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Integration of septic tank and constructed wetland for the treatment of wastewater in Egypt

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ABSTRACT

Integration of septic tank and constructed wetland systems as simple and low cost techniques is the main objective of this study. The area of the study is located at east of Sharquiya Governorate, Egypt. Three-chamber septic tank of the volume of 56 m^3 was constructed followed by 200 m^2 subsurface flow constructed wetland. The calculated hydraulic residence time for septic tank and constructed wetland was about 5, 6, and 7 day, respectively. The characteristics of raw wastewater, septic tank, and wetland effluents were studied in terms of physico-chemical and bacteriological parameters. The obtained results revealed that the level of organic load represented by COD and BOD were reduced by 87 and 89%, respectively, while the fecal coliform count was reduced by about 5 log units. The quality of the treated wastewater was found to be within the permissible Egyptian standards for irrigating. No problems with odor or insects exist.

Keywords: Constructed wetland; Horizontal flow; Treated effluent reuse; Wastewater treatment; Sewage farm; Groundwater protection

1. Introduction

Decentralized approach offers flexibility in management and a series of processes can be combined to meet treatment goals and address environmental and public health protection requirements. It is not only a long-term solution for small communities but also more reliable and cost effective. However, understanding the receiving environment is crucial for technology selection and should be accomplished by conducting a comprehensive site evaluation process [1]. Similar to sanitation in rural areas of developing countries, investments for centralized water supply systems are often unaffordable given the remote locations and lack of financial resources [2]. In the rare cases where centralized systems are installed, the system often fails due to unprofessional maintenance and management [3]. Decentralized approaches for supplying water are already applied in many parts of developing countries. Several potential solutions, both quality and quantity related, are reviewed by Varbanets et al. [2]. Regional differences occur in their implementation due to the local socio-cultural, economic, and political situations and due to local environmental conditions of available water sources [2].

A main part of the pollutants contained in wastewater are nutrients that can be removed in wastewater

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treatment plants by reproducing natural self-purification processes. Conventional treatment plants are energy intensive reactors with relatively small area demand that are suitable for centralized wastewater treatment. Constructed wetlands (CWs) are principally using the same natural degradation processes and nutrient uptake but they are acting as "extensive systems" [4]. The high degree of biodiversity present in these systems allows multiple and various degradation mechanisms for several classes of compounds, and therefore higher performances in comparison with the technological treatment plants in which only few families of specialized bacteria are grown [5]. The purifying processes take place without input of "human produced" energy by, for instance, oxygenating pumps. Furthermore, there is no excess sludge to be removed since there is a balance of biomass growth and decomposition in the CW system [6]. As compensation to the low energy demand, there is a relatively large area demand. Accordingly, CWs are usually suitable and cost effective for small and medium size wastewater treatment where the required land area is available [7].

Within the last 20–30 years, various types of CWs have been developed in different countries [8–10]. There is a wide acceptance and interest within the population because of the following advantages:

- Less expensive to build than other treatment options.
- Simple construction, operation, and maintenance.
- Low operation and maintenance costs.
- High ability to tolerate fluctuations in flow and inlet quality.
- High process stability (buffering effect).
- Sludge produced only by the primary treatment stage.
- High pathogen removal, good water reuse, and recycling options.
- Optimal esthetic appearance.

The system is field constructed for the treatment of sewage water and reuse for irrigation purpose.

2. Objective of this study

The main objective is to combine the European experience with the Egyptian practice for wastewater management and reuse for irrigating timber plantations as well as protecting the groundwater. Furthermore, the purpose is to implement an integrated model of wastewater management for remote regions to save and recycle the wastewater and to make the effluent suitable, safe, and appropriate for its intended reuse while protecting the environment.

3. Materials and methods

3.1. Site description for the applications of CWs

The area of the study located at east of Sharquiya Governorate 55 km northeast of Cairo. This area called Sekem (longitude 31 E, latitude 32 N, and 10 m above the mean sea level).

3.2. Design, operation, and sampling schedule

The number of population served by this system was 100 p.e. Assuming that 100 liter of water consumed by 1 p.e., Table 1 shows the dimensions and operating conditions of septic tank (ST) as well as subsurface flow (SSF) constructed wetland unit used in this study. Three-chambers ST of 56 m^3 total volume was designed and manufactured from concrete followed by the SSF constructed wetland. The plant used in this study was *phragmites australis*. The root of this plant may exceed 0.7 m [11] and, consequently, the depth of SSF constructed wetland was 1 m. All the units located under the surface of land to use the gravitational movement of fluid (wastewater). Samples were collected after reaching the steady-state conditions (two months after plantation). The organic loading rate (OLR) (based on BOD) did not exceed 110 kg BODha^{-1}day^{-1} [11].

The effluent was further treated by an SSF of 200 m^2 horizontal flows and depth of 1 m. The final effluent was flowing by gravity without any energy input to a collection tank from which it is used for irrigating forest lumber trees.

Extensive program was designed to collect weekly samples of the raw wastewater and different treatment effluents, during the period from July 2011 to

Table 1
Dimensions and operating conditions of the ST and SSF constructed wetland systems

Parameter	ST	SSF wetland
Length	6.5 m	20 m
Width	3.45 m	10 m
Depth (water)	2.5 m	1 m
Aspect ratio	–	2:1
Plant	–	*Phragmites australis* (common reed)
No. of rhizomes (m^{-2})	–	3
Substrate void ratio	–	0.35
HRT	5.6 day	7 day
HLR	0.18 $m^3\,m^{-3}\,day^{-1}$	500 $m^3\,ha^{-1}\,day^{-1}$
OLR (COD)	0.11 $kg\,m^{-3}\,day^{-1}$	175 $kg\,ha^{-1}\,day^{-1}$
OLR (BOD)	0.6 $kg\,m^{-3}\,day^{-1}$	90 $kg\,ha^{-1}\,day^{-1}$

December 2012. During this period, the ambient temperature ranged from 10°C to 42°C. All samples were subjected to the physico-chemical analysis according to APHA [12]. Efficiency of treatment and percentage of removal was studied and calculated. The flow rate was measured regularly.

3.3. Microbiological characteristics

Microbiological characteristics of the raw and treated effluents were investigated. Determination of fecal *coliform* (FC) and fecal *streptococci* (FS) counts were carried out according to APHA [12] using most probable number (MPN) method.

4. Results and discussion

4.1. Characteristics of raw wastewater

The physico-chemical characteristics of the raw wastewater namely total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and oil and grease were 136, 329, 588, 55, and 85 mgl^{-1}, respectively (Table 2). The main microbiological characteristics of raw wastewater are given in Table 2. The FC counts ranged from $4.5\text{x}10^7$ to $3.8\text{x}10^9$ MPN/100 ml^{-1} with a mean value of $9\text{x}10^8$ MPN/100 ml^{-1}. The counts of FS ranged from $4.5\text{x}10^5$ to $1\text{x}10^7$ MPN/100 ml^{-1} with a mean value of $6\text{x}10^6$ MPN/100 ml^{-1}.

4.2. Effluent of the ST

By subjecting the raw wastewater to the ST, the removal rate for the TSS, BOD, and COD was 59, 46, and 41%, respectively (Fig. 1). The removal rate of TKN and oil and grease was 11 and 49%. No removal was achieved in terms of both the ammonia and the sulfides. This is mainly due to the anaerobic nature of the ST as a closed system.

Table 2
Physico-chemical characteristics of raw wastewater

Parameter	N	Unit	Raw wastewater
pH	38		6.8–8.3
COD	38	mgO$_2$/l	588 ± 84
BOD5	38	mgO$_2$/l	329 ± 47
TKN	38	mgN/l	55 ± 16
Ammonia	38	mgN/l	44 ± 15
TN	38	mgN/l	55.33 ± 15
Organic n	38	mgN/l	10.67 ± 3
Nitrates	38	mgN/l	0.33 ± 0.1
TSS	38	mg/l	136 ± 31
VSS	38	mg/l	89 ± 20
Oil and grease	38	mg/l	85 ± 10
Sulfides	38	mgS/l	14.6 ± 1.7
FC	15	MPN/100 ml	$9 \times 10^8 \pm 1 \times 10^8$
FS	15	MPN/100 ml	$6 \times 10^6 \pm 1 \times 106$

The geometric mean of FC and FS counts in raw wastewater and effluent of the ST during the study period are shown in Fig. 2. In most cases, the removal of FC and FS by the ST did not exceed 2 log units.

4.3. Effluent of the SSF

Further removal was achieved by treating the effluent of the ST through the SSF. The efficiency of the wetland reached 78 and 79% for COD and BOD, respectively. The depth of filtration bed has usually 0.6–0.1 m in order to allow roots of wetland plants (*Phragmites*) to penetrate the whole bed and ensure

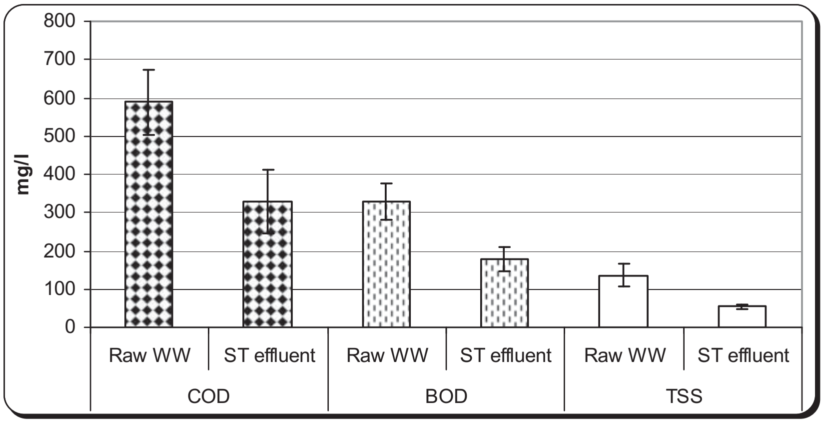

Fig. 1. The average level of COD, BOD, and TSS in the raw wastewater, effluent of ST effluent.

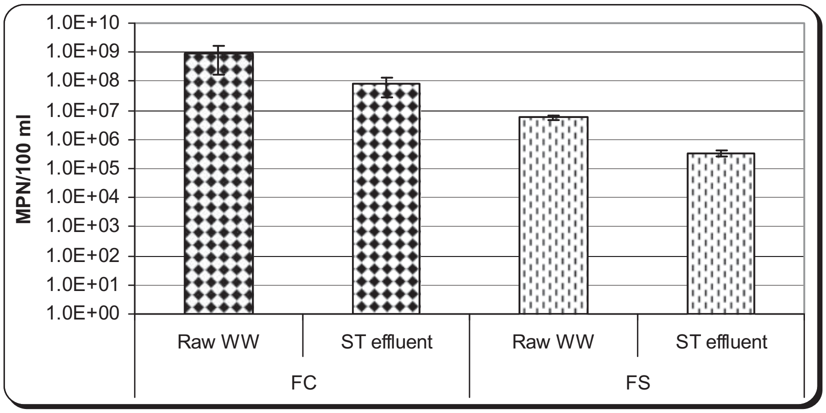

Fig. 2. Comparison between the counts of FC and FS in raw wastewater and ST effluent.

oxygenation of the whole bed through oxygen release from roots. The role of plant for removing (absorbing) pollutants from wastewater is very limited according to Brix [13]. The main function of the plant is to aerate the root zone and facilitate the movement of water and avoid clogging the system [13,14]. Roots and rhizomes of reeds and all other wetland plants are hollow and contain air-filled channels that are connected to the atmosphere for the purpose of transporting oxygen to the root system. The majority of this oxygen is used by the roots and rhizomes themselves for respiration, but as the roots are not completely gastight, some oxygen is lost to the rhizosphere [13,15]. However, many studies have shown that the oxygen release from roots of different macrophytes is far less than the amount needed for aerobic degradation of the oxygen consuming substances delivered with sewage and that anoxic and anaerobic decompositions play an important role in SSF CWs [16,17]. As a result, organic compounds (as presented by COD and BOD) are degraded aerobically as well as anaerobically by bacteria attached to plant underground organs (i.e. roots and rhizomes) and media surface, and the removal of organics is generally very high in SSF [17].

The average residual concentration of TSS was 11 mgl^{-1} with corresponding removal rate of 80%. Suspended solids that are not removed in pretreatment system were effectively removed by filtration and settlement. Most of the suspended solids were filtered out and settled within the first few meters beyond the inlet zone [17].

Ammonia, TKN, and organic nitrogen were reduced from 49, 45, and 3.7 mgl^{-1} to 14, 10.7, and 3 mgl^{-1}, respectively. The corresponding removal rates were 69, 69, and 19%, respectively. The major removal mechanism of nitrogen in SSF is nitrification/denitrification [18]. Field measurements have shown that the oxygenation of the rhizosphere in SSF was insufficient and, therefore, incomplete nitrification (i.e. oxidation of ammonia to nitrate) was the major cause of limited nitrogen removal. Min et al. [19] pointed out that no obvious nitrification could be observed when dissolved oxygen concentration is lower than 0.5 mgl^{-1}. Volatilization, adsorption, and plant uptake play much less important role in nitrogen removal in SSF [16–18].

The main microbiological and virological characteristics of SSF effluent are given in Table 3. Fig. 3 shows the geometric mean of FC counts in the SSF effluent varied from 1×10^3 to 6.3×10^3 MPN 100 ml^{-1} with an average count of 3×10^3 MPN 100 ml^{-1}. The trend line in Fig. 3 shows that FC count (average) tend to decrease to be less than 10^3. The variation in FS count is shown in Fig. 4. The count ranged from 6.6×10^1 MPN 100 ml^{-1} to 6.3×10^2 MPN 100 ml^{-1}, with an average value of 2×10^2 MPN 100 ml^{-1}.

4.4. *Efficiency of the combined treatment system*

The overall efficiency of the combined treatment systems, which exhibited remarkable improvement in the characteristics of the treated wastewater, reached 73, 92, and 91% for TKN, TSS, and VSS, respectively (Table 3). The overall removal efficiency is 89% for the BOD and 87% for the COD. The TKN and oil and grease decreased from 55 to 14 mgl^{-1} and from 85 to 16.7 mgl^{-1}, successively. The overall decrease in TSS, BOD, and COD were from 136 to 11 mgl^{-1}, from 329 to 36 mgl^{-1}, and from 588 to 74 mgl^{-1}, successively (Table 3). Masi and Martinuzzi [20] studied the performance of combined horizontal flowed by vertical flow constructed wetland for the treatment of wastewater in a resort. The surface area of the unit

Table 3
Physico-chemical characteristics of septic tank and wetland effluents

Parameter	Unit	Raw wastewater	ST effluent	Efficiency (%) of ST	SSF effluent	Efficiency (%) of CW	Efficiency (%) of the combined system
pH		6.8–8.3	7.3–8.1	–	7.1–8.3	–	–
COD	mgO_2/l	588 ± 84	348 ± 82	41	74 ± 16	78	87
BOD5	mgO_2/l	329 ± 47	178 ± 34	46.0	36 ± 9	79	89
TKN	mgN/l	55 ± 16	49 ± 14	11	14 ± 4	69	73
Ammonia	mgNl	44 ± 15	45 ± 15	−4	10.7 ± 3	76	76
TN	mgNl	55.33 ± 15	49.31 ± 14	11	15.27 ± 4	69	72.4
Organic N	mgNl	10.67 ± 3	3.69 ± 1.5	65	3 ± 0.6	19	72
Nitrates	mgN/l	0.33 ± 0.1	0.31 ± 0.1	6.1	0.2 ± 0.08	12.9	18.2
TSS	mg/l	136 ± 31	54 ± 16	59	11 ± 3	80	92
VSS	mgl	89 ± 20	45 ± 12		8 ± 3		
Oil and Grease	mgl	85 ± 10	44.8 ± 14	48.6	16.7 ± 5	61.0	80.3
Sulfides	mg/l	14.6 ± 1.7	14.9 ± 6	−2.2	3.5 ± 1	76.2	76.0
FC	MPN $100\,ml^{-1}$	$9 \times 10^8 \pm 1 \times 10^8$	$8 \times 10^7 \pm 2 \times 10^7$	89.893	$3 \times 10^3 \pm 1.2 \times 10^3$	99.991	99.999
FS	MPN $100\,ml^{-1}$	$6 \times 10^6 \pm 1 \times 10^6$	$3 \times 10^5 \pm 1 \times 10^5$	92.5118	$2 \times 10^2 \pm 1 \times 10^2$	99.9361	99.9956

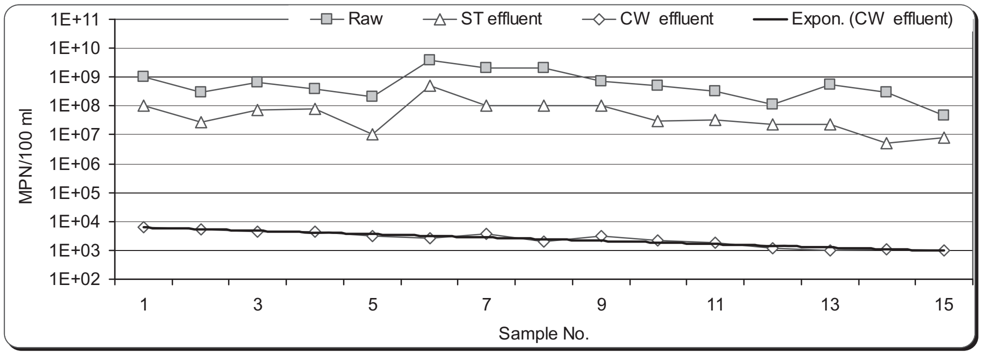

Fig. 3. Variation of FC counts in raw sewage, ST, and SSF wetland effluents.

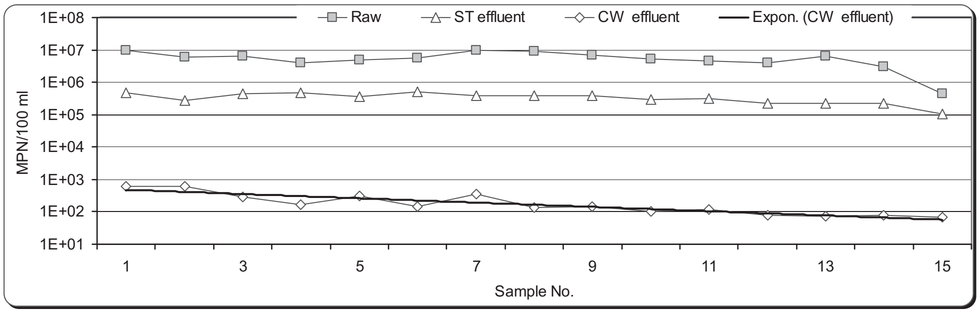

Fig. 4. Variation of FS counts in raw sewage, ST, and wetland effluents.

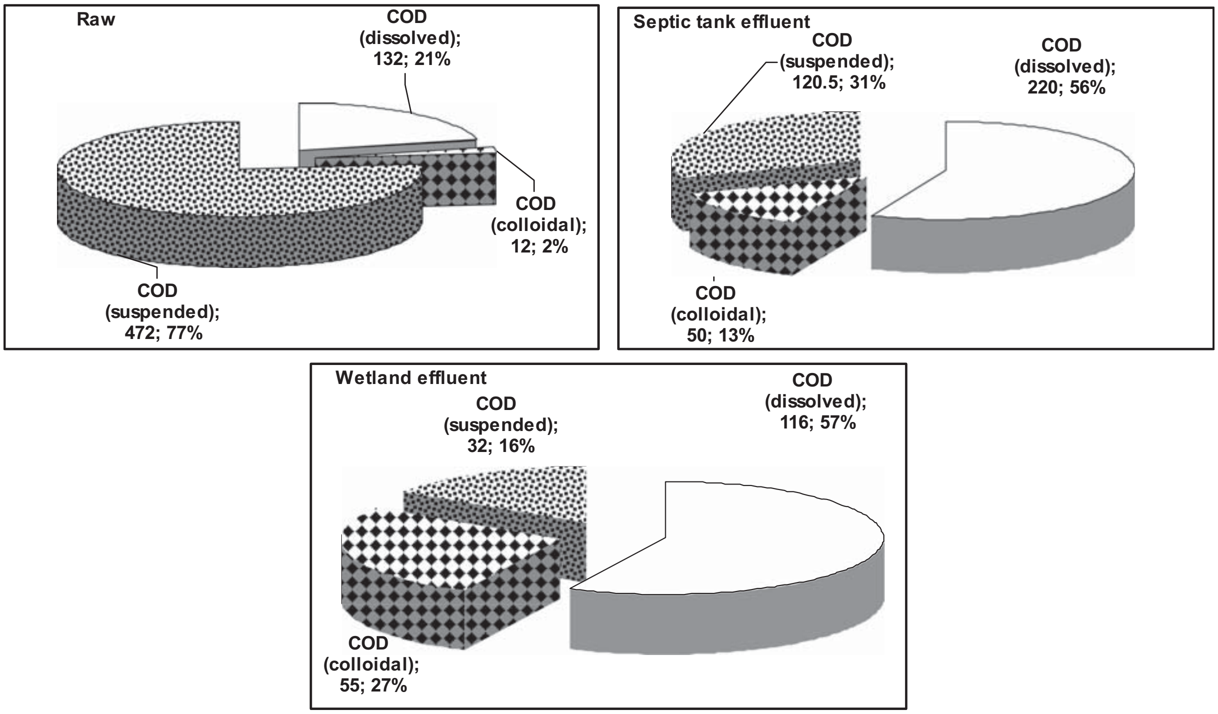

Fig. 5. Different COD fractions in raw sewage, ST, and SSF wetland effluents.

was 160 and 180 m^2 with total HRT of 3 days for the horizontal and vertical flow, respectively. The overall performance of this system was found to be higher than that obtained in our study (COD 94%, BOD_5 95%, total suspended solids 84%, NH^{4+} 86%, and total nitrogen 60%). This may be attributed the splitting of the treatment stage to two steps instead of one step.

Fig. 5 shows the different fractions of COD in raw sewage as well as different treated effluents. The major fraction in the raw sewage was the COD suspended (77%) followed by dissolved fraction (21%) and the last was the colloidal fraction. After the primary treatment (ST), the suspended fraction decreased from 77 to 31%. This attributed to the precipitation that may take place in the ST. Due to hydrolysis process in ST, the dissolved and colloidal fractions of COD were increased from 21 and 2% to 56 and 13%, respectively. Dramatic reduction of the suspended COD fraction was achieved in the SSF effluent from 31 to 16%. The wetland media enhanced the filtration process and this may account for this reduction. This result was found to be in a good agreement with that obtained by Abdel-Shafy et al. [21].

Similarly, great achievement in the elimination of biological contamination was reached (Table 3). Similar achievement was reached by other investigators also [22]. The level of biological parameters in the final effluent became within and even lower than the permissible limits of the irrigating plantations according to the Egyptian Guidelines [23] and [24].

Presently, the treatment system is fully operated for three years. The treated water is reused for irrigating Eucalyptus trees that are used for manufacturing packaging boxes. Improving of the irrigated sandy soil is expecting in terms of water holding capacity, nutrient elements, and physical characteristics.

5. Conclusions

- The CWs are important treatment systems particularly for the decentralized areas.
- Employing the proper design of a CW as well as an efficient primary treatment system has improved the quality of the wastewater (WW) effluent.
- No problems with odor or insects occurred by employing the subsurface CW.
- The treated WW can be reused for irrigating the lumber forest trees.
- Indeed, the treated effluent can be safely used, particularly on the sandy soil to improve its physical quality and recycling the nutrient elements.
- Improvement of treated wastewater is indeed an achievement towards the protection of the public health, the environment, and the groundwater.
- About 10 m^3/d of fresh water were saved for irrigating the agricultural area by using the efficiently treated wastewater.

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