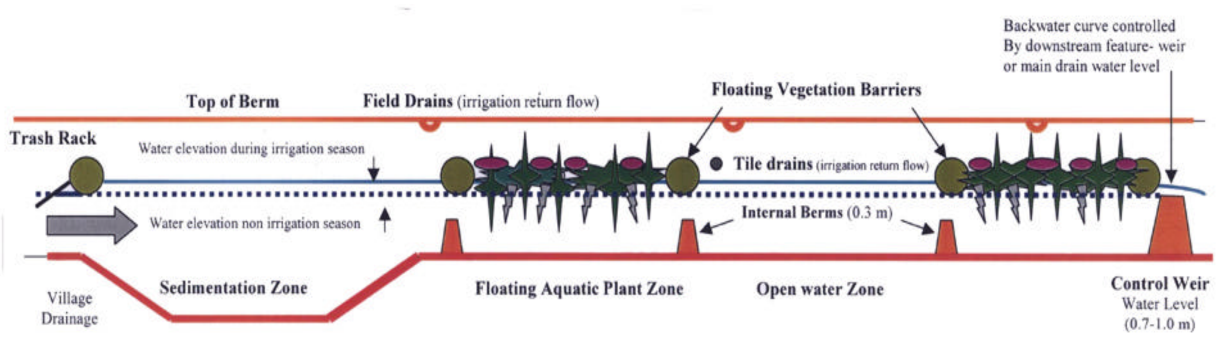


Figure (1): Profile view of an in-stream wetland treatment system

4. In-stream Wetland Design Criteria

Organic waste removal and land requirement

The design equation of wetland systems considers the environmental conditions especially the evapo-transpiration losses since it affects on the large surface area of the basin. Also, filter media condition is taken into consideration. Therefore, the equations would be as mentioned in [Reed et al., 1988] as follows

$$\frac{C_e}{C_i} = 0.52 \exp\left[-\frac{0.7 K_t (A_v)^{1.75} L W d n}{Q}\right] \qquad (1)$$

$$K_t = 0.0057 (1.1)^{T-20} \qquad (2)$$

Where:

C_e = effluent BOD (mg/l)

C_i = influent BOD (mg/l)

K_t = the rate constant at water temperature (day^{-1})

A_v = specific surface area for for microbial activity (m^2/m^3)

n = porosity of system (decimal fraction)

L = length of pond at surface water (m)

W = width of pond at surface water (m)
d = Depth of the pond (m)

When the bed slope or hydraulic gradient is equal to 1 percent or greater it is necessary to adjust the equation to [Bingham, 1994]

$$\frac{C_e}{C_i} = 0.52 \exp\left[- \frac{0.7\, K_t\, (A_v)^{1.75}\, L W\, d\, n}{4.63\, s^{1/3}\, Q}\right] \qquad (3)$$

The next assumptions will be used as design criteria for the free water surface wetlands:

- The specific surface area (A_v) for attached microbial growth = 15.7 m^2/m^3
- Porosity (n) of wetland flow path = 0.75
- Aspect ratio (L/W) > 10:1
- Water depth in warm months < 10 Cm and in cool months < 45 Cm

Then the hydraulic residence time will be as follows:

$$t = \frac{(\ln C_i - \ln C_e) - 0.6539}{65\, K_t} \qquad (4)$$

If the bed slope or hydraulic gradient is equal to 1 percent then

$$t = \frac{(\ln C_i - \ln C_e) - 0.6539}{301\, s^{1/3}\, K_t} \qquad (5)$$

The surface area of the wetland is given by

$$A = \frac{Q\, (\ln C_i - \ln C_e - 0.6539)}{65\, K_t\, d} \qquad (6)$$

And if the bed slope or hydraulic gradient is equal to 1 percent then

$$A = \frac{Q\, (\ln C_i - \ln C_e - 0.6539)}{301\, s^{1/3}\, K_t\, d} \qquad (7)$$

Pathogen removal

Pathogen removal in many wetland systems is due to essentially the same factors as in facultative pond systems. Equation (7) can be used to estimate the removal of bacteria and virus in wetland systems where the water path is above the surface. Although the detention time is less in constructed wetlands as compared with ponds, the opportunities for adsorption and filtration will be greater. [Johnston, 1993]

Suspended solids removal

Suspended solids removal is very effective in both types of constructed wetlands. Most of the removal occurs with in the few meters beyond the inlet, owing to the quiescent conditions and the shallow depth of liquid in the system [Reed et al., 1988]

Nitrogen removal

Nitrogen removal is very effective in both the free water surfaces, submerged flow constructed wetlands, and the major removal mechanisms are similar for both. Although plant uptake of nitrogen does occur, only a minor fraction of the total nitrogen can be removed in this system. [Reed et al., 1988]. The major contribution to nitrogen removal, as with the hyacinth systems, is believed to result from nitrification/denitrification. [Hammer, 1990]. In constructed wetlands, nitrogen removal ranges between 25-85 percent. Reed stated that the total nitrogen removal is up to 79 percent at nitrogen loading rates up to 44Kg/(ha. day) in a variety of wetland systems.

5. Pilot Study in the Nile Delta of Egypt

Study outline

One of the key elements impacting the in-stream wetland biological treatment efficiency is the used vegetation type. Pilot study in the Nile Delta drain system was conducted to:

- demonstrate the technical feasibility of the in-stream study
- define the most appropriate vegetation type for the Egyptian environment to be used in the in-stream treatment system

Further, certain performance and design attributes can be evaluated and enhanced in the proposed demonstration study to be incorporated into a full-scale implementation. A preliminary survey was done on three plant species, which are:

- Emerged plant : Cyperus Rotundus and Phragnites Australis
- Floating plant : Eichhornia Crassipes (Water Hyacinth)

Three polluted tributary drains by domestic wastes were selected where they have mostly the same physical, hydraulic and water quality characteristics and each of them were covered by one of the concerned vegetation (dominant). The following table illustrates the characteristics of the studied drains.

Table (2): Physical and hydraulic characteristics of the studied drains

Drain	Studied Reach Length (Km)	Average width (m)	Flow m^3/day	Detention time (Day)	Dominant Species
D1	4.5	3.2	4,320	0.67	Cyperus Rotundus
D2	3.75	3.0	5,120	0.61	Phragnites Australis
D3	4.2	3.5	4,890	0.59	Eichhornia Crassipes

Short term monitoring scheme

Short term monitoring scheme was conducted covering three months of April to June 2003. Water sampling frequency was adopted to be three time a month and in total nine samples were collected for each monitor sites. For each monitor drain, two sampling sites were defined; one site upstream the concerned reach and the other site downstream the reach.

Biological Oxygen Demand (BOD_5) was used as an indicator for removal performance assessment for the three selected species. BOD was analyzed using ORION BOD fast respirometry system model 890 with a measuring range 0 to 4000 mg/l at 20 ^oC incubation in a thermostatic incubator chamber model WTW.

Species performance analysis and assessment

The overall in-stream wetland treatment efficiency varies between 60% to 85% based on the designed detention time and the sedimentation zone. Normally, the minimum detention time can be define as four days and the sedimentation zone can contribute to about 25% to 30% of the overall treatment efficiency. So, it is expected that the performance of the concerned species can varied between 25% to 35% where in nature the detention time in drain almost below a day and no sedimentation zone was constructed. Following is the performance assessment of the concerned vegetation species.

Cyperus Rotundus

The average BOD influent and effluent concentrations are 86 mg/l and 58 mg/l respectively as shown in Figure (2) with an average BOD removal of Cyperus Rotundus is about 32%.

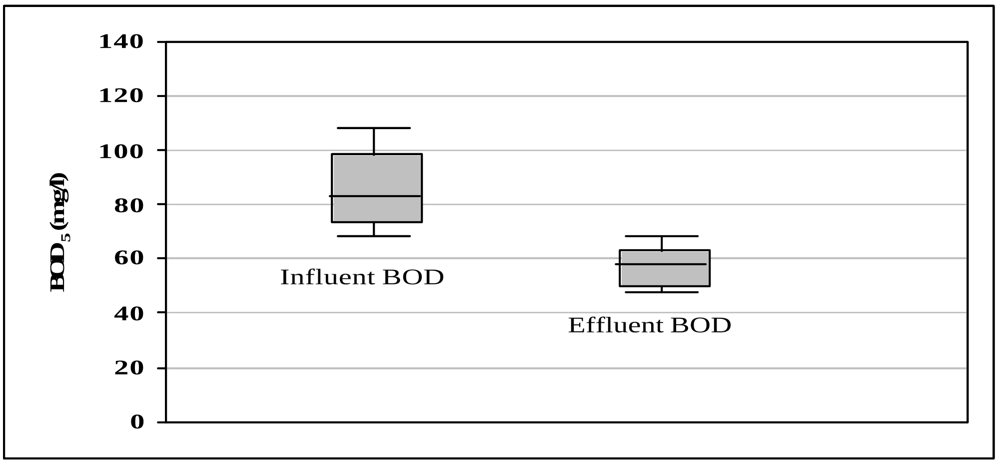


Figure (2): Box Whisker Plot for BOD concentrations of Cyperus Rotundus case

Phragnites Australis

The average BOD influent and effluent concentrations are 88 mg/l and 55 mg/l respectively as shown in Figure (3) with an average BOD removal of Phragnites Australis is about 37%

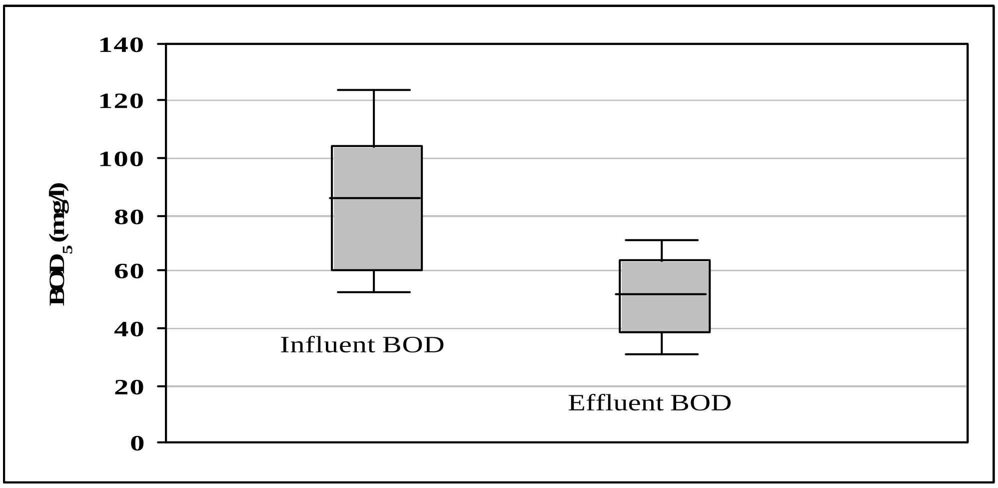


Figure (3): Box Whisker Plot for BOD concentrations of Phragnites Australis case

Eichhornia Crassipes

The average BOD influent and effluent concentrations are 102 mg/l and 71 mg/l respectively as shown in Figure (4) with an average BOD removal of Eichhornia Crassipes is about 29%

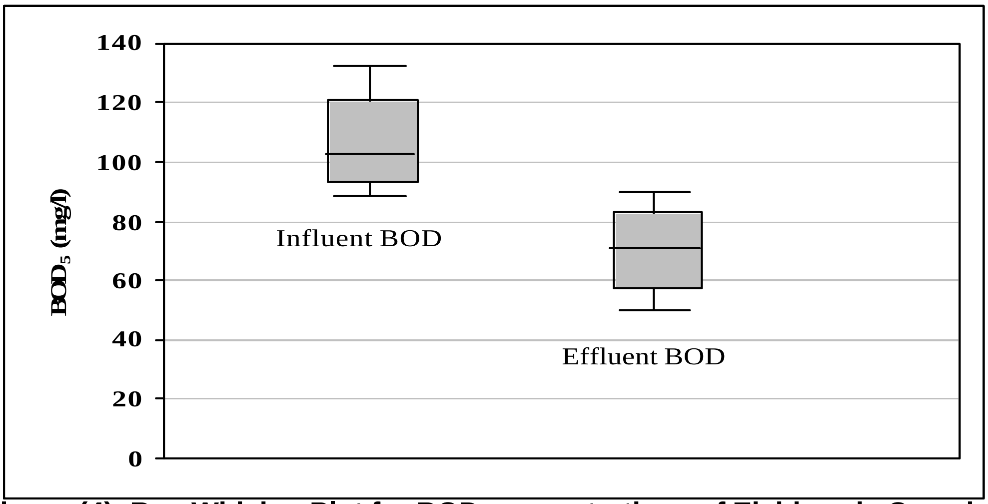


Figure (4): Box Whisker Plot for BOD concentrations of Eichhornia Crassipes case

It can be concluded from the above analysis that the performance of the studied aquatic species varies in narrow range as presented in the following Table.

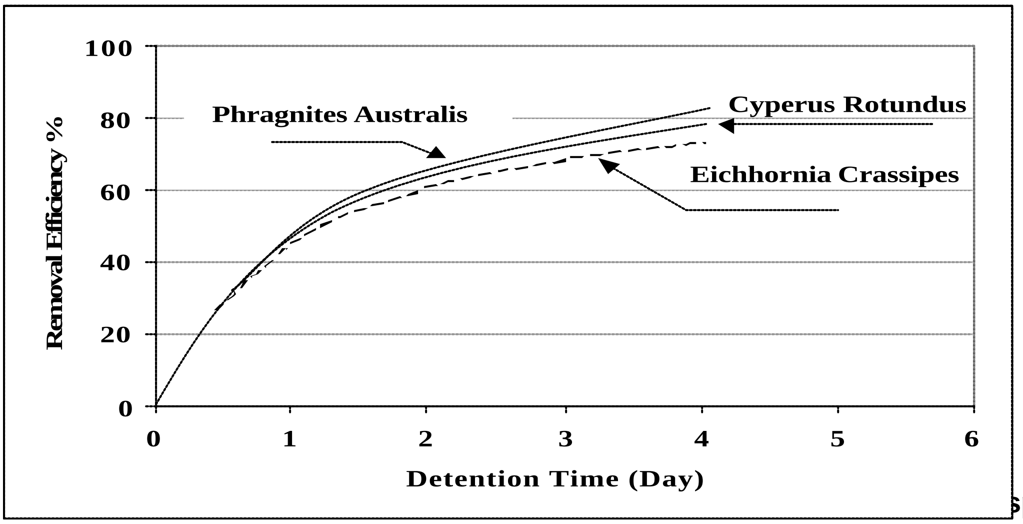
Table (3): Summary of aquatic species removal efficiency for BOD

Dominant Species	Detention time (Day)	Removal Efficiency %
Phragnites Australis	0.61	37
Cyperus Rotundus	0.67	32
Eichhornia Crassipes	0.59	29
Average	0.62	33

Expected performance for a full scale study

The following figure illustrates the expected performance of the in-steam wetland treatment system for a full-scale system considering the three studied aquatic species, which requires the following:

- a sedimentation zone with detention time of half day
- floating aquatic zones with detention time varies between one to four days



species

Figure (5) shows that, in case of detention time one day, the overall efficiency of the in-stream wetland can reach up to 40%, 45% and 50% for Eichhornia Crassipes, Cyperus Rotundus and Phragnites Australis respectively. Those values can reach 75%, 80% and 85% for four days detention time.

The performance of the in-steam wetland treatment system under Egyptian condition is equivalent to the primary to secondary conventional treatment and based on the designed detention time and aquatic species used.

6. Conclusions and Recommendations

The sanitation facilities of Egyptian rural areas are facing lags far behind potable water supply. Economics of scale make conventional wastewater treatment cost prohibitive in smaller more dispersed rural settlements. Domestic wastewater is typically discharged directly or indirectly to drainage canals. This practice has contributed to widespread degradation of drainage water quality and, so, the reuse of drainage water plans in Egypt.

Identifying appropriate treatment options for improving drainage water quality has a high priority since villages without sanitation facilities can be expected to continue discharging their sewage to near by agricultural drains and contamination of drainage water by untreated domestic sewage negatively impacts human health of downstream users and limits drainage water reuse.

Several treatment alternatives that vary in efficiency and cost are available. In general, the advantages of using natural biological processes relate to their "low-tech/no-tech" nature, which means that these systems are relatively easy to construct and operate, and to their low cost, which makes them attractive to communities with limited budgets. However, their simplicity and low cost may be deceptive in that the systems require frequent inspections and constant maintenance to ensure smooth operation. Concerns include hydraulic overloading, excessive plant growth, and loss of exotic plants to natural watercourses. In-stream wetland treatment system has additional advantage that it requires limited land where the treatment process takes place inside the drain.

One of the key elements impacting the in-stream wetland biological treatment efficiency is the used vegetation type. Pilot studies in the Nile Delta drain system were conducted to demonstrate the technical feasibility of the in-stream study and to define the most appropriate vegetation type for the Egyptian environment. Three vegetation species were tested including Emerged plant Cyperus Rotundus, Phragnites Australis and Eichhornia Crassipes (Water Hyacinth). Short-term intensive monitoring scheme was conducted covering three months of April to June 2003.

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The performance of the in-steam wetland treatment system under Egyptian condition is expected to be equivalent to the primary to secondary conventional treatment and based on the designed detention time and aquatic species used.

It is recommended to conduct a full pilot scale in-stream wetland treatment system to be able to design the system under the Egyptian conditions. To minimize the failure risk, three elements should be considered; public acceptance and participation, dredging management of sediments and vegetation control.

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