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Effectiveness of Short-Deep Treatment Beds for Biological Management of Domestic Wastewater

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ABSTRACT

Biological treatment of domestic wastewater using constructed wetlands is gaining acceptance worldwide due to low cost and simple operation and maintenance. A treatment system (BIOWATSYST) was established at Abo-Attwa Experimental Station, Ismailia, Egypt in 1998. The system consists of six parallel short-deep treatment beds, three sterilization ponds and a disinfection pond. The beds were filled with gravel and/or sand. Four beds were planted with *Phragmites australis* and two beds were planted with *Cyprus papyrus*. The study evaluates the performance of the treatment beds for the removal of nutrients and pathogens from primary treated domestic wastewater, with minimizing the length of the treatment beds. Maximum removal efficiency was 76.3% for the biochemical oxygen demand, 83.9% for chemical oxygen demand, 59.2% for total suspended solids, 58.6% for organic matter, and 22.1% for the total nitrogen. Maximum removal efficiency was 82.6% for fecal coliforms, 79.8% for fecal enterococci, and 87.4% for the coliphages. The results revealed that sand bed was the most effective treatment bed for the removal of both nutrient and pathogenic bacteria from primary treated domestic wastewater.

Key words: Constructed wetland, *Cyprus papyrus*, *Phragmites australis*, physicochemical monitoring, sewage, wastewater, biological management, treatment beds.

INTRODUCTION

There is an increasing need for developing low cost and energy saving wastewater treatment systems suited to rural areas (Dewedar *et al*., 1995; Vaillant *et al*., 2003). Recently, considerable attention has been directed toward constructed wetlands that are relatively inexpensive to construct and maintain and provide effective wastewater treatment (Cooper, 1999; Philippi *et al*., 1999; Huang *et al*., 2000).

Usage of non-conventional water resources such as treated industrial, agricultural or domestic wastewater is valuable sources of water reuse (Baggi *et al*., 2001). However, highly efficient wastewater treatment systems are required to control the pathogens present in the wastewater, convert the waste materials into stable oxidized end products, and recycle the valuable components of the wastewater. Thus, treated effluents can be safely discharged to inland or coastal waters or reused for irrigation (Senzia *et al.*, 2003).

Constructed wetlands are engineered systems that have been designed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial biofilms to assist in treating wastewater (Cooper *et al.,* 1996). Applied research indicated that engineered wetlands significantly reduce suspended solids, oxygen depleting substances, organic matter, nutrients, and most chemical and biological pollutants including hydrocarbons, heavy metals and pathogenic bacteria (Mashauri *et al*., 2000; Dewedar *et al*., 2005). Generally, supporting filling materials, vegetation and microorganisms influence the ability of constructed wetlands to retain or metabolize and degrade constituents contained in the influent, while simultaneously releasing organic matter and other substances into the outflow (Nuttall *et al*., 1997).

Macrophytes such as *Phragmites australis* are common plants that present in natural wetlands, worldwide. *P. australis* is usually planted in the treatment beds in order to contribute to bed stability, release small amounts of oxygen from the roots, influence soil hydraulic conductivity, provide support for microbial attachment and absorb nutrients, heavy metals and other contaminants from the wastewater (Cooper *et al*., 1996; Brix, 1997; Decamp and Warren, 2000).

Gravel Bed Hydroponics (GBH) systems are subsurface horizontal-flow constructed wetlands established at Abu-Attwa, Ismailia, Egypt to treat domestic wastewater (Butler *et al*., 1990). The efficiency of the GBH system in a semi-arid climate like Egypt has been reported (Butler and Dewedar, 1991). GBH technology combines the benefits of aerobic biological filtration with the traditional concept of natural wetlands (Butler and Loveridge, 1991; Bahagat, 1992).

BIOWATSYST has been constructed at Abu-Attwa, Ismailia, Egypt in 1998 in order to overcome the problem of large land area that has been required previously in constructing the GBH treatment beds (50 or 100 m long beds) (Butler and Dewedar, 1991; Hamdy and Sardo, 1999).

The present study aims at investigating the efficiency of different filling materials and depths as well as plant species of short-deep biological treatment beds. The performance of the treatment beds was determined seasonally through monitoring various physicochemical parameters as well as counts of indicator bacteria and coliphages in water samples of the influent and effluents of the beds.

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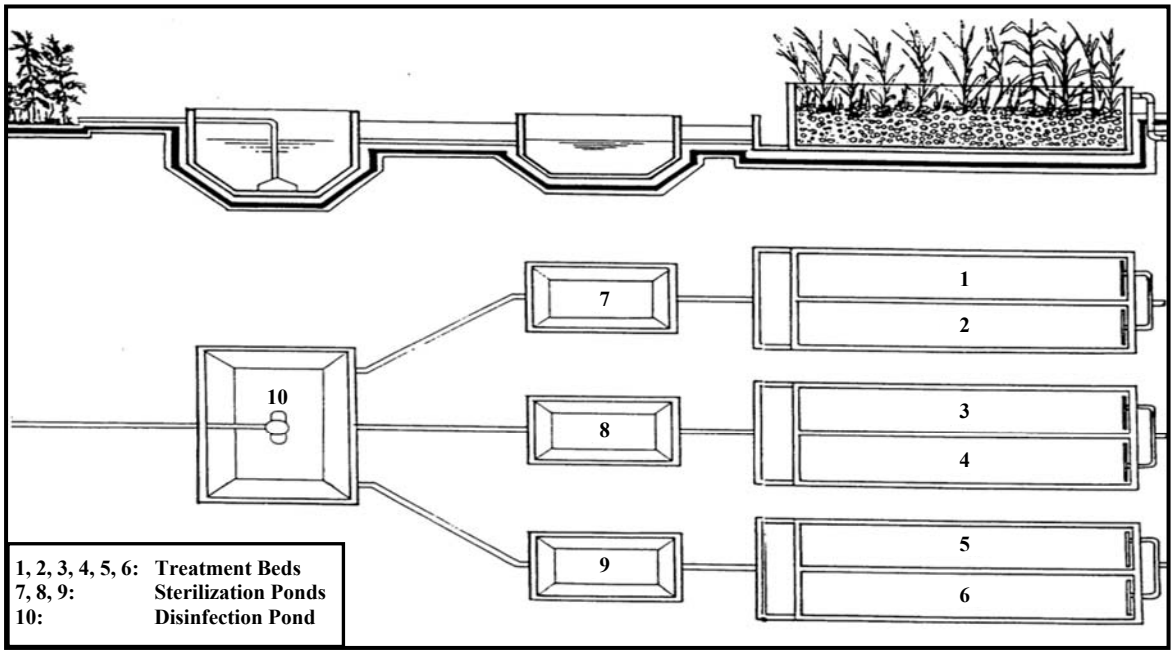

Figure (1): Design of the BIOWATSYST treatment system constructed at Abo-Attwa Station, Ismailia, Egypt. The system has six (1-6) short-deep beds filled with gravel and/ or sand and planted with either *Phragmites australis* or *Cyprus papyrus*. The sterilization ponds 7-9 as well as the final disinfectant pond 10 are not included in the study.

MATERIALS AND METHODS

Wastewater Treatment System

BIOWATSYST is a bological wastewater treatment system established at Abu-Attwa experimental station, Ismailia, Egypt. It was constructed in 1998 for the treatment of primary treated domestic wastewater that has been collected from Ismailia city. Primary treatment at Abu-Attwa experimental station is usually achieved through sedimentation in a large lagoon for 24-48 hours with continuous stirring.

The constructed wetland system (Fig. 1) consists of six-parallel treatment beds, three sterilization ponds and a disinfection pond. Each bed is 20 m length, 2.5 m width, 1.0 m depth, and filled with gravel and/or sand as filling material. The first two beds (G_1 and G_2) were filled with gravel. The gravel depths were 0.3 m and 0.6 m for G_1 and G_2 beds, respectively. The second adjacent beds (S_1 and S_2) were filled with gravel (0.2 m) as bottom layer and top layer of coarse sand. The sand depth in S_1 bed was 0.3 m and in S_2 bed was 0.6 m. The last adjacent beds (GS_1 and GS_2) were filled with gravel (0.2 m depth) as bottom layer followed by coarse sand of 0.2 m depth and top layer of gravel of various depths. The gravel depth in GS_1 bed was 0.3 m and in GS_2 bed was 0.6 m. Beds G_1 and GS_1 were planted with papyrus, *Cyprus papyrus* while other treatment beds were planted with common reed, *Phragmites australis*. Plants were planted every 0.5 m in treatment beds. Aboveground shoot systems produce very dense mass in a short time. Also, plant rhizomes increase in size and produce very thick underground root system in few weeks.

Effluents of the gravel beds (G_1 and G_2), sand beds (S_1 and S_2) and gravel/ sand beds (GS_1 and GS_2) were collected in the sterilization ponds (P_1, P_2 and P_3), respectively. Finally, effluents from the three sterilization ponds were collected in the disinfection pond (P_4). The present study was carried out on five only of the six treatment beds. The sand bed S_2 was excluded as it was clogged more often. The three sterilization ponds and the disinfection pond are not included in this study.

Water samples

Six water samples were collected from the BIOWATSYST seasonally during the period from June 2000 to May 2001. The samples represent the primary treated wastewater (influent) sample and effluents of the five treatment beds. Water samples were collected in two replicates of clean, wide-mouthed, plastic bottles. One bottle was used for physicochemical analyses in which turbulence was carefully avoided. The second bottle was used for microbiological analyses. Samples were stored in an ice box while transported to the laboratory.

Physicochemical analyses

The water quality of both influent and effluents of the treatment beds was monitored through determination of various physicochemical parameters according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1992). The flow rate of the influent feeding the treatment beds was measured regularly and adjusted manually to 10 l/min to achieve a final volume of 9.6 m^3/day. Dissolved oxygen (DO) was measured using an Eil probe connected to a Kent oxygen meter. The probe was calibrated using 5% sodium sulfide solution for zero and fully aerated distilled water for saturation point. The results were expressed as mg O_2/l (APHA, 1992).

The biochemical oxygen demand (BOD_5) is used as a measure of the oxygen that is required for the biochemical degradation of organic material and the oxygen that used to oxidize inorganic material such as sulfides and ferrous iron (APHA, 1992). The BOD_5 was determined from the difference between initial and final DO as follows:

$$\text{BOD (mg/l)} = \frac{(D_1 - D_2) - (B_1 - B_2)\, f}{P}$$

Where, $\boldsymbol{D_1}$ = DO of diluted sample immediately after preparation, mg/l, $\boldsymbol{D_2}$ = DO of diluted sample after 5 days incubation at 20ºC, mg/l, $\boldsymbol{B_1}$ = DO of seed control (blank) before incubation, mg/l, $\boldsymbol{B_2}$ = DO of control (blank) after incubation, mg/l, $\boldsymbol{f}$ = ratio of nutrient solution in sample to seed in control = (% nutrient solution in D_1) / (% seed in B_1), $\boldsymbol{P}$ = decimal volumetric fraction of sample used.

Chemical oxygen demand (COD) was used as the measure of the oxygen equivalent to the organic matter content of a sample that was susceptible to oxidation by a strong chemical oxidant. COD was measured using closed reflux, colorimetric method (APHA, 1992). Closed tubes with digested samples were measured with a spectrophotometer (CECIL, CE2393) at wavelength 600 nm. Five concentrations from potassium hydrogen phthalate solution with COD equivalents from 20 to 900 µg O_2/l were prepared to make the calibration curve. The absorbance was compared with the calibration curve. The Chemical oxygen demand (COD) was calculated from the following formula:

$$\text{COD (mg } O_2\text{/ l)} = \frac{\text{mg } O_2 \text{ in final volume X } 1000}{\text{ml sample}}$$

Organic matter was determined as the volatile solids ignited in a muffle furnace at 550ºC. Ammonia was determined using the titrimetric method after preliminary distillation in a kjeldahl apparatus. The Devard's Alloy reduction technique was used to determine oxidized nitrogen in wastewater samples. Total nitrogen is the sum of oxidized nitrogen and total kjeldahl nitrogen that is determined by the semi-micro-kjeldahl method. Soluble reactive phosphate was measured using the ascorbic acid method (APHA, 1992).

Microbiological analyses

Microbiological analyses were carried out according to the standard methods for the examination of water and wastewater (APHA, 1992). Total viable bacteria (TVB), total coliforms (TC), fecal coliforms (FC) and fecal enterococci (FE) were determined using the pour plate method. Suitable dilutions of the water samples were prepared. Triplicate plates were used for each sample dilution. Plates giving 30-300 cfu/ml were selected to count their colonies.

Coliphages counting

Coliphage counts (pfu/ml) were determined in water samples against *Escrichia coli* strain # NRRL B-3704. The agar-overlay technique has been used for the determination of the coliphage count according to Beishir (1996); Stukus (1997) and Wistreich (1997). Experiments were done three times with three replicates for various treatments.

Statistical analysis

Means and standard errors of the means were calculated for replicate determinations of various parameters monitored in the biological treatment system. Differences among the influent and effluents in physical, chemical and microbiological parameters were analyzed by the analysis of variance test (ANOVA). Statistically significant differences between influent and effluents in nutrients, bacterial indicators and coliphages were assessed at $p \leq 0.05$ using Tukey's test (Zar, 1984; Lentner and Bishop, 1986).

RESULTS

The present study was carried out on five different BIOWATSYST treatment beds. Seasonal variation of physical, chemical and microbiological parameters was studied from June 2000 to May 2001 to evaluate the performance of short-deep beds for treating domestic wastewater. Also, counts of coliphages were traced seasonally in influent and effluents of various treatment beds of the system. The filling materials of the beds (Gravel, sand or gravel/sand) and the efficiency of two different wetland plants were evaluated.

The DO values of the influent ranged from 0 to 0.7 mg/l throughout the study period (Fig. 2A). Generally, the DO values of the effluents in all beds were slightly higher than influent during different seasons of the study as shown in Figure (2A). The differences in DO between influent and effluents were statistically significant ($p = 0.03$).

Seasonal variation of physicochemical parameters

(a) Biochemical and chemical oxygen demand

The BOD_5 values of the influent ranged from 122.6 to 171.0 mg/l throughout the study period. The mean BOD_5 value of the influent was 132.9 mg/l in summer, which was slightly higher during autumn (Fig. 2B). The lowest value (129.9 mg/l) throughout the study period was recorded in winter followed by the highest reading (162.2 mg/l) in spring. The effluent of the sand bed (S_1) showed the highest reduction (76.3%) in the BOD_5 values where the percentage removal of G_1, G_2, GS_1, and GS_2 effluents was in the range of 60.0-66.6% (Fig. 2D).

The COD values of influent ranged from 520.0 to 855.0 mg/l throughout the study period. The highest COD mean value (843.7 mg/l) was recorded in winter (Fig. 2C). The lowest COD value (532.5 mg/l) was recorded in spring. Figure (2D) showed a great reduction in COD

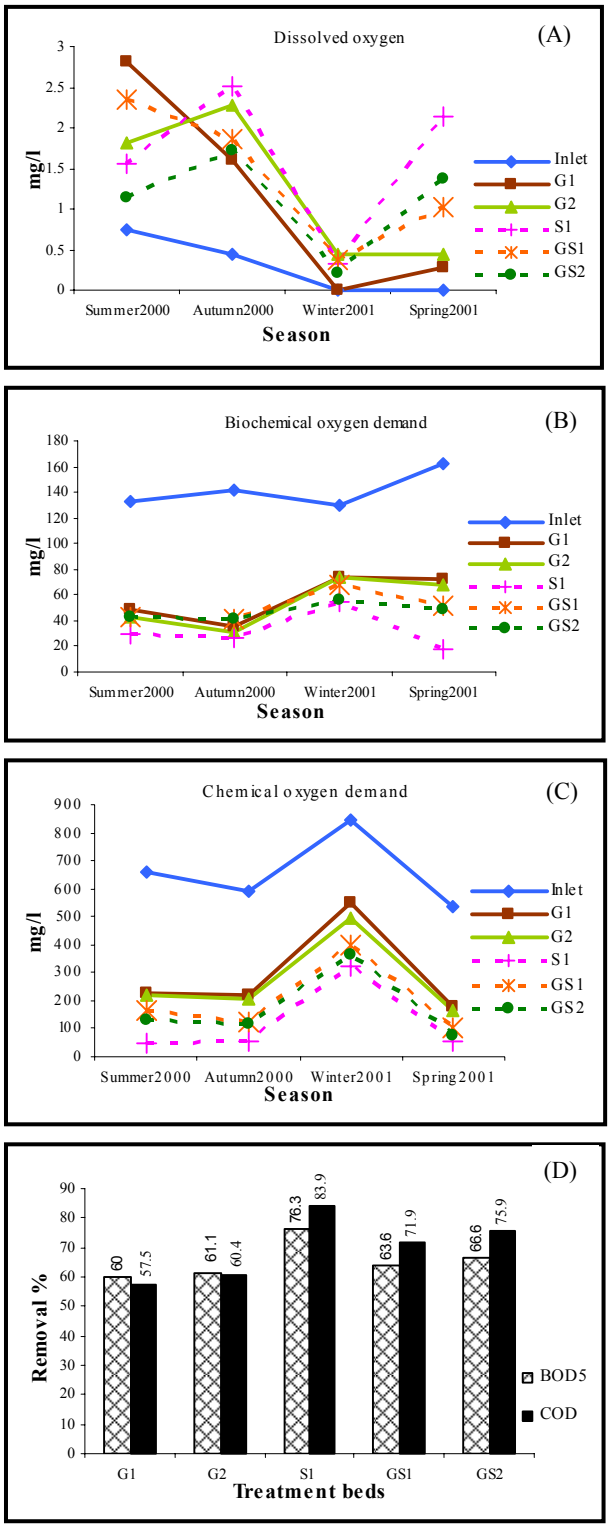

Figure (2): Seasonal variation of (A) Dissolved oxygen, (B) Biochemical oxygen demand, (C) Chemical oxygen demand (mg/l) monitored in water samples collected from the short-deep treatment beds during the study period and (D) Biochemical oxygen demand (BOD_5) and Chemical oxygen demand (COD).

values of the effluents. The analysis of variance detected a high significant difference between the influent and the effluents (p = 0.000) for COD values (Table 1). The sand bed (S_1) showed high reduction efficiency (83.9%) followed by the gravel/sand beds (GS_2 and GS_1), where their percentage removals were 75.9 and 71.9%, respectively. The gravel beds (G_2 and G_1) showed lower reduction efficiencies (60.4, and 57.5 %), respectively (Fig. 2D).

Table (1): Analysis of variance (ANOVA) summary table for some selected physicochemical parameters monitored in BIOWATSYST treatment beds in different seasons

Parameter	Influent & effluents		Season	
	F-value	*p*-value	F-value	*p*-value
BOD (mg/l)	111.83	< 0.001	2.05	0.1130
COD (mg/l)	35.48	< 0.001	14.85	< 0.001
TSS (mg/l)	32.22	< 0.001	5.68	0.0013
TDS (mg/l)	38.05	< 0.001	5.40	0.0018
Organic matter (mg/l)	36.24	< 0.001	3.58	0.0169
Total nitrogen (mg/l)	4.32	0.0014	9.18	< 0.001
Total phosphorus (mg/l)	0.22	0.9518	222.79	< 0.001

(b) Total suspended and dissolved solids

Total suspended solids (TSS) of the influent ranged from 24 to 75 mg/l throughout the study. In summer, the mean TSS values of the influent were 53.2 mg/l, while some increase was observed in autumn (Fig. 3A). The lowest mean value throughout the study was 30 mg/l in winter and the highest one was 69.2 mg/l in spring. The sand bed (S_1) showed the highest reduction efficiency (60.0%) followed by GS_2 (50.9%) and GS_1 (57.0%) beds. Lower removal efficiency for TSS was recorded from G_1 and G_2 beds (31.5 and 44.4%), respectively (Fig. 3D).

Total dissolved solids (TDS) of the influent ranged from 719.0 to 890.0 mg/l. The highest mean TDS value of the influent during the period of study was 878.0 mg/l in summer and no detectable variations were observed in the other seasons (Fig. 3B). Low percentage removal for the TDS was observed in the treatment system ranging from 7.0 to 23.8 % (Fig. 3D).

(c) Organic matter

The organic matter values of the influent ranged from 22 to 61 mg/l throughout the study period. The mean organic matter value of the influent was 44.5 mg/l in summer and no detectable change was observed in autumn (Fig. 3C). During winter, the lowest mean value was detected (27.5 mg/l). The highest value for organic matter (56.2 mg/l) was recorded in spring. Percentage removals for organic matter were subjected to the filling materials and plant species of the treatment beds as S_1 (58.6%), GS_2 (56.9%), GS_1 (47.5%), G_2 (38.1%) and G_1 (28.2%) (Fig. 3D). The sand bed and gravel/sand beds showed best removal efficiency of the organic matter (47.5–58.6%).

(d) Ammonia, oxidized nitrogen and total nitrogen

Generally, no seasonal variations in ammonia of influent and effluents were recorded. Values of ammonia of the influent ranged between 25.2 and 36.4 mg/l during the study period (Fig. 4A). Best reduction rate of ammonia was recorded from the sand bed S_1 (30.4%).

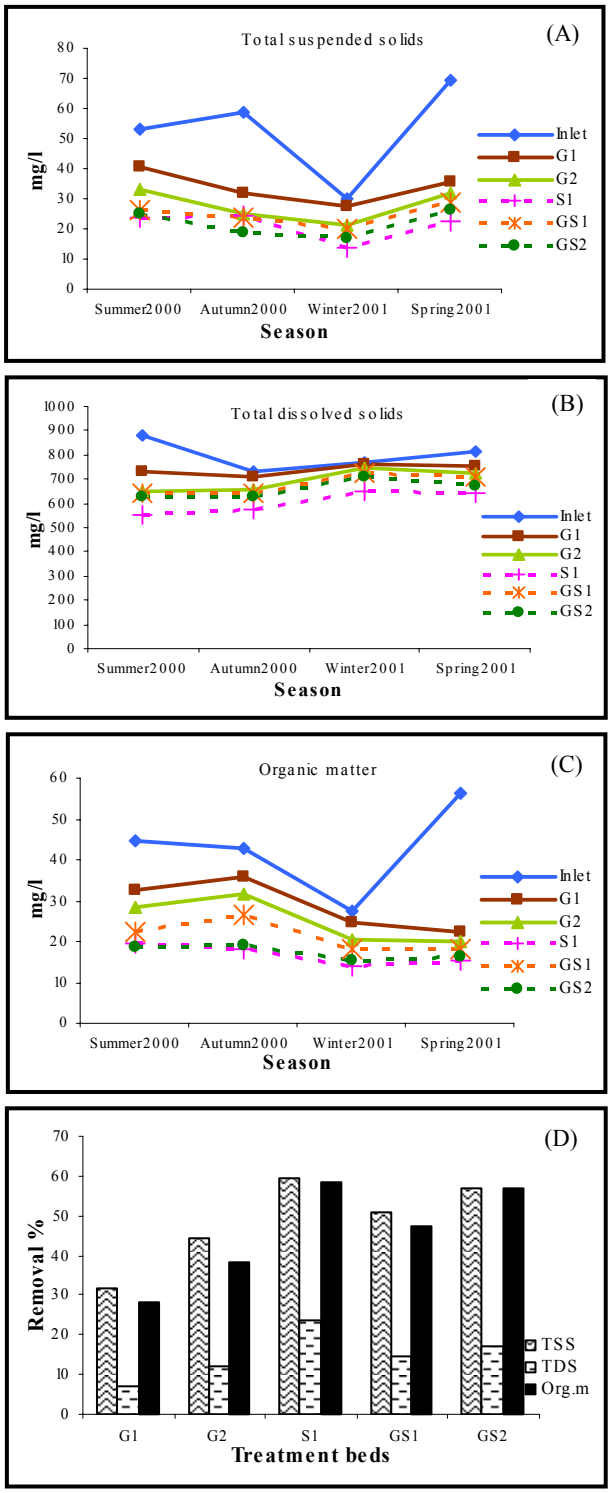

Figure (3): Seasonal variation of (A) Total suspended solids, (B) Total dissolved solids, (C) Organic matter (mg/l) monitored in water samples collected from the short-deep treatment beds during the study period and D) Total suspended solids TSS, Total dissolved solids TDS and Organic matter Orgm)

The oxidized nitrogen of the influent ranged from 0 to 1.4 mg/l throughout the study period. The highest mean value of influent (0.8 mg/l) was recorded in autumn (Fig. 4E). During winter, nitrification rate was neglected. Generally, treatment beds showed very little tendency for nitrification. There were no statistically significant differences between influent and effluents except in the case of effluent of the sand bed (S_1) (Table 1).

Generally, no seasonal variations in the values of total nitrogen of influent and effluents were recorded (Fig. 4C). The total nitrogen values of influent ranged between 28.84 and 40.6 mg/l during the studied four seasons while the effluent readings ranged from 18.2 mg/l in the case of S_1 bed to 40.88 mg/l in the case of GS_2 bed. The total nitrogen removal capacities of the treatment beds were relatively low ranged from 7.8 to 22.1% (Fig. 4E).

(e) Removal efficiency of nutrients

The sand bed S_1 was significantly different from other treatment beds for the removal of BOD_5 (76%), COD (84%), TSS (60%), TDS (24%), organic matter (59%) and ammonia (30%) from primary treated domestic wastewater (Fig. 2D, 3D, 4E). The two gravel/sand beds (GS_1 and GS_2) were significantly different from the gravel bed G_1 for the removal of TSS, TDS and Organic matter (Fig. 3D). It was noticed that the differences in the removal of nutrients from the BIOWATSYST was slightly affected by changes of the plant from papyrus to reed. Filling materials of the treatment beds have more direct effect on nutrient removal. The sand bed and the two gravel/sand beds showed better treatment efficiency for nutrients than gravel beds.

Seasonal variation of indicator bacteria

(a) Total viable bacterial counts

Total viable bacterial counts of the influent ranged from 15 x 10^4 to 141.6 x 10^4 cfu/ml throughout the study period. In summer, mean TVB counts of the influent was 50.38 x 10^4 cfu/ml, while in autumn, it was 18.88 x 10^4 cfu/ml (Fig. 5A). Gradual increase in mean TVB counts of influent was observed in winter and spring giving 71.62 x 10^4 and 129.46 x 10^4 cfu/ml, respectively. The reduction percentage of TVB in the treatment beds was 36.58% in G_1 bed and 45.56% in G_2 bed. On the other hand, the percentage removal of TVB counts was 59.32 and 68.33% in GS_1 and GS_2, respectively. The highest reduction rate (81.05%) of TVB occurs in the sand bed (S_1) (Fig. 5E).

(b) Total coliforms (TC)

Total coliform counts of the influent ranged from 13 x 10^2 to 361.7 x 10^2 cfu/ml throughout the study period. Mean TC counts of the influent were 68.82 x 10^2 cfu/ml in summer. The lowest mean (20.07 x 10^2 cfu/ml) was recorded in autumn. A sharp increase in TC counts was noticed in winter recording the highest mean count (349.1 x 10^2 cfu/ml) in spring (Fig. 5B). Reduction of 30.11% and 44.93% was obtained from G_1 and G_2 beds, respectively (Fig. 4E). Higher rates of reduction were recorded in GS_1 and GS_2 beds (64.2 and 73.6%), respectively. The highest reduction of TC counts was observed in the sand bed S_1 (86.9%).

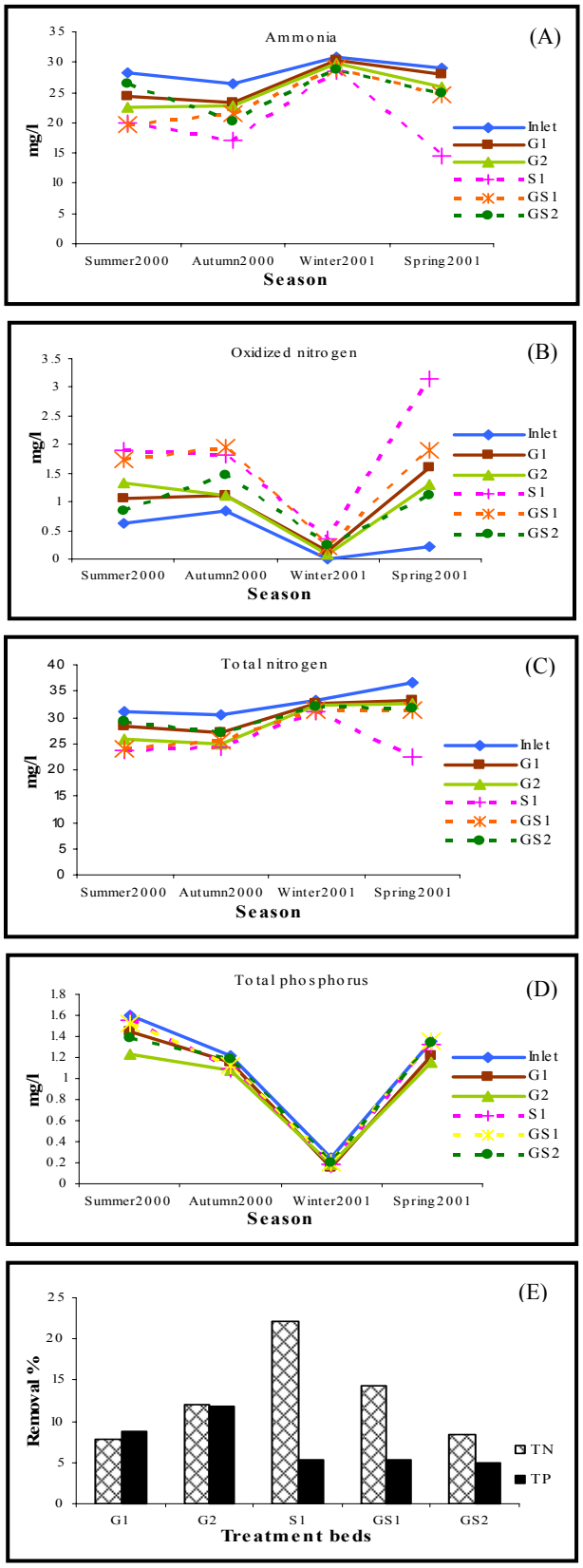

Figure (4): Seasonal variation of different nutrients (A) Ammonia, (B) Oxidized nitrogen, (C) Total nitrogen, (D) Total phosphorus (mg/l) monitored in water samples collected from the short-deep treatment beds during the study period and (E) Total nitrogen and Total phosphorus from the short-deep treatment beds.

(C) Fecal coliforms (FC)

Fecal coliform counts of the influent ranged from 12.6 x 10^2 to 118 x 10^2 cfu/ml throughout the study period. As shown in Figure (5C) the mean FC counts of the influent was 49.25 x 10^2 cfu/ml in summer followed by 16.07 x 10^2 cfu/ml in autumn. In winter, the FC counts were high with mean of 100.1 x 10^2 cfu/ml. The reduction percentage in FC counts was 21.50% in G_1 bed, 42.17% in G_2 bed, 62.49% in GS_1 bed and 69.38% in GS_2 bed. The highest percentage removal was 82.49% in the sand bed (S_1) (Fig. 5E).

(d) Fecal enterococci (FE)

Fecal enterococci counts of the influent ranged from 1 x 10^2 to 61 x 10^2 cfu/ml throughout the study period. The mean FE counts of the influent was 15.88 x 10^2 cfu/ml in summer (Fig. 5D). In winter, the mean counts of FE increased to 48.66 x 10^2 cfu/ml. The highest percentage removal of fecal enterococci 79.79% was observed in S_1 bed followed by that of GS_1 and GS_2 beds (59.07 and 66.71%), respectively (Fig. 5E).

(e) Removal efficiency of bacterial indicators

The efficient reduction rates of the sand bed (S_1) for the removal of bacterial indicators are given in Figure (5E). The analysis of variance test (ANOVA) followed by Tukey's HSD test revealed the efficiency of the sand bed (S_1) for the removal of both total and fecal coliforms and fecal enterococci (Table 2). Also, gravel/sand beds were significantly different than gravel beds in the removal of pathogenic bacterial indicators (Table 2).

(f) Coliphage counts (pfu/ml)

Somatic coliphage counts of the influent ranged from 34.0 x 10 to 225 x 10 pfu/ml during the period of study. High mean coliphage counts of the influent was observed in winter and spring (197.5 x 10 and 215.0 x 10 pfu/ml) compared to summer and autumn (95.5 x 10 and 35.0 x 10 pfu/ml) (Fig. 6A). In all treatment beds, the count (pfu/ml) of somatic coliphages of the effluents were lower than that of the influent (Fig. 6A). The highest removal rate (87.4%) was gravel/sand beds (63 and 71%, respectively) (Fig. 6B).

(g) Removal efficiency of coliphages

Results obtained from the differences in somatic coliphage counts (pfu/ml) between the influent and effluents of the treatment beds (Fig. 6B) showed that the sand bed (S_1) is the best for removing 88% of coliphages. The two gravel/sand beds (GS_1 and GS_2) showed good removal efficiency (63 and 71 %, respectively). The analysis of variance test ANOVA (Table 2) followed by Tukey's test indicate the significant difference ($p < 0.001$) between the efficiency of sand bed (S_1) for the removal of coliphages and other treatment beds. Also, the differences between gravel/sand beds (GS_1 and GS_2) and gravel beds (G_1 and G_2) for the removal of coliphages were significant ($p < 0.001$).

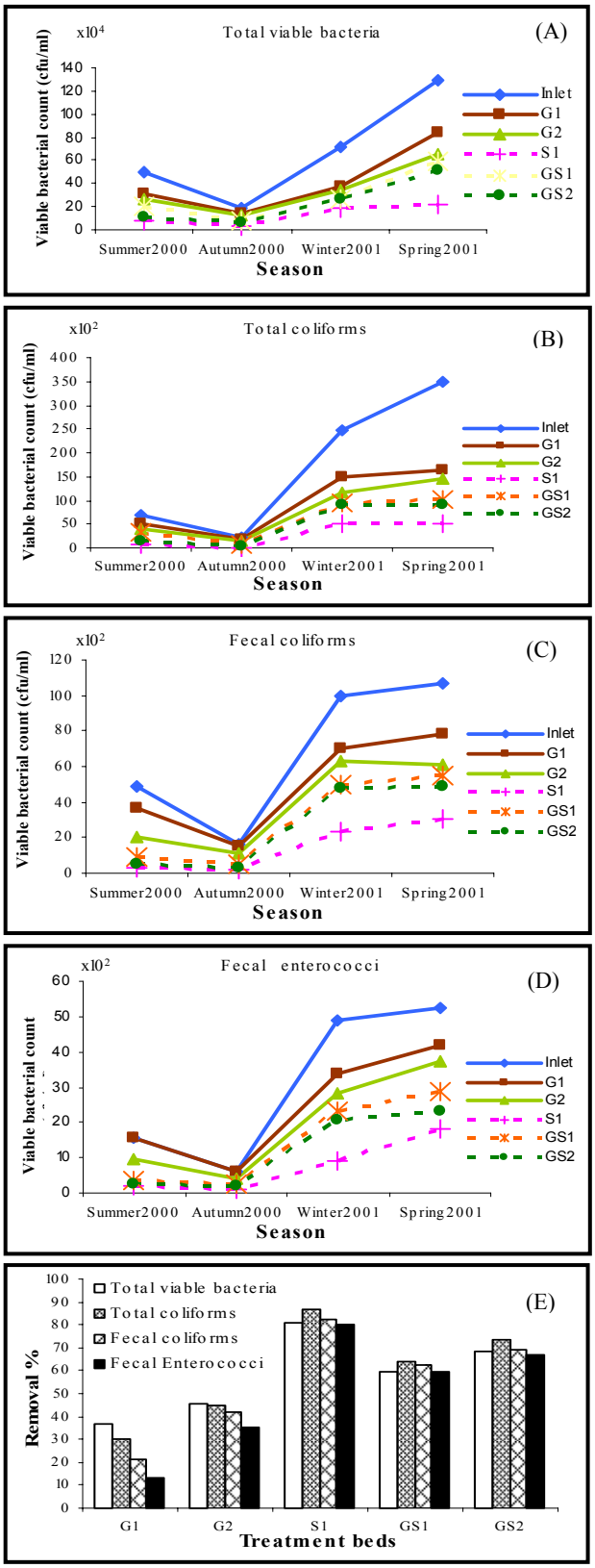

Figure (5): Seasonal variation in counts of the indicator bacteria, (A) Total viable bacteria, (B) Total coliforms, (C) Fecal coliforms, (D) Fecal enterococci (cfu/ml) monitored in water samples collected from the short-deep treatment beds during the study period, and (E) Percentage removal of bacterial indicators: Total viable bacteria, Total coliforms, Fecal coliforms and Fecal enterococci from the short-deep treatment beds.

DISCUSSION

Biological treatment systems using constructed wetland are by far natural alternative to conventional treatment systems that needs no sophisticated operation or maintenance facilities. Higher plants, microbial biofilm built around plant roots and gravel particles as well as bacteriophages are the main possible contributors to the treatment processes (Butler and Dewedar, 1991).

The main scope of the present study is to investigate a type of short–deep treatment beds to overcome the problem of large land area that has been required previously in constructing long beds e.g. GBH system (Bahgat, 1992). The beds filled with sand, gravel or sand/gravel as filling materials and planted with *Phragmites australis* (common reed) or *Cyprus papyrus* (papyrus). The treatment process usually accomplished through microbial biofilms attached to gravel surfaces and plant rhizospheres as well as physical filtration. The role of plants, microbial biofilms and filling materials (Gray, 1989; Decamp, 1996) were studied extensively in most constructed wetland systems established worldwide (Hammer, 1989; Cooper, 1999; Vaillant *et al.*, 2003).

Table (2): Analysis of variance (ANOVA) summary table for bacterial indicators monitored in BIOWATSYST treatment beds in different seasons

Parameter	Influent & effluents		Season	
	F-value	*p*-value	F-value	*p*-value
TVB (cfu/ml)	8.97	< 0.001	32.59	< 0.001
Total coliform (cfu/ml)	8.09	< 0.001	30.36	< 0.001
Fecal coliform (cfu/ml)	8.21	< 0.001	43.66	< 0.001
Fecal enterococci (cfu/ml)	5.47	0.0002	50.84	< 0.001
Coliphage (pfu/ml)	15.22	< 0.001	57.83	< 0.001

The performance of BIOWATSYST was studied in parallel projects in six Mediterranean coastal countries including Egypt, Spain, Morocco, Greece, Italy and Jordan. The BIOWATSYST, which was constructed in Abu-Attwa experimental station, Ismailia, Egypt should be regarded as a moderate system compared to long GBH treatment beds constructed at the same environment (Butler *et al.*, 1990; Butler and Dewedar, 1991; Butler and Loveridge, 1991) in the removal of BOD_5 (68%), COD (71%), TSS (46%), TDS (15%), Organic matter (43%), TN (15%), TVB (59%), TC (59%), FC (52%), and FE (47%). On the other hand, the 100 m GBH beds proves to remove BOD_5, COD, TSS and TN in the range of (84-92%) and (99.9%) for both TC and FC, while the 50 m long GBH treatment beds proves to remove BOD_5, COD, TSS, TN in the range of (70-77%) and (99.3%) for both TC and FC. Similarly, Mandi *et al.* (1996) who assessed the efficiency of three reed beds differing in length (30, 40 and 50 m). Their results revealed that removal efficiency of (50 m) bed is greater than that of (30 m) bed. The 50 m bed had removal efficiency of COD (62%), TN (43%) and TP

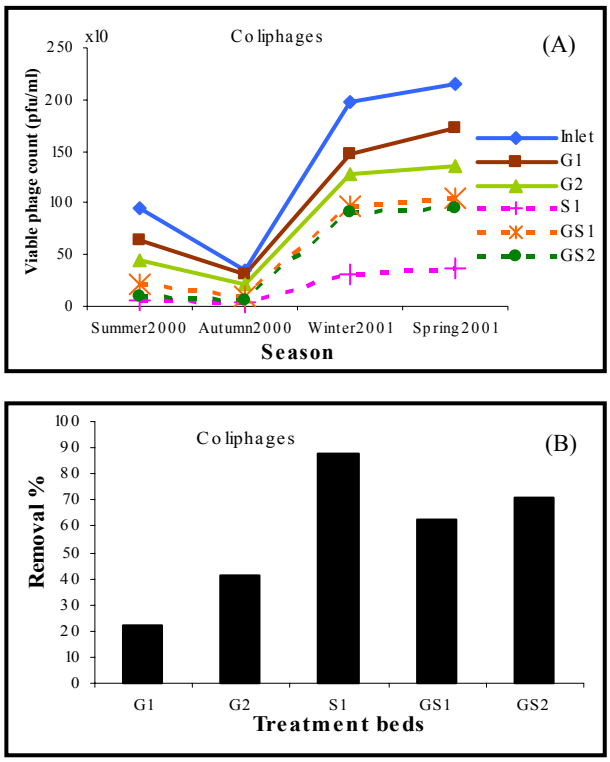

Figure (6): (A) Seasonal variation in counts of somatic coliphages (pfu/ ml) monitored in water samples collected from short-deep treatment beds during the study period. (B) Percentage removal (%) of somatic coliphages from the treatment beds.

(14%) while, the 30 m bed had removal efficiency of COD (48%) and TN (23%). This ability may be mainly because long beds expose the wastewater to more root-gravel matrix as well as microbial biofilm which enhance the physical filtration and biological degradation of pollutants.

Also, it was noticed that the plant species was a factor that may slightly affect the treatment process as *Phragmites* beds (G_2 and GS_2), which had slightly better efficacy than *Papyrus* beds (G_1 and GS_1). Senzia *et al.* (2003) reported that treatment beds planted with *Phragmites* had better removal efficiencies than that planted with *Typha*. This may be due to the relatively shallow roots of *Papyrus* and *Typha*, which might have less impact on filtration and sedimentation than *Phragmites*.

Filling materials of the constructed beds are effective components of the system that play an important role in the treatment process. Also, the depth of this material affects the treatment process. Results obtained in the present study reveal that the sand bed (S_1) was the most effective in the removal of nutrients [BOD_5 (76%), COD (84%), TSS (59%), TDS (24%), Organic matter (59%), and TN (22%)], and bacterial indicators; TVB, TC, FC, FE, (79-87%), and coliphages (87%). Also, gravel/sand beds (GS_1 and GS_2) showed better treatment efficiency than gravel beds (G_1 and G_2). Similarly, Decamp (1996) reported that concentrations of dissolved oxygen are different in gravel beds than in soil beds.

Pathogenic bacteria are the most serious elements that contaminate domestic wastewater (Borrego and Figueras, 1997). Comparison of the numbers of indicator bacteria present in the primary treated wastewater that enter the BIOWATSYST may reveal that it is in the range of most published results (Hench *et al.*, 2003; Senzia *et al.*, 2003; Kaseva, 2004). However, the viable counts of such pathogenic bacteria that still contaminate the effluents of the treatment bed of the BIOWATSYST are still higher than national and international guidelines for the safe wastewater disposal (Egyptian Environmental Law, 4/1994; Hench *et al.*, 2003; Senzia *et al.*, 2003; Kaseva, 2004).

Several studies traced the presence of coliphages in the wastewater treatment systems. For example, Thurston *et al.* (2001) reported that the influent of the wetland system contained 2.5 x 10^2 pfu/ml and the effluent contained 4.7 pfu/ml with reduction efficiency of 95.2%. Furthermore, Hench *et al.* (2003) reported that the influent of the wetland mesocosm contained 16 x 10^2 pfu/ml and the effluent contained 31.6 pfu/ml with reduction efficiency of 98%.

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كفاءة الأحواض القصيرة العميقة فى المعالجة البيولوجية لمياه الصرف الصحى

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اكتسبت طرق المعالجة البيولوجية لمياه الصرف الصحى بواسطة الأحواض الزلطية تأييدا عالميا لتميزها ببساطة التصميم وقلة التكلفة وسهولة الصيانة والمتابعة. لقد تم انشاء نظام المعالجة البيولوجى بمحطة أبو عطوة التجريبية بالإسماعيلية- مصر فى عام 1998، وهو مشروع دولى مدعم من السوق الأوروبية المشتركة، ويتكون من ستة أحواض قصيرة وعميقة تخرج مياهها على ثلاثة برك للتعقيم ثم تتجمع جميع المياه المعالجة فى بركة كبيرة فى النهاية. وقد ملأت الأحواض بالزلط أو بالرمل أو بطبقات متبادلة من الرمل والزلط وزرعت بالبوص (أربعة أحواض) أو(و) بالبردى (حوضين).

تتناول هذه الدراسة مدى كفاءة أحواض المعالجة القصيرة والعميقة، والتى تتطلب مساحة أراضى صغيرة، فى التخلص من الملوثات العضوية والميكروبات الممرضة. وقد أثبتت النتائج أن نظام المعالجة يساهم فى التخلص من الأكسجين الحيوى المستهلك بنسبة 76.3%، والأكسجين الممتص كيميائيا بنسبة 83.9%، وإجمالى الأملاح الصلبة العالقة بنسبة 59.2 %، والمواد العضوية بنسبة 58.6%، وإجمالى النيتروجين بنسبة 22.1%. كما أثبتت النتائج كفاءة الأحواض فى تقليل أعداد بكتريا القولون بنسبة 82.6%، والبكتريا المعوية من أصل حيوانى بنسبة 79.8% ولاقمات البكتريا بنسبة 87.4%. ويظهر جليا من الدراسة تفوق حوض الرمل على الأحواض المملوءة بالزلط أو بالرمل والزلط فى تقليل ملوثات مياه الصرف الصحى المعالج معالجة أولية.