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Greywater Treatment for Safe Recycling via Hybrid Constructed Wetlands and sludge Evaluation

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Abstract

Arid and semi-arid areas suffer from scarcity of water resources. Nile River is the primary source of drinking water in Egypt. It supplies about 85% of the country need of water. In the meantime, 86% of the total source of Egypt goes for agriculture purpose. Therefore, adequate treated sewage water could be considered unconventional source of water. The separation of sewage water into grey and black wastewater is new trend that could be implemented in the remote areas as an economical and feasible solution for reuse purposes. The present study is concerning with grey wastewater treatment using hybrid constructed wetlands (HCW) enhanced by sedimentation process as pre-treatment. The HCW was subsurface flow (SSF-CW) followed by vertical flow (VF-CW). The hydraulic loading rate (HLR) was 56.6 m^3 $ha^{-1}.day^{-1}$ and the corresponding organic loading rates (OLR) was 239.13 kg BOD_5 $ha^{-1}.day^{-1}$ at 3 days retention time. The COD, BOD_5, and TSS in the final treated effluent were reduced by 90.42, 90.65, and 91.4% respectively. The treatment efficiency proved to be in accordance with the Egyptian laws of discharging the treated wastewater into the sewerage networks, as well as the Egyptian code concerning the reuse of the treated effluent. The study was extended to investigate the quality of the produced sludge. The obtained results indicated that the sludge characteristics comply with the limits of Law (93/1962) for safe reuse as soil conditioner.

Keywords: Greywater; Hybrid constructed wetland, Hydraulic loading rate (HLR); Organic loading rates (OLR); sludge reuse; wastewater treatment

1. INTRODUCTION

The main reason for the growing interest in the reuse of treated wastewater is the increased demand for water resources [1]. Water is the major component of life and is necessary for human existence. It is used for personal hygiene; industrial development, irrigation, farming, and other sectors. Surface and groundwater resources are thought to be at risk from the release of wastewater that hasn't been fully or even partially treated [2]. It is important to maintain the water quality standards set by applicable regulations and to eliminate hazardous substances from wastewater before discharging into the ecosystem [3]. Water scarcity has appeared recently, as it is insufficient for various uses [4], Millions of people around the world are suffering from the problem of water hygiene [5]. This problem increases at this time as the water consumption increases [6,7]. The statistics on water use appear that about 20% of people in many regions suffer from water shortage and this percentage may increase to 50% in the summer period [2,7]. The storm-water runoff, industrial, and domestic are classes of wastewater[8]. Domestic wastewater can be classified into greywater (Bathroom, Laundry and Kitchen), and black water (urine and feces[9]. runoff water quality is determined by many physico-chemical tests. There are many sources of runoff such as parking areas and which have contained extremely high levels of bacteria and rainwater that is quality determined

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chemically and ecologically. Rainwater is produced after a rainfall event that runs through drains or sewers [9]. The main source of industrial wastewater is the sewage of industrial facilities, including battery factories, power plants, food factories, and iron and steel factories. Filtration and chemical precipitation are important wastewater treatment processes [9]. Domestic wastewater is produced from homes, hotels, and other institutions such as universities. Domestic wastewater concentration depends on the water supply, the uses, the climate, the wealth, and the habits of the people [10,11]. Greywater contains shampoo, soap, cooking oils, toothpaste, food scraps, detergents [4,11]. organic matter and heavy metals [10].Greywater produced from the kitchen contains suspended solids [12], while that produced from the dishwasher is very alkaline and shows high-suspended solids and salt concentrations. On the other hand, greywater produced from the bathroom is considered the least contaminated source within a household. Greywater that results from the washing process contains large concentrations of chemical pollutants such as oils, fats, fibers, phosphorous and sodium, and also contains a low percentage of microorganisms [13,14]. Biological treatment is used to treat and break down organic materials.

The selection of cost-effective methods for the treatment of wastewater is important especially in developing countries [9]. Often not especially method applied in developing countries for social and economic reasons. Different methods were used according to the concentrations of pollutants, classes of pathogens, and the quality of the treated effluent [2]. The wastewater treatment process helps greatly in reducing the incidence of diseases caused by water pollution [19-21]. There are many ways to remove pollutants from wastewater such as anaerobic treatment, activated sludge systems, CW systems, and adsorption processes [16].

The CWs are defined as engineered systems that have been designed and constructed to utilize natural processes involving wetland vegetation [22].The CWs are a low-energy system and use much less power than other treatment systems. The treated effluent will be of better quality, suited for reuse in land irrigation. These systems are environmentally friendly, has no contact with the wastewater, and no noise from the system as compared with many other conventional treatment techniques. There is no odor either, the system works effectively to reduce pathogenic bacteria, and thus making it a lot safer to be on-site [23]. CWs possess the microbial assemblages to assist in treating wastewaters, and the biochemical transformation of pollutants, it is biologically productive and self-sustaining [24]. These systems have been constructed to reduce chemical oxygen demand (COD), biological oxygen demand (BOD_5), total suspended solid (TSS), nitrogen (N), phosphorus (P), and heavy metals [25-26]. High space availability, and sunlight, is required for CWs [27]. CWs have low energy consumption, operating cost, maintenance, and are easy to operate [28]. There are several parameters selected for designing CWs which are depending on the type of wastewater and climate, surface area (A), oxygen input, and oxygen consumption, the detention time (t), depth of water (d), depth of substrate (d) [29], sedimentation tank (ST), hydraulic loading rate (HLR), organic loading rate (OLR) and plants [29,30]. The basic classification of CWs is according to the water flow system there are two types, free water surface wetland (FWS-CW) and subsurface flow wetland (SSF-CW). The classification according to the direction of flow, there are three types of SSF-CW horizontal flow constructed wetlands (HF-CWs), vertical flow constructed wetlands (VF-CWs), and hybrid systems (HF+VF). The hybrid systems are combined the two different classes of CWs such as FWS-CW, and VF-CWs) [31-34]. There are some limitations with the use of CWs needed to more space than other wastewater treatment plants. The efficiency of CWs treatment systems may vary seasonally in response to changing environmental conditions, including rainfall. The substrates may be clogged if inlet wastewater is not pretreated well [35]. The removal of pollutants in CWs is a complicated process mainly, including sedimentation, filtration, volatilization, adsorption, plant uptake, and microbial [32].

The FWS-CW has the water surface exposed to the atmosphere resembling natural wetlands. These systems contain shallow wastewater columns. The wastewater is usually on the top of the substrate to support the roots of the plants that are planted. In the FWS-CW, the above layer in the substrate is aerobic while the deeper substrate is anaerobic, aerobic, and/or anoxic [22].The advantages of the FWS-CW are high removal efficiency of suspended solids, organic matter, nutrients (N & P), and high efficiency in the ability of the plants to transport oxygen from the air to the root zone. Uptake of nutrients by plants with subsequent plant harvesting is essential for the export of nutrients (N & P) [2]. The FWS-CW operating costs are low, and construction, operation, and maintenance are straightforward. But, the disadvantage of FWS-CWs requires a larger land area [31]. The wastewater flows through a porous medium under the surface of the bed planted with emergent vegetation. The SSF-CW depends on a substrate that provides a greater area for treatment than FWS-CW [4,11]. The advantages of SSF-CW systems are minimization of odor problems and providing surface area for porous substrate than FWS-CWs systems so that the treatment responds faster [36]. In HF-CWs, wastewater flows horizontally through the under porous substrate until it reaches the outlet. The HF-CWs are using gravel materials as the substrate [27]. The important criteria for designing HF-CWs such as the organic loading rate (OLR) should be BOD_5 is 4 to 10 (g/m².d) or COD is around 16 (g/m².d), the hydraulic retention time (HRT) is around 70 mm/day for greywater [37], the gravel as substrate, the depth of the gravel is (0.5 –1.0) m [38,39]. The slope of the substrate is 1 % to facilitate water [5]. The HF-CWs are used as secondary treatment. It effectively removes COD, TSS, and heavy metals [22]. However, removing the nitrogen is limited [27]. HF-CWs for wastewater treatment can be easily adapted to cold climates [24]. In VF-CWs. the flow of wastewater is slowly and vertically through the substrate until it is discharged [27].

The substrates must have high porosity (comparative with the HLR), and chemical stability [36] The substrates are divided into inorganic materials such as sand, rice husk, and gravel [30] the organic material such as mulch, oak leaf, and sheep manure [52]. The substrate should not contain loam, silt, and fine material [36]. The efficiency of the substrate depends on the HLR, OLR, type of wastewater, and grain size (porosity) [53].

The sedimentation tank (ST) acts as the primary treatment step for the influent wastewater to prevent clogging [30] and increase the performance of the treatment process [31], During this treatment, heavy materials settle to the bottom of the tank as sludge [40], The sludge accumulate in sedimentation tank must be removed regularly [44]. The separation of sludge and liquids is considered the primary treatment, and bacteria naturally occur in sewage entering the ST. They begin to break down and dissolve organic materials in the wastewater under anaerobic conditions [45]. Different plants were used in CWs such as *Pragmatis Australia*, and the *Typha*, Papyrus sedges, *Heliconia*, *Canna lily*, Reeds, *Cyperus altostratus*, etc., [35].Vascular plants can be classified into three types, floating, emergent, and, submerged. The emergent plants grow on water-saturated or submerged soil. The floating plants float on the water surface. The submerged plants grow with both steam and leaves [37]..Planting density is usually about 4 to 6 rhizome/m^2.

The performance of CWs for pollutants removal depends on the design, and operating factors such as the hydraulic loading rate (HLR), the hydraulic retention time (HRT), sunlight exposure, and organic loading rate (OLR) [25]. Sewage sludge is a byproduct of wetland processes, the pollutants in wastewater such as organic matter, nutrients, heavy metals, and microorganisms. The nutrients present in the sewage sludge could help improve and fertility of soil, the organic matter is act as a soil conditioner. This is because sewage sludge contains high amounts of plant nutrients such as nitrogen, phosphorus, calcium, magnesium, and a low concentration of potassium.

The aim of this work was to study the performance of the combined septic tank (ST) and hybrid constructed wetland. The work was extended to study the characteristics and possible reuse of the produced sludge as soil conditioner.

2. MATERIALS AND METHODS

The CWs were constructed as a pilot plant in the premises of National Research Centre, Giza, Egypt. Greywater was collected from a house adjacent to the pilot plant system. The study was carried during the period from October 2019 to October 2021. Figure (1) illustrates the arrangement of the wetland system.

2.1 Sedimentation tank (ST)

The volume of the sedimentation tank was 50 L, which was used as the primary treatment step. The effluent from the sedimentation tank was fed to the horizontal free water surface wetland (H-CW).

Figure 1: Photo of the h-CW that used in the study

2.2 The h-CW

The SSF-CW was used as a secondary treatment step. The effluent of (SSF-CW) was fed to the vertical flow wetland (VF-FWS). The VF-FWS was the final step in wetland system treatment. Table (1) shows the dimensions and the operating conditions of the SSF-CW, and V-CW used in this study.

Table 1: Operating conditions of the SSF-CW, and V-FWS wetland

Dimensions and Operating Conditions	
Length	2.0 m
Width	0.60 m
Depth (substrate)	0.50 m
Plant	Reeds
No. of rhizomes m^{-2}	3
Porosity of gravel	0.34
HRT	3 days
HLR	56.6 m^{3}ha^{-1}.day^{-1}
OLR	239.13 g BOD_5 ha^{-1}.day^{-1}

2.3 Aquatic Plants in CWs

Phragmites australis (Reeds*)* as an aquatic plant was used in the present study. Such plants have a high productivity, and available in the environment scale [58]. The plant rhizomes were collected from a nearby drain, Marutia, Giza. The plant was washed several times with tap water before planting in the CWs at a density of 3 rhizomes/m^2.

2.4. Calculations of the constructed wetlands "CWs"

2.4.1 Hydraulic retention time (HRT)

The operating conditions were monitored according to the equations (1, 2, 3) [8]:

$$Q = \frac{A\,.\,d.\,\eta}{t} \quad (1)$$

Where Q is flow rate m^3/day, A is surface area m^2, d is the depth of substrate m, h is the porosity of substrate, and t is detention time (day).

$$OLR = \frac{C.\,d.\,F1.\,\eta}{t.\,F2} \quad (2)$$

Where OLR is organic loading rate, C is a concentration of BOD$_5$ of the influent, mg/L, d is the depth of substrate m, h is the porosity of substrate, t is detention time (day), F$_1$ is constant = 0.001 kg g^{-1}, F$_2$ is constant = 0.0001 ha.m^{-2}.

$$HLR = \frac{Q}{A} \quad (3)$$

Where Q is flow rate m^3/day and A is surface area (m^2).

2.5 Analytical Methods

2.5.1 Greywater characteristics

The greywater characteristics indicated that such wastewater is relatively strong as exhibited by the ammonia, COD, BOD$_5$, nitrate, oils & greases, phosphate, and TSS.

2.5.2 Sampling and testing

The samples were collected in glass bottles from the inlet (greywater) and the effluents of ST, SSF-CW, and V-FWS. The analysis was carried out weekly for the samples. The physicochemical analysis was performed according to standard methods for the examination of water and wastewater, American Public Health Association (APHA) [59].

2.5.3 Characteristics of the sludge

- **Sludge management**

The sludge was collected from the ST. The sludge was dried using drying beds located in the experimental field. The sludge was dried for a period of one week to ten days, then the sample is crushed, and then sieved with a size of (700-900) µm, then an extract of the sludge was made and dissolved in water (1 g per 1L of distilled water). Then calcium was measured according to APHA [59]. The heavy metals were determined when 20 ml of nitric acid is added to 1 g of sludge sample and placed on a hot plate for 40 minutes. Then it is left to cool and then filtered, supplemented to 1L with distilled water. The solution is used for the determination of heavy metals by the atomic absorption spectrometer equipped with a graphite furnace (Thermo Fisher Scientific American provisional of scientific) [60].

- **Calculation of sludge physical characteristics**

The sludge moisture content acts as a ratio of weights before and after the drying process in an oven at a temperature of 105 °C until a steady mass is obtained equation (4). The volatile content acts as weights before and after the drying process in an oven at a temperature of 550 °C until a steady mass is obtained according to equation (5) [60]. Ash content is obtained according to equation (6) [60]. Solid content act as the total solid of sludge obtained according to equation (7)[60].

$$\text{Sludge moisture at } 105°\text{C } (\%) = \frac{(\text{W B} - \text{W A}) \times 100}{\text{W B}} \quad (4)$$

Where W$_B$ is the weight of the initial sample and W$_A$ is the weight of a dry sample

$$\text{Volatile content at } 550°\text{C } (\%) = \frac{(\text{W B} - \text{W A}) \times 100}{\text{W B}} \quad (5)$$

Where W$_B$ is the weight of the initial sample and W$_A$ is the weight-burning sample

$$\text{Ash content } (\%) = \frac{\text{W of ash} \times 100}{\text{W B}} \quad (6)$$

Where W$_B$ is the weight of the initial sample and W$_{ash}$ is the weight of ash content

$$\text{Solid content } (\%) = 100 - (\text{ volatile content } \% + \text{ moisture content } \% + \text{ ash content } \%) \; (7)$$

2.5.4 Physicochemical characteristics of Greywater

The physicochemical characteristics are ammonia-nitrogen (NH$_3$–N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), organic nitrogen (Org. N), chemical oxygen demand (COD), biological oxygen demand (BOD$_5$), nitrate (NO$_3$-N), nitrite (NO$_2$-N), oils & greases, total phosphate (PO$_4^{3-}$), total suspended solids (TSS), pH, total dissolved solids (TDS), temperature (T °C), sodium (Na), potassium (K), electrical conductivity (EC), calcium (Ca), magnesium (Mg), and turbidity. The testing methodology was carried out according to the APHA [59].

3. RESULTS AND DISCUSSION

3.1 Characteristics of raw greywater

Table (2) shows the characteristics of greywater compared to the law:48/1982 [3]. It can be concluded that the level of COD and BOD$_5$ do not comply even with the permissible limits for reuse under the category of third class “primary treated effluent” [11, 16]. The COD and BOD_5 ranged from 670 to 770 mg/L and 385 to 460 mg/L, respectively. The ratio of BOD_5/ COD ranged from 0.57 to 0.6. The TSS and oil&grease varied from 401 to 475 mg/L and 95 to 133 mg/L, respectively. The turbidity ranged from 111.2 to 128 NTU. The total nitrogenous species represented by ammonia, nitrate, nitrite, and Kjeldahl nitrogen in influent samples varied from 4.8 to 5.3 mg/L, 0.8 to 1.05 mg/L, zero mg/L, and 19 to 35 mg/L, respectively. Total phosphate in greywater varied from 7.1 to 10.5 mg/L.

Table (2): Physicochemical characteristics of raw greywater

Test	Max.	Min.	*Ave.	law:48/1982
pH (Unit)	7.60	6.30	----	6.00 - 9.00
TDS (mg/L)	670	565	617.5	2000
EC (µs/cm)	1005	980	992.5	250-750
BOD_5 (mg/L)	460	385	422	40
COD (mg/L)	770	670	720	80
TSS (mg/L)	475	401	438	40
Oils (mg/L)	133	95	114	5
Turbidity NTU	128	111.20	119	-----
NH_4^+ (mg/L)	5.30	4.80	5.05	2.5
PO_4^{3-} (mg/L)	10.5	7.70	9.10	2
NO_3^- (mg/L)	1.05	0.80	0.92	40
NO_2^- (mg/L)	ND	ND	ND	-----
TKN (mg/L)	35	19	27	15

Note: - ND is Not Detected; NTU is Nephelometric Turbidity Unit. *Average for 10 samples from raw greywater

3.1.1 Heavy metals

The presence of heavy metals in raw greywater is presented in Table (3).

Table (3): The heavy metals concentrations in the raw greywater

Test	Zn mg/L	Fe mg/L	Cd mg/L	Ni mg/L	Cr mg/L	Cu mg/L	Pb mg/L
Max. values	0.07	0.50	0.05	0.02	0.02	0.04	0.03
Min. values	0.02	0.20	0.03	0.01	0.00	0.01	0.01
*Average	0.045	0.35	0.04	0.015	0.01	0.025	0.02

*Average for 10 samples from raw greywater

3.2 The performance of ST for removal of

The raw greywater was subjected to a sedimentation process within the ST.

3.2.1 Chemical Oxygen Demand (COD), Total Suspended Solid (TSS) and Biological Oxygen Demand (BOD_5)

The results of COD, BOD_5, and TSS after sedimentation ranged 1.0 to 2.0 hr, 460 mg/L, 243 mg/L, and 295 mg/L, with corresponding removal value of 60.0%, 60.86 %, and 62.17 %, respectively. The results indicated that the concentration of COD, BOD_5, and TSS of greywater was significantly reduced after sedimentation process for 1 to 2 hr. These results are in a good agreement with Ahmed et al., (2017) [63]. The sedimentation tank allowed solids to separate from the liquid, the accumulated solids have undergone biological degradation that resulted in reducing the TSS, turbidity, BOD_5, and COD [65]. The average BOD_5/COD ratio was (0.57-0.65) which means that most of the TSS in the greywater was organic, so using a sedimentation tank enhances the quality of the greywater. The decrease in COD, BOD_5, TSS, and Turbidity by these processes is attributed to the precipitation of particulate organics matters. The COD and BOD_5 removal are due to the biodegradability of organic pollutants, and have enhanced for settling rate needed to decrease the concentration of COD in the greywater [66].

3.2.2 Removal of nitrogenous species and Phosphate (PO_4^{3-})

Variations of NH_4^+, PO_4^{3-}, NO_3^-, and TKN values of raw greywater are shown in Table (2). The concentrations of NH_4^+, PO_4^{3-}, NO_3^-, and TKN after sedimentation ranged from 0.98 mg/L, 1.49 mg/L, 0.12 mg/L, and 3.14 mg/L with removal rates of 84.68%, 75.85 %, 87.23 %, and 77.57%, respectively. The sedimentation processes of plays a vital role in the removal of nitrogenous species. The TKN and NH_4^+ can be removed from greywater by volatilization of ammonia gas (NH_3^+), the removal of TKN, and NH_4^+ were enhanced by converting ammonia to NH_3^+ form at settling process [66].

3.2.3 Heavy metals

Table (4) shows the measured concentrations of heavy metals in raw greywater as well as the effluent of sedimentation tank. The effluent of sedimentation tank contains heavy metals as in the following ascending order: Pb < Fe < Cu < Zn < Cd < Ni = Cr

3.3 Performance of the h-CW system

The HRT was kept constant at 72 hrs. The OLR was 239.13 BOD_5 ha/day. The plant rhizomes were planted at a density of 3/m^2 rhizomes began to grow after two weeks.

The objective of this experiment was to the determine performance of the SSF-CWs at HRT = 72 hrs. This study carries out on 10 samples. The performance of the h-CW is summarized below (Figures 3-9).

Table (4): Performance of sedimentation tank for heavy metals removal

Test	Zn mg/L	Fe mg/L	Cd mg/L	Ni mg/L	Cr mg/L	Cu mg/L	Pb mg/L
Raw greywater	0.02	0.50	0.05	0.02	0.019	0.04	0.03
After chemical coagulation ($FeCl_3$)	0.002	0.29	0.003	ND	ND	0.012	0.024
R %	90	42	94	100	100	70	20

Note: - ND is below detection limits (0.001 mg/l); R %= percentage of removal.

3.3.1 Chemical Oxygen Demand (COD), Total Suspended Solid (TSS) and Biological Oxygen Demand (BOD_5)

The COD, BOD_5, and TSS removal was 90.42%, 90.65%, and 91.41%, respectively. The concentrations of COD, BOD_5, and TSS in SSF-CWs effluent are presented in Figures (2-5). The data indicated the good performance of SSF-CWs concerning organic compounds, and suspended solids removal. This good performance could be attributed to the high detention time; which improves the hydrolysis and biodegradation of organic matter contents of the greywater [70].

The removal of COD and BOD_5 is a biological, chemical, and physical treatment process. Oxygen supply is an important factor in the operation of any biological system. The roots would supply oxygen and provide additional surface for biofilm growth [71]. Simple bacteria decompose the organic pollutants present in the greywater. Through their degradation, the organic pollutants are transformed into cellular mass [29]. The TSS is removed by physical processes such as sedimentation and filtration followed by aerobic microbial degradation in the substrate [20]. The TSS is removed by the wetlands system due to the filtrations process in the substrate gravel. The filtration process occurs by the effect of particles onto the roots or the gravel in the SSF-CWs [24]. The removal of TSS, COD, and BOD_5 in this process according to equation (12) [1],

$$\text{Organic matters} + O_2 + NH_3 + PO_4^{3-} \xrightarrow{\text{Microorganism}} CO_2 + H_2O + \text{New Cells} \quad (1$$

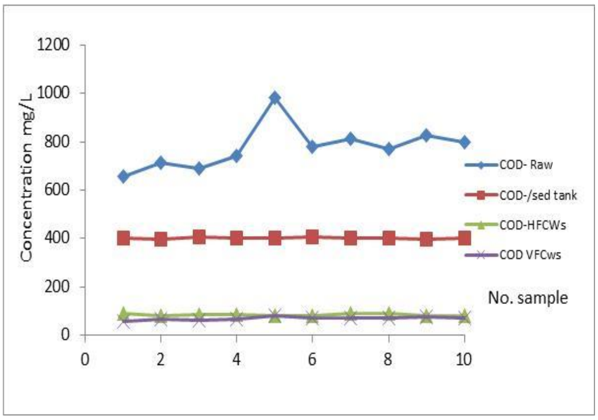


Figure (2): Variation in COD of raw greywater and different treated effluents

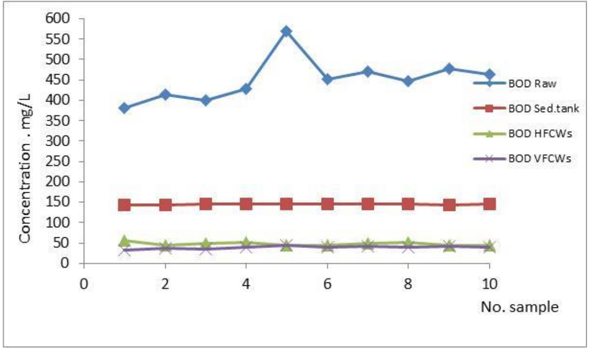


Figure (3): Variation in BOD_5 of raw greywater and different treated effluents

3.3.2 Removal of nitrogenous species and Phosphate (PO_4^{3-})

The TN, Org. N, NH_4^+, $PO_4^{3-,}$ NO_3^-, and TKN removal are presented in Figures 6-9. The TN, Org. N, NH_4^+, PO_4^{3-}, NO_3^-, and TKN were 98.11%, 99.38%, 96.30%, 98.80%, 97.65%, and 98.16%, respectively. Different forms of nitrogen can be existed simultaneously at varying concentrations, including Org. N, NH_4^+, NO_2^-, NO_3^-, and N_2, So the removal rate of TN depends on the removal rate of NH_4^+ and NO_3^- [٥٦]. Removal of nitrogenous occurred in a series of complex transformations including nitrification/denitrification process [73]. The concentration of ammonia was decreased in SSF-CWs due to the nitrification process [70] according to equation (13).

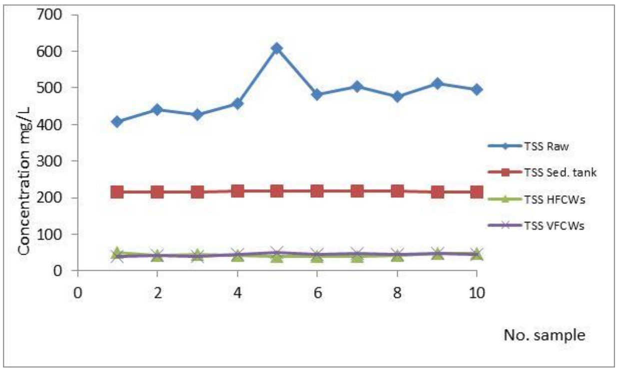


Figure (4): Variation in TSS of raw greywater and different treated effluents

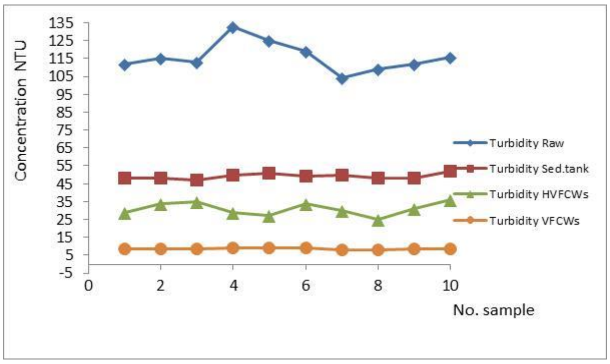
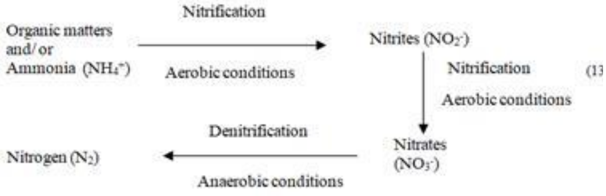


Figure (5): Variation in turbidity of raw greywater and different treated effluents



The concentration of total phosphate (PO_4^{3-}) was reduced in the h-CW system by sedimentation and filtration by gravel, and uptake by plants [70]. The nitrogen and phosphorus uptake by plants is not a significant process due to the taken up and released in the cycle of plant's growth and death [70].

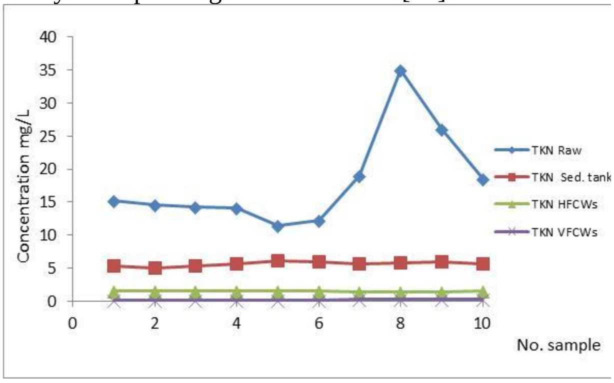


Figure (6): Variation in TKN of raw greywater and different treated effluents

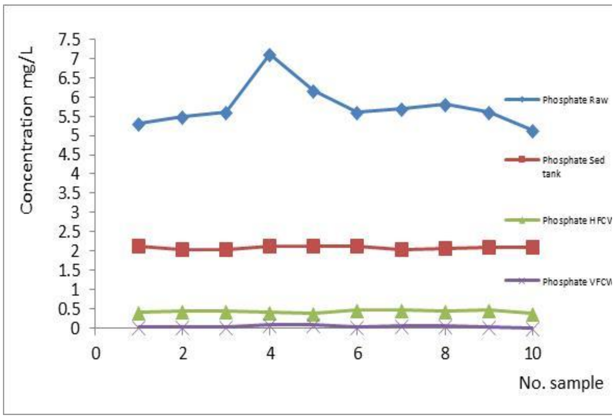


Figure (7): Variation in PO_4^{3-} of raw greywater and different treated effluents

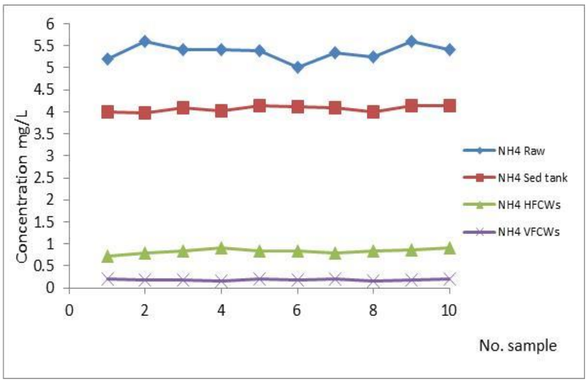


Figure (8): Variation in NH^{4+} of raw greywater and different treated effluents

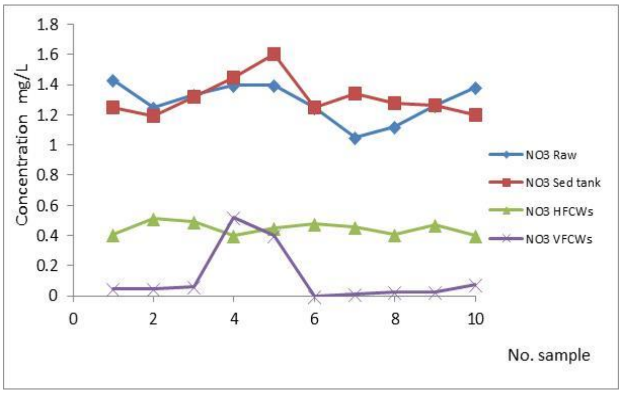


Figure (9): Variation in NO_3 of raw greywater and different treated effluents

3.4 Evaluation of Sludge Produced during the Sedimentation process

3.4.1 Sludge management

The sludge contains useful concentrations of nitrogen, phosphorus (N, P) and other valuable metals that consider plant nutrients including Fe and Mn. Sludge contains also other metals such as Ca as soil conditioner. The results in Table (5) indicate that the sludge contains of low concentration of heavy metals. The sludge physical characteristics are given in Table (5). The concentrations of toxic elements in soils must not exceed certain limits within the normal depth of cultivation as a result of sludge application. In order to prevent any adverse impact on plants, the availability of phosphorous content in this system is about 6.5%. Meanwhile, the availability of nitrogen is more dependent on sludge application within 4.68%. Similarly, the phosphorous is readily available from sludge application to plants particularly to grasslands. The organic matter in sludge can improve the water-retaining capacity and structure of some soils. So the sludge obtained from the sedimentation tank can be treated to be used as soil fertilizer [75-77]. Organic matter added to the soil as greywater sewage sludge composts improved the soil properties, such as bulk density, porosity, and water holding capacity [78].

The greywater sewage sludge was characterized to evaluate its fertilization value, Table (5). These results indicated that this sludge contained organic carbon, and other macronutrients including (N, P, and K) which can be important as soil conditioners [57]. In meantime, level of heavy metals including (Fe, Cu, Zn, Mn, Ni, Cr, Cd, and Pb) are within the permissible limits according to law 93/1962. It is well documented that the total N and P contents increased in the soil fertilities [81, 82,83].

Table (5) Chemical, and microbial analysis of sludge

Element	Raw sample mg/Kg	After sedimentation mg/Kg	Concentration limit (Law 93/1962)
pH	7.9	8.25	----
P	0.42	6.5	----
Ca	0.35	18.3	----
Mo	0.14	4.50	18
N	0.57	4.68	----
Se	0.78	4.52	36
Hg	0.038	0.041	17
Zn	0.85	0.75	2800
Pb	0.014	0	300
Ni	13	16.5	420
Cu	0.20	0.42	1500
Cd	0	0	39
As	0.015	0.015	41
protozoa	+Ve	ND	ND
Faecal coliform	$64*10^{5}$	$<1.8*10^{2}$	$1.8*10^{2}$

3.4.2 Dewatering and Storage

Digestion of sludge was applied by drying process. Dewatering of sludge can be occurred through water evaporation technology that employs dewatering by sludge drying beds. The effect of thermal change on sludge samples was studied. The physical, chemical, and biological properties of sludge are given in Table (6) [83, 84]. The higher organic matter proportion in sludge decreases the bulk density and increases the aggregate stability. These improves the soil's physical properties [82, 85]. Drying sludge by sludge drying beds took between 2 to 3 months [75, 86].

Table (6) physical characteristics of sludge

Content	Raw	After sedimentation
Moisture %	5.10	8.14
Volatile %	65.10	34.51
Ash %	8.50	3.35
Fixed %	21.3	54.00

Conclusions

- Treatment of greywater by constructed wetlands exhibited promising results particularly in the removal of organic loads and the treated effluent can be safely re-used for agriculture purposes [84].
- The final treated effluent proved to be in compliance with the law of 84 for the year 1982 (concerning the protection of the Nile River) from pollution.
- The obtained results indicated that the SSF-CWs at the implemented HRT are effective in removal of NH_4^+, PO_4^{3-}, NO_3^-, Org. N, TKN, TN, turbidity, COD, BOD_5, and TSS.
- The removal efficiency of NH_4^+, PO_4^{3-}, NO_3-, Org. N, TKN, T.N, COD, BOD_5, TSS and turbidity reached 96.30%, 98.80%, 97.65%, 99.38%, 98.16%, 98.11%, 90.42%, 90.65%, 91.41%, and 92.53% respectively.
- The characteristics of the final treated effluent proved to be in accordance with the Egyptian laws of discharging the treated effluent comply and with the limits of Law (93/1962) for safe reuse in agriculture.
- It is recommended to use the h-CW treatment system for the treatment of greywater not less than 48 hrs HRT.
- This study deals with the evaluation of the sludge resulting from the implemented treatment process.
- The obtained sludge proved to is a good source of organic matter as well as nutrients for the plant. Dry sludge can be used as soil fertilizer and can be replaced in the future by costly inorganic fertilization. The sludge provides the soil with essential nutrients as well as increasing the pH of the soil through the use of coagulants materials during the sedimentation process.

- **Conflicts of interest**

  There are no conflicts to declare

- **Formatting of funding sources**

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