Extensive Post Treatment Using Constructed Wetland

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Abstract: The feasibility of using treatment scheme consists of an ubflow anaerobic sludge blanket (UASB) reactor followed by subsurface follow constructed (SSF) wetland for the treatment of sewage water has been studied. The results showed that the efficiency of the UASB reactor (as a primary treatment step) for the removal of COD, BOD and TSS was found to be 67.7, 71.4 and 65.5% with corresponding residual concentration of 197, 120 and 79.3 mg/l, respectively. The FC count reduced by one or two log units in most cases. The residual count was $1.6x10^6$ MPN/100 ml. The anaerobically treated effluent was subjected to post treatment step using SSF wetland. The residual concentration of COD, BOD and TSS was reduced greatly to 56.7, 20.6 and 5 mg/l, respectively. Fecal coliform (FC) count was reduced to $1.1x10^3$ MPN/100ml. The quality of the finally treated effluent was found to be complying with the WHO Standards for irrigation. It therefore, recommended that the combination of UASB and SSF is an effective system for the treatment of sewage water in Skaka City.
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1. Introduction

As the nation's population continues to grow, development is pushed further into rural areas where septic systems must be used for wastewater treatment. Constructed wetlands (CWs) for wastewater treatment are an inexpensive and technologically appropriate solution for wastewater treatment in developing countries (Denny, 1997; Haberl, 1999 and Kivaisi, 2001).

CWs wastewater treatment can be defined as a man-made, engineered wetland area specifically designed for the purpose of treating wastewater by optimizing the physical, chemical, and biological processes that occur in natural wetland ecosystems. CW can provide economical on-site wastewater treatment that is both effective and aesthetically pleasing (El-khateeb and El-Gohary, 2003; Hegazy *et al.,* 2007 and El-Khateeb *et al.,* 2009).

CWs have only been used for wastewater treatment since the 1970s, which makes them a relatively new wastewater treatment technology. However, interest in their use has quickly become widespread. For example, CW technology was recommended most frequently as a topic for future articles. Wetland systems also are a popular subject with the many community leaders, health officials, and homeowners (USEPA, 2000 and Thaddeus *et al.,* 2007).

In developing countries the use of constructed wetlands is certainly lower in comparison to their use in Europe or the United States, despite the enormous potential and the great necessity of these countries to implement low-cost treatment systems. (Belmont *et al.,* 2004; Zurita *et al.,* 2006, 2008). Constructed wetlands are effective treatment systems that can be very useful in developing countries since they are simple technology and involve low operational costs. Most of the time, the wetlands can be constructed with local materials which lowers the construction cost significantly. Furthermore, these treatment systems are good at removing not only pathogenic and nutrients but also toxic metals and organic pollutants (Belmont et al., 2006).

Interest in, and the utilization of, constructed wetlands for treatment of a variety of wastewaters has grown rapidly since the mid 1980s. In principle, the land application of wastewater uses the physical, chemical and microbial properties of the soil and vegetation to remove contaminants from the applied wastewater. The upper soil-plant zone is used to stabilize, transform, or immobilize wastewater constituents and support crop growth, leading to an environmentally acceptable assimilation of the waste. When proper design principles are used, land application is a desirable method of wastewater treatment (USEPA, 2000).

The gains in vegetation biomass in constructed wetlands can provide economic returns to communities when harvested for biogas production, animal feed, fiber for paper making, and compost (Lakshman, 1987). Economic benefits from constructed wetlands are an important consideration in developing countries where additional incentives are required to encourage communities to maintain treatment wetlands. At present, the most common aquatic plants used in subsurface wetlands are bulrush (Scirpus sp.), cattail (Typha sp.) and reeds (Phragmites sp.). However, there is potential to use other types of moisture-tolerant plants in constructed wetlands. (Belmont *et al.,* 2006 and Zurita *et al.,* 2009). The roots provide a huge surface area for attached microbial growth, and in temperate regions the plant litter provides an insulation layer against frost during winter. Plants can also facilitate aerobic degradation by releasing oxygen to the rhizosphere, but oxygen release rates are difficult to quantify and the overall effect on pollutant removal is probably varying (Brix, 1997 and Langergraber *et al.,* 2009).

Regarding uptake of nitrogen (N) and phosphorus (P) many studies in temperate climates have shown that the amount which can be removed by harvesting is generally insignificant (Tanner, 2001). However, in tropical climates where the plants grow faster and throughout the year, the uptake of nutrients can probably contribute to significantly higher removals of nutrients as has been reported in several studies (Koottatep & Polprasert, 1997; Kyambadde *et al.,* 2004 and Greenway, 2005). However, if the plants are not harvested the incorporated nutrients will be released again during decomposition of the biomass.

Another function of the plants that is not related to treatment performance is to give the wetland a nice appearance: ornamental plants like Canna and Heliconia increase the aesthetics of the wastewater treatment wetland. This function is emphasized in some of the newly built tropical CWs worldwide, which are designed as park-like areas in the villages to increase the local people's awareness of wastewater treatment (Zurita *et al.,* 2009). It is envisaged that the people will show more interest in the operation and maintenance of the nice-looking systems, and that this will thus benefit the long-term operation of the systems. Flowers like Heliconia have an economic potential as they can be sold in the markets, which is another benefit. However, there is a need for studies to elucidate how suitable these tropical, ornamental plants are for use in CWs.

CWs have proven to be highly effective at wastewater treatment. They can achieve stringent water quality standards, with BOD removal of 85%, and fecal coliform (FC) removal of 95% or more (USEPA, 2000). Studies show that they are effective at removing nutrients such as nitrogen and phosphorous. These systems are being used worldwide to protect groundwater and surface water resources, the simplicity of the design results in low operation and maintenance requirements. The wetland vegetation (ornamental and/or non-flowering) used in these systems give them the appearance of a flower garden, and the sub-surface flow minimizes odor and vector problems (mosquitoes) while eliminating contact with wastewater. The flowering area of the wetlands provide a natural habitat for birds and other forms of wildlife by attracting worms, bees and other small creatures (Anders and Veronika, 2005; Gabriela *et al.,* 2005). It was therefore, the purpose of the present study to combine the advantages of the UASB followed by SSF wetland in an integrated treatment system for the treatment of wastewater. The capability of the system to produce wastewater suitable for irrigation has been assessed.

2. Material and Methods

UASB reactor was used as primary treatment step. Horizontal subsurface flow constructed wetland (SSF) unit was used in this project. The dimension of SSF will be 1 m width, 2 m length and 1m depth. The media used will be pea gravel (2 to 4 mm).

The treatment system was operated in a continuous pattern and outdoor at ambient temperature. Several plants could be used in the wetland unit. The common reed (phragmites australis) plant was selected due to its wide spread in the area nearby the location of the treatment system. Evaluation of the performance of the treatment system was carried out after reaching the steady state conditions. This was investigated through a regular monitoring program of influent and treated effluent for physico-chemical and bacteriological examinations.

The UASB reactor designed according to Al-Enazi *et al.,* 2012. Table 1 shows the operating conditions of the reactor.

Table 1: Operating conditions of the UASB reactor

Item	Value
HRT (hr)	6
HLR (m^3/m^3/day)	4
OLR (kg/m^3/day)	2.45

Table 2 shows the operating conditions of the wetland unit. Calculations of hydraulic (HRT) and organic loading rates (OLR) were carried out according to Crites and Tchobanoglous (1998).

Figure 1 shows the dimensions of the wetland unit.

Table 2: Operating conditions of the SSF wetland

Dimensions	
Length	2.0 m
Width	1 m
Depth (water)	0.6 m
Plant	Common reed
No. of rhizomes m^{-2}	3
Substrate	Pea gravel (2-4 mm)
Operating conditions	
HRT	3 days
HLR	730 $m^3 ha^{-1}.day^{-1}$
OLR_{Avg}	84 kg BOD $ha^{-1}.day^{-1}$ 138 kg COD $ha^{-1}.day^{-1}$

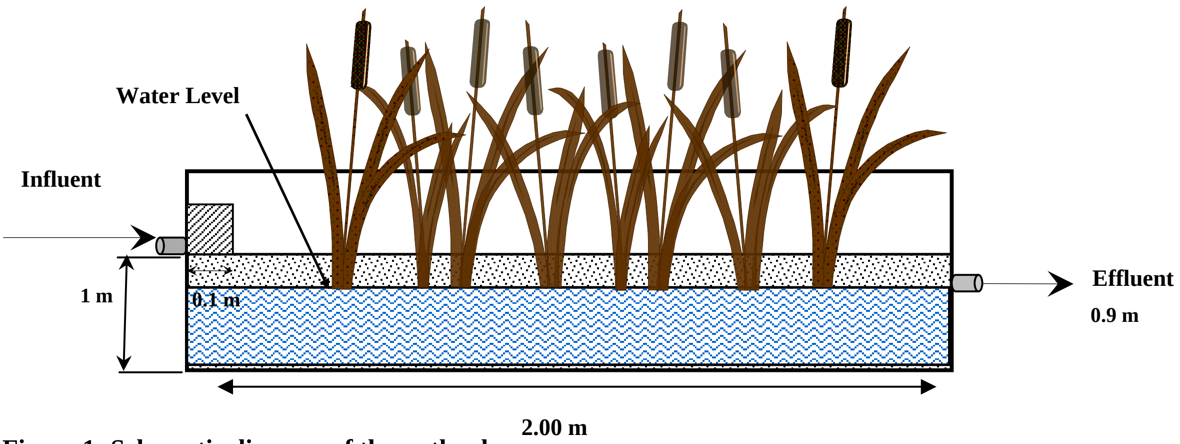

Figure 1: Schematic diagram of the wetland

Sampling and analytical methods

Composite samples of raw sewage and UASB effluent were collected and analyzed for total chemical oxygen demand (COD_{tot}), soluble chemical oxygen demand (COD_{sol}), particulate chemical oxygen demand (COD_{part}), colloidal chemical oxygen demand (COD_{coll}), biological oxygen demand (BOD), total suspended solids (TSS), total phosphorus (TP), total Kjeldahl nitrogen (TKN) and ammonia. Physicochemical analyses were carried out according to Standard Methods for Examination of Water and Wastewater (APHA, 2005).

Microbiological examination

Three-fold dilutions were prepared from each sample and used to determine the count of FC (APHA, 2005).

Statistical analysis

The arithmetic averages of percent removal and descriptive statistics were applied to the collected data using Microsoft Excel XP version 2003.

3. Results and Discussion

Raw sewage

Table 3 reflects the average characteristics of raw sewage used in this study. The COD_{tot} values were in the range of 546-678 mg/l with an overall average of 612 mg/l while, the concentration of BOD and TSS were in the range of 389-467 mg/l and 179-290 mg/l, respectively. The ratio of BOD/COD is about 0.7. The average concentration of TKN, ammonia and TP were 57.5, 51.7 and 5.9 mg/l, respectively.

Performance of the UASB reactor

The performance of the UASB reactor for the treatment of sewage water at 6 hours detention time is shown in Table 3. The concentrations of COD_{tot}, BOD and TSS were reduced by 67.7%, 71.4% and 65.5%, with corresponding concentrations of 197, 120 and 79.3 mg/l, respectively. The concentration of TKN was reduced from 57.5 to 53 mg/l by removal efficiency of 11.3%. On the other hand, concentration of TP was reduced from 5.9 to 4.5 mg/l with removal efficiency of 23%. The bacterial count represented by FC was reduced only by one log unit (on the average) during this run from $4.8x10^7$ and $1.6x10^6$ MPN/100 ml, with removal efficiency of 96.7%.

Table 3: Performance of the UASB reactor at 6 hours detention time

Parameter	N*	Unit	Raw sewage	UASB Effluent	%R
CODTOT	22	mg/l	612 (± 295)	197 (±43.4)	67.7
BOD	22	mg/l	419 (± 155)	120 (±35)	71.4
TSS	22	mg/l	235 (± 37.6)	79.3 (±28)	65.5
TKN	22	mg/l	57.5 (± 13)	53 (±23)	11.3
Ammonia	22	mg/l	51.7 (± 11)	51.8 (±18)	
TP	22	mg/l	5.9 (±0.7)	4.5 (±1.7)	23
Organic nitrogen	22	mg/l	5.8 (± 2.4)	1.3 (± 1.1)	77.6
FC	8	MPN/100 ml	4.8×10^7 (± 1.9×10^7)	1.6×10^6 (±5.7×10^5)	96.7

* Number of samples

This quite good performance towards the removal of COD_{tot} and BOD can be attributed to the relatively high sludge residence time (SRT = 38.1 days); which improves the hydrolysis and biodegradation of organic matter content of the wastewater. The TKN was reduced by 11.3% due to particulate N removal, and/or conversion to ammonia by ammonification process (Mahmoud, 2002). Similarly, the level of TP was reduced in the UASB reactor by 23%. The UASB reactor removed only the particulate nutrients by sedimentation and filtration and, therefore, it had relatively low removal of nutrients (Elmitwalli & Otterpohl, 2007 and Aiyuk *et al.,* 2010).

It was observed that the effluent from the UASB reactor still contains significant count of FC. The FC counts are greater than the permissible limit (log 3 or 1000 MPN/ml) specified by WHO (1989) for unrestricted irrigation. The use of post treatment is of vital importance to meet the WHO (1989) standards for treated effluent reuse. In an attempt to enhance the removal of bacterial indicators (FC), the use of SSF wetland to treat the UASB effluent has been investigated. Table 5 shows the performance of SSF wetland unit.

Performance of SSF wetland unit

Figures 2 to 10 show the performance of the combined UASB/SSF system for the treatment of wastewater.

Table 5: Performance of the SSF unit

Parameter	N*	Unit	UASB Effluent	SSF Effluent	%R	T%R
COD_{tot}	22	mg/l	197 (±43.4)	56.7 (±12)	71	90.7
BOD	22	mg/l	120 (±35)	20.6 (±7)	82.7	95.1
TSS	22	mg/l	79.3 (±28)	5 (±1.5)	93.7	97.8
TKN	22	mg/l	53 (±23)	13.3 (±4.8)	74.8	76.7
Ammonia	22	mg/l	51.8 (±18)	6 (±2.4)	88.5	88.5
TP	22	mg/l	4.5 (±1.7)	3 (±1.2)	33	49eh
Organic nitrogen	22	mg/l	1.3 (± 1.1)	7.4 (±2.1)		
FC	8	MPN/100 ml	1.6×10^6 (±5.7×10^5)	1.1×10^3 (±2.1×10^2)	99.88	99.997

* Number of samples

The wetland unit was found to be efficient for removal of COD_{tot}, BOD and TSS. The residual concentration of COD_{tot}, BOD and TSS 56.7, 20.6 and 5 mg/l, respectively. Figure 2 summarizes the efficiency of the combined treatment system (UASB/SSF).

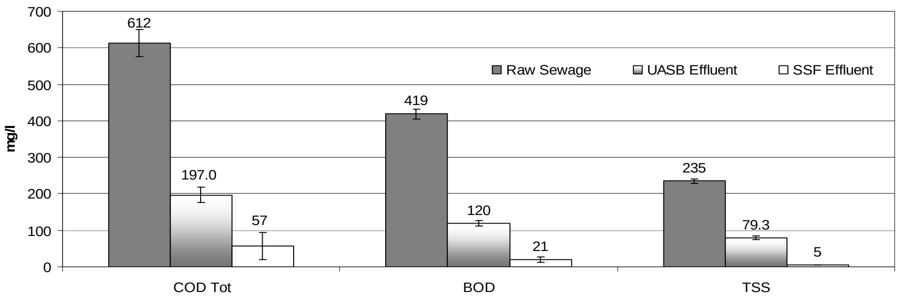

Figure 2: Efficiency of the combined UASB/SSF system for removal of COD_{tot}, BOD and TSS

The level of TKN was reduced from 57.5 to 53 mg/l in the UASB effluent. Further reduction in the level of TKN was recorded in the SSF effluent (from 53 to 13.3 mg/l). The level of ammonia was decreased greatly in the final treated SSF effluent. This may be attributed to the aerobic conditions near the root zone of the plants in the SSF unit (USEPA, 2000 and El-Khateeb & El-Gohary, 2003).

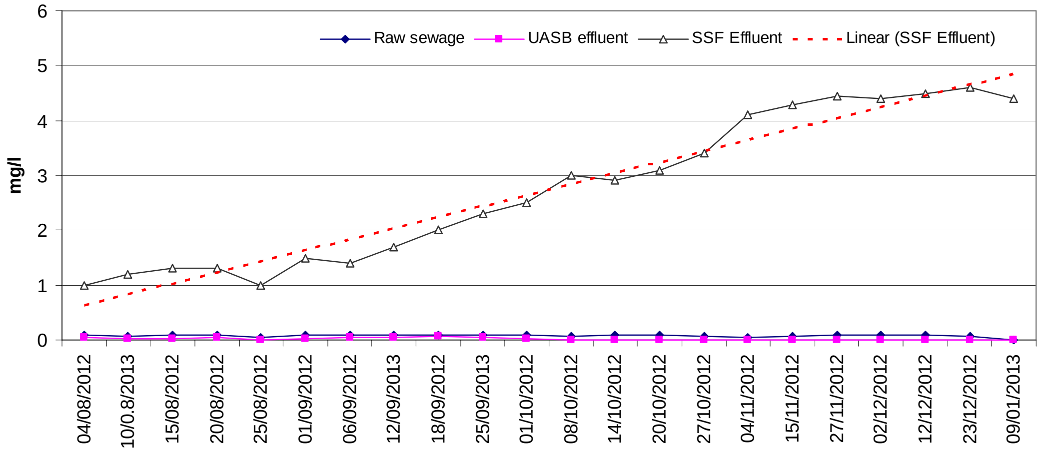

Figure 3: Variation of nitrates in raw sewage, UASB and SSF effluent

The dotted line in Figure 3 shows the nitrification process increased gradually reaching the maximum level. The aeration process around the SSF root zone increased by increasing the maturity of the plant. Consequently, conversion of ammonia to nitrates increased (USEPA, 2000 and El-Khateeb & El-Gohary, 2003). The total nitrogen removal throughout the treatment steps is shown in Figure 4.

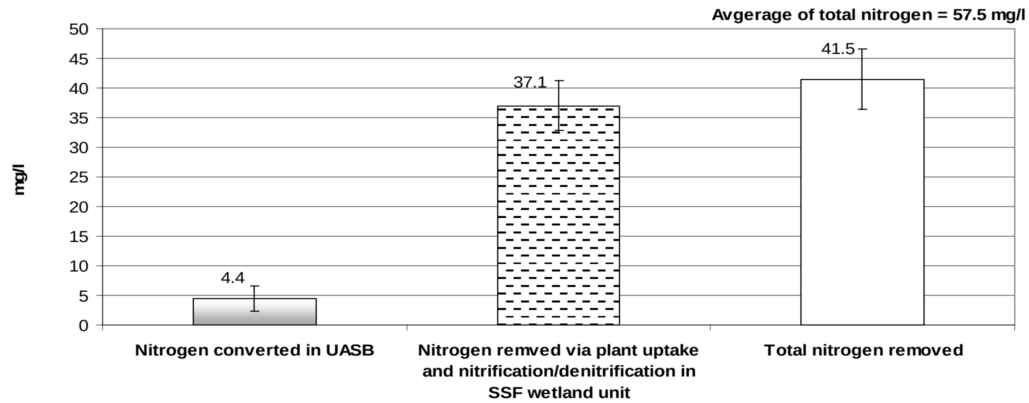

Figure 4: Fate of nitrogen throughout the treatment system

The wetland unit removes 37.1 mg/l nitrogen via plant uptake and nitrification/denitrification process (Figure 4). The major part of nitrogenous compounds removed is attributed to the process of nitrification/denitrification (USEPA, 2000 and Vymazal, 2010).

Previous studies indicated that nitrogen and phosphorus uptake by plants is not a significant mechanism for the removal of these elements in wetlands receiving partially treated municipal wastewater because nitrogen and phosphorus are taken-up and released in the cycle of plant growth and death (Tanner *et al.,* 1999; Griffin *et al.,* 1999).

The removal of TP was found to be high at the beginning of the experiment. As the plant reaches the maturation state the removal of TP was decreased and there are some releases of phosphorus from the dead parts of the plant (USEPA, 2000).

The fate of FC throughout the treatment system is shown in Figures 6 and 7. As the maturity of SSF reached the removal of FC was increased. The dotted line in Figure 6 shows the trend of FC counts. The counts tend to be lower than 10^3. It was noted that the final effluent was complying with WHO (1989) guidelines for treated effluent reuse.

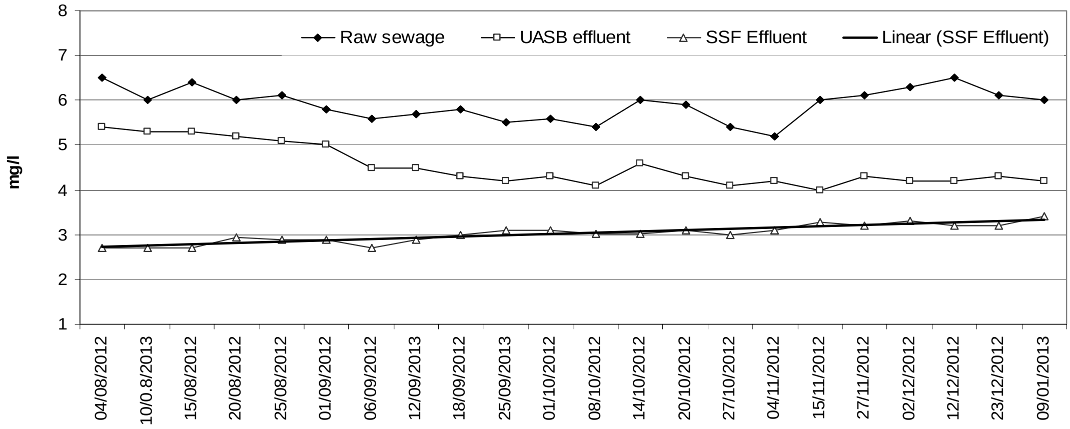

Figure 5: Variations of TP in raw sewage, UASB and SSF effluent

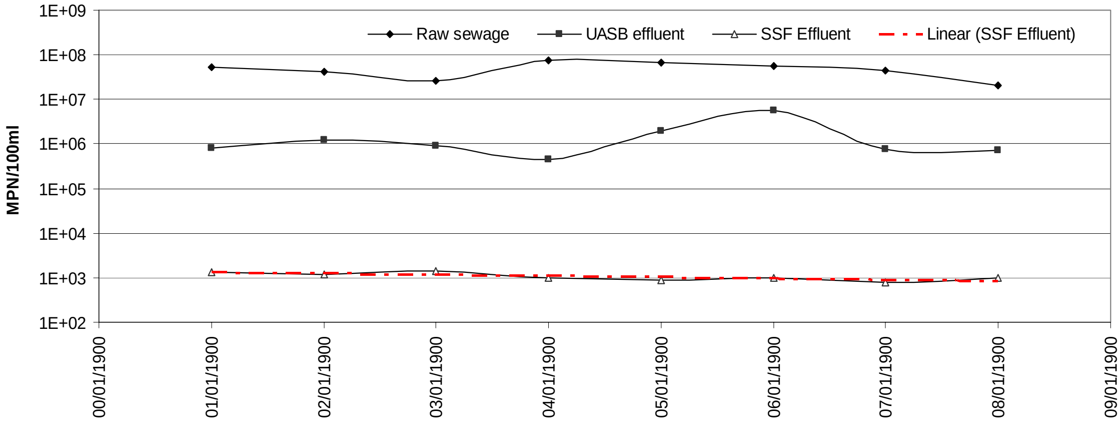

Figure 6: Variations of FC in raw sewage, UASB and SSF effluent

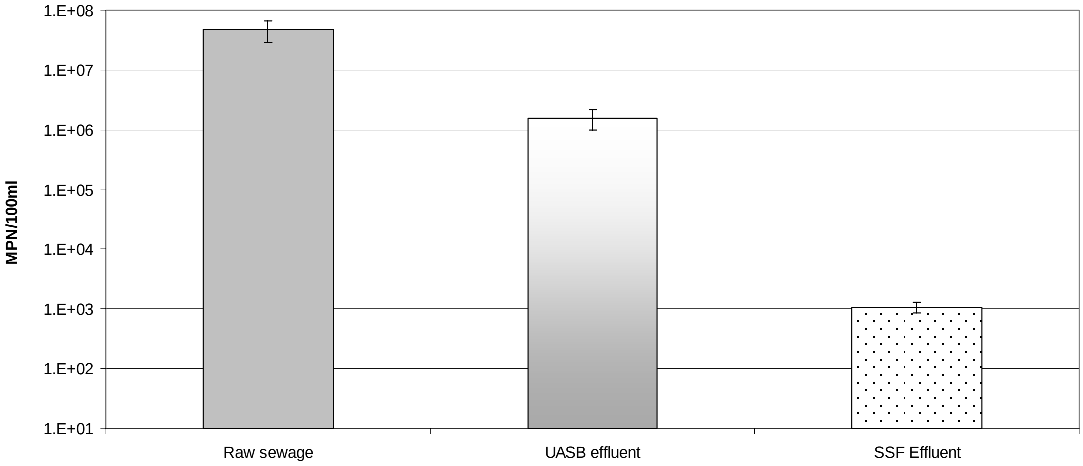

Figure 7: Fate of FC counts throughout the treatment system

Comparison between COD fractions throughout the treatment steps

The fractions of COD (Soluble, colloidal and particulate) are presented in Figures 8, 9 and 10 for sewage water, UASB as well as SSF wetland effluents.

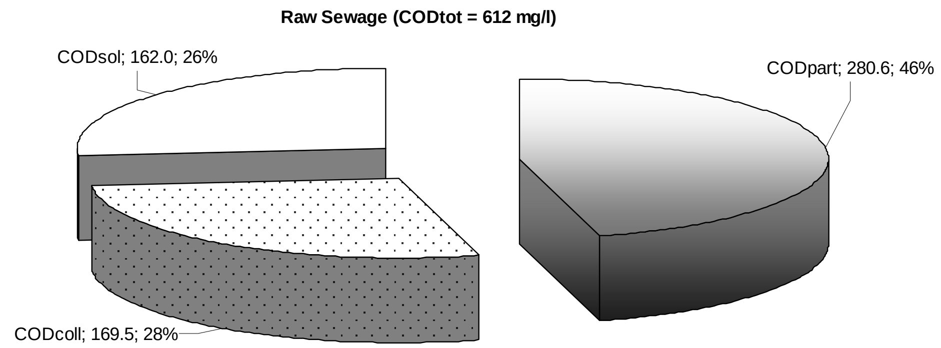

Figure 8: COD fractions of sewage water

It is clear that the major COD fraction in the raw sewage water is COD_{part}, which constitute 46% of the COD_{tot}. While, COD_{coll} and COD_{sol} constitute 28% and 26%, respectively. The pattern of COD fractions is as the following:

COD_{part} □ COD_{coll} □ COD_{sol}

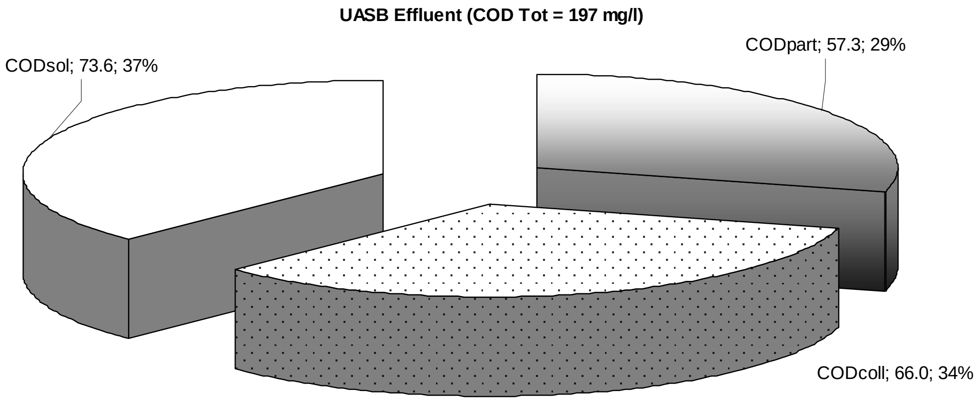

Figure 9: COD fractions of UASB effluent

The UASB reactor affects the COD fractions pattern.

COD_{sol} □ COD_{coll} □ COD_{part}

The hydrolysis process of COD_{part} fraction that were carried out in the UASB reactor increases the COD_{sol} fraction from 26% in raw sewage water to be 37% in the effluent of the UASB reactor.

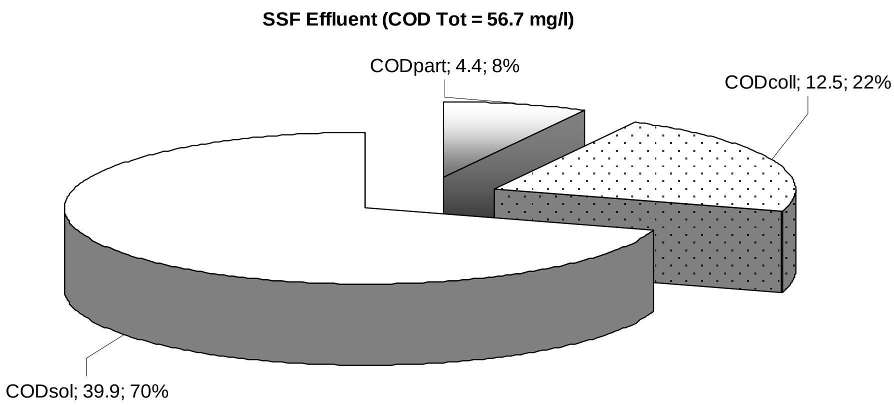

Figure 10: COD fractions of SSF effluent

The treatment of the UASB effluent using SSF shows further enhancement in the percentage of COD_{sol} fraction which increased from 37% to 70%. While, COD_{part} fraction was decreased from 29% to 8%. The COD fraction pattern is as the following:

COD_{sol} □ COD_{coll} □ COD_{part}

The obtained results of the fate of COD fractions were found to be in a good correlation with that obtained by Abdel-Shafy *et al.,* 2009.

4. Conclusions

It was observed that the finally treated effluent was found to be complying with WHO (1989) for treated effluent reuse. Table 6 summarized the efficiency of the combined UASB/SSF wetland system for removal of FC with correlation to WHO Standards (1989).

Table 6: Residual FC count in the effluent of UASB compared with WHO guidelines for treated effluent reuse

Finally treated effluent	1.1 x 10^3 (MPN/100 ml)
WHO guidelines (1989)	$\leq 10^3$ (MPN/100 ml)

Disinfection step could be added to be quite sure that the effluent in a good complying with WHO (1989) guidelines. Application of such treatment systems is a promising technology in the Middle East countries.

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