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Assessing Domestic Wastewater Treatment Based on Wastewater Quality Index WWQI Using Constructed Wetland at Al-Diwaniyah, Iraq

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ABSTRACT

This study investigated suitability of domestic wastewater treated by wetlands at Al-Diwaniyah city in Iraq for irrigation purposes. A physical model has been built to consist of a primary sedimentation tank feeding a vertical subsurface flow-constructed wetland (VSSFCW) unit, and operated with a continuous flow rate of 150, 86 and 75 liters/hr of raw domestic wastewater supplied from a manhole of a residential area at Al-Diwaniyah city. The sedimentation tank was gravitational type with a rectangular shape. The VSSFCW unit was 0.24 m^3 in active size having underdrain and three stratified gravel layers supporting 8 cm sand layer. The unit vegetated with 12 plants of Typha domingensis. The model operated over the course eight months, August 2022 to April 2023, through which influent and effluent samples of the unit were collected and tested for Potential of Hydrogen (pH), Electrical Conductivity (EC), Total Suspended Solids (TSS), 5-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Phosphorous (TP), and Total Nitrogen (TN). The objectives of this study were; to evaluate the treatment efficiency based on water quality index (WQI) classifications of the Canadian Council of Ministers of the Environment (CCME), and assessing treated water validity for irrigation use according to Iraqi standards (IQS-2012) and Egyptian guidelines for the reuse of recovered water (Egypt Decree 2013). It was observed that using VSSFCW can effectively improve the characteristics of the wastewater. Some parameters in the treated wastewater agreed with the Iraqi standards (IQS-2012) like; pH (7.16 to 7.5), EC (1919–1948 μS/m), TSS (7 to 10 mg/L) and TN (2.14 to 6.25 mg/L). The other parameters were slightly higher than the limits like; BOD_5 (12 to 75 mg/L), COD (104 to 200 mg/L) and TP (2.182 to 3.35 mg/L). However, the WQI computed according to water quality index of Canadian Council of Ministers of the Environment (CCMEWQI) is 69.6 considered fair within the range 66 – 79 and can be used for irrigation directly or after dilution with clean water. Results of this study encourage adopting the VSSFCW to treat domestic wastewater with saving in cost of construction, operation and transportation requirements as compared with conventional treatment systems.

1. INTRODUCTION

Water is recognized as the lifeblood and nerve of the planet and as the first fundamental tenet upon which all other development is predicated. There are issues with the remaining freshwater that is used by people, animals, and plants; these issues are reflected on the freshwater declining quantity and quality caused by problems of water pollution and noticeable population growth [1].

Global shortages of energy and water have prompted significant efforts to develop energy-efficient wastewater remediation technologies. In addition to the issue of fresh water scarcity, pollutants have negatively impacted numerous sources, including rivers and lakes, by degrading the quality of the water. Global shortages of both energy and water have prompted significant efforts to develop energy-efficient wastewater remediation technologies [2-4]. Water quality is crucial to understanding the acceptability of treated effluent wastewater for a range of applications before releasing it into freshwater bodies. Treated wastewater is considered an effective alternative water resource that can be consumed in a variety of water usages purposes. Treating wastewater with wetlands is one of the simple and low-cost methods that has proven effectiveness [5]. Constructed wetlands offer a low-cost, secure, efficient and environmentally sound method of wastewater treatment, making them highly suitable techniques. Nowadays, constructed wetlands rank among the most widely applied techniques around the world.

Numerous studies have been thoroughly examined and extensively employed constructed wetlands, and confirmed their noticeable benefits for the treatment of wastewater generated from a variety of sources, including residential and commercial wastewaters [6-9].

De Troyer et al. [10] examined chemical and ecological water quality in a riverine environment at rapidly expanding city in southwest Ethiopia and suggested potential remediation measures that were assessed using an empirical model. They showed that after the contaminated river water passed through wetlands, the contamination decreased more than 92%, demonstrating the natural wetlands capacity for purification and the significance of preserving and safeguarding those ecosystems. Their findings confirmed that when municipal wastewater is efficiently collected and sent to wetlands for treatment, the quality of treated water could be significantly enhanced. Abdelhakeem et al. [11] investigated performance of a vertical subsurface flow wetland for the treatment of sewage in Egypt over the course of eight months under various operating conditions, The purpose of their study was to determine how vegetation and substrate type affect the removal of NH_4, Chemical Oxygen Demand (COD), 5-day Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), and Total Phosphorous (TP) in all conditions examined. For unplanted beds, the average removal efficiencies of COD, BOD_5, TSS, NH_4, and TP were 29, 37, 42, 26, and 17%, respectively; for planted beds, these values increased to 75, 84, 75, 32, and 22%. Abdel-Shafy and Al-Sulaiman [12] confirmed that adopting constructed wetland alternative for both; horizontal flow (CWHF) and vertical flow (CWVF) as easy, affordable, energy-efficient, and environmentally acceptable methods for treating greywater in urban and decentralized settings. As degreasing and settling procedure come first, they focused on evaluating ideal degreasing/settling time. They looked explored additional treatment using a hybrid-built wetland. The final removal rates they reached for TSS, COD, BOD_5, TP, NO_3, oil and grease, and Total Kjeldahl Nitrogen (TKN) were 87%, 83%, 88%, 91%, 36%, 92%, and 58%, respectively. García-Ávila et al. [13] examined the capacity of two plant species to purify household wastewater in subsurface created wetlands with vertical flow that were set up on a pilot scale and supplied with wastewater that had undergone prime remediation. Cyperus papyrus and Phragmites Australis were the selected species. They concluded considerable capacities for eliminating pollutants such as TP (50%), ammoniacal nitrogen (69.69%), fecal coliforms (95.61%), BOD_5 (80.69%), and COD (69.87%). Barya et al. [14] evaluated the potential efficacy of Acorus calamus and Canna indica, two macrophytes, in remediating household wastewater using VSSFCWs. Their results illustrated removal of BOD_5, TDS, TP, and Total Nitrogen (TN) was successfully accomplished by both wetland systems. Canna indica-grown wetland was the most successful in eliminating 81.79%, 22.31%, 80%, and 60.37% of the sample, in that order. Other studies have confirmed that subsurface vertical flow wetland as an efficient decentralized method for removing contaminants from household and municipal wastewater [15, 16]. This approach is easy to use, inexpensive, energy-efficient, and suitable for urban and decentralized settings.

To evaluate treated wastewater quality and associated treatment, numerous wastewater quality indicators have been created, including wastewater quality index (WWQI) that allow for quick, efficient and easy judgment and decision-making [17]. The WWQI, which displays a single value that represents the entire characteristics of the wastewater, may be regarded as a practical and efficient method for evaluating wastewater quality. It could be used to show whether a wastewater is suitable for a certain application in managing water quality and making decisions. Among different types of WWQI, CCMEWQI, has proven as a successful tool that simply utilized for evaluating treated water suitability for irrigation proposes [18].

This study is focusing upon the treatment of domestic wastewater using the VSSFCW that comes after the primary sedimentation process. The WWQI is monitored for particular wastewater elements under various operating settings during the various settling periods that the VSSFCW follows in order to evaluate the water quality produced by such a system. In accordance with the Iraqi standards and the CCMEWQI, the treated wastewater is repurposed for irrigation and other uses.

2. MATERIALS AND METHODS

2.1 Sources of raw wastewater

Domestic wastewater is collected from one manhole belongs to sewage collecting network in Al-Diwaniyah city south-central Iraq at the coordinates: Lat: (31°58ʹ28.809" N) and Long: (44°53ʹ24.173" E). No contribution for industrial and commercial areas in the wastewater collected. It represents collection of wastewaters generated from kitchen sinks, cloth washing machines, dishwashers, and hand wash sinks. The wastewater is pumped into a sump tank with (0.4 × 0.4 × 0.8) m dimensions, from which the wastewater is pumped again by means of submerged pump (0.5 hp) to the sedimentation tank and the VSSFCW unit those connected in series as illustrated in Figure 1. The physical process, which involved the sedimentation tank and pre-treatment to remove relatively large particles, was the first operation unit of the experiment. The sedimentation tank effluent was redirected into biological processes as constructed wetlands by means of gravity.

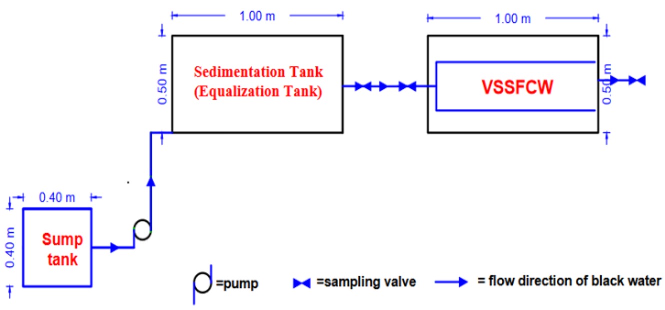

Figure 1. Schematic diagram for the arrangement of the treatment system

2.2 Sedimentation tank

The settling tank was with a capacity of 300 liters made of polyvinyl chloride "PVC". The dimensions of the tank were 0.60 m height, 0.50 m width and 1.00 m length. The tank outlet was connected to the second tank (CSSFCW) such that the flow is by gravity to the CSSFCW. Settling tank inflow rates were 150, 86 and 75 liters/ hr corresponding to a surface overflow rate "SOR" of 0.3, 0.172 and 0.15 m/hr, and a retention time of 2, 3.5 and 4 hr, respectively. Such retention times match what adopted in previous studies mentioned. The tank removal efficiency was evaluated at 2, 3.5, and 4 hours of settling time. A hole was used at the bottom of the sedimentation tank and fitted it with a valve to remove the sludge after each experiment. After every experiment, the sedimentation tank was cleaned and rinsed with tap water.

2.3 Constructed wetland unit

The vertical subsurface flow constructed wetland tank made of galvanized iron located at the top of an iron stand situated about 0.25 m above the ground. Tank volume of was 0.24 m^3, containing gravel stratified layers as supporting media. The depth of the bed is 8 cm that agrees with minimum bed thickness [19]. The tank had a PPR entrance pipe at its top fed by gravity from the sedimentation tank, connected with a horizontal network of perforated diffusing pipes 2.5 cm in diameter located 5 cm above the packed bed. The media substrate was 0.48 m deep, whereas the basin was 0.6 m deep. The surface area of the tank was 0.5 m^2 indicating wetland aspect ratio (length to width, L/W) as 2:1 which is attached to the depth to length of the influx route that guarantees a proper hydraulic gradient across the bed [20-22]. To enable sampling at the head and bottom of the bed, two sampling tubes are positioned along the bed. These tubes are composed of straightforward 50 mm (PPR) cleft pipe lengths. The Hydraulic Retention Time "HRT" of the system to reach acceptable equilibrium state was 2 days [23]. The dimensions and operating conditions through the CW are represented in Table 1.

Table 1. The constructed wetland dimensions and operating conditions [23]

No. of Units	1
Length	1.0 m
Width	0.6 m
Total Water Depth	0.48 m
Plant	Typha domingensis
No. of Rhizomes / m^2	12 plants
Substrate Layers	(8 cm) thick layer of sand (0.6–1) mm; (15 cm) thick layer of small gravel (6–10) mm; (10 cm) thick layer of middle gravel (20–40) mm; (15 cm) thick layer of large gravel (40–50) mm.
Inlet and Outlet Pipes Material	PVC
Release and Retain Greywater	By valves

2.4 The manmade wetland vascular plants

The common Typha domingensis found in Iraq was employed. The plants were gathered from the AL-Saniyah sub-district that belongs to Al-Diwaniyah. The rhizomes were taken out of a nearby marsh, numerous times cleaned with distilled water, and then planted at a density of 24 rhizomes/m^2 [24] in the CW.

2.5 Collection of samples

Treated water samples were taken from Sedimentation and CW tanks, while raw water samples were collected from the submerged water pump before to the sedimentation tank. Under different operating conditions, a comprehensive program was followed to collect weekly samples of the raw water and various remediation effluents between August 2022 and April 2023. The temperature varied within a range of 10-32.5°C during the program period. The physico-chemical analysis of all water samples was conducted in accordance with APHA (2017) [25]. One hundred samples were tested; 30 samples were measured in the field. (Temperature, pH, and EC), and 70 samples were measured in the laboratory (TSS, BOD_5, COD, TP, TN, Fecal-Coliform, and total fecal–coliform). A mercury Celsius thermometer of the centigrade type was used to measure the temperature of samples with an accuracy of ±1°C. A Schott type device was used to measure pH and EC of water at the pilot plant. COD tests were carried out for the samples following Colorimetric Method 5220D, while TN test was according to the Kjeldahl system instrument. TP was tested using the stannous chloride technique with a UV-VIS spectrophotometer used to measure the blue color intensity at a wavelength of 690 mm. BOD tests were carried out according to the 5210B standard method using magnesium sulfate (Mg_SO_4), calcium chloride ($CaCl_2$), and ferric chloride ($FeCl_3$). TSS tests were according to 2540 D.

Comparison of the results was continuously carried out with the allowable limits for irrigation water reuse in Iraq [26] and Egypt's standards (Egypt Decree 2013) [27].

2.6 Water quality index adopted

The WQI is a unitless number that ranges from 0 to 100 and describes the overall characteristics of water by indicating the quality value of an aggregated collection of measurable physical, chemical, and biological data [28]. This index aids in developing a capable model to optimize the treatment procedures and suitability assessment of the treated effluent for irrigation or other purposes. The following formula was used to calculate the water quality index.

$$CCMEWQI = \left[100 - \left(\frac{\sqrt{f_1^2+f_2^2+f_3^2}}{1.732}\right)\right] \tag{1}$$

where, f_1 is the scope, f_2 is the frequency, and f_3 is the amplitude.

$$f_1 = \left[\left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right) \times 100\right] \tag{2}$$

$$f_2 = \left[\left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right) \times 100\right] \tag{3}$$

$$f_3 = \left[\left(\frac{NSE}{T0.01\ NSE + 0.01}\right)\right] \tag{4}$$

$$NSE = \left[\left(\frac{\sum_{i=1}^{N} excursion}{number\ of\ tests}\right)\right] \tag{5}$$

$$excursion_i = \left[\left(\frac{failed\ test\ values_i}{Obective_i}\right) - 1\right] \tag{6}$$

where, *NSE*: Normalized sum of excursions.

3. RESULTS AND DISCUSSION

3.1 Characteristics of raw wastewater

Tables 2 and 3 list the analysis results of the raw wastewater characteristics. Generally, the levels of physical, chemical and microbiological parameters of the raw wastewater were higher than the permissible limits, whereas those of the treated effluent were within limits.

Table 2. Influential characteristics of raw wastewater before CW

Parameters	Units	Minimum Value	Maximum Value	Mean Value	Permissible Limits IQS	Egypt Decree (2013)
Temperature	°C	27.0	27.6	27.3		
pH		7.66	7.8	7.72	4-8.6	
EC	µs/cm	2140	2190	2169		<=2000
TSS	mg/l	41	88	65.67	40	
BOD_5	mg/l	71	116	91.33	40	
COD	mg/l	205	297	242.33	100	
TP	mg/l	4.39	5.245	4.76		<=3
TN	mg/l	8.2	10.69	9.31		<=15
Fecal - Coliform	CFU/ml	893	1049	980.7		
Total - Coliform	CFU/ml	845	905	867		

Table 3. Effluent Characteristics of treated wastewater after CW

Parameters	Units	Minimum Value	Maximum Value	Mean Value	Permissible Limits IQS	Egypt Decree (2013)
Temperature	°C	23	24.2	23.73		
pH		7.16	7.5	7.12	4-8.6	
EC	µs/cm	1918	1948	1929.5		<=2000
TSS	mg/l	4	10	6.667	40	
BOD	mg/l	12	75	40.87	40	
COD	mg/l	104	200	152.67	100	
TP	mg/l	2.18	3.35	2.93		<=3
TN	mg/l	2.14	6.25	4.45		<=15
Fecal- Coliform	CFU/ml	590	670	639.3		
Total- Coliform	CFU/ml	550	600	573.3		

3.2 Potential of Hydrogen

The Potential of Hydrogen (pH) of wastewater has a significant impact on the organic matter and nitrogen removal capabilities of wetland ecosystems. The anaerobic decomposition of organic materials depends on the pH levels of wastewater [29]. Figure 2 displays the findings of the average pH measurements made during the study period of the wetland influent and effluent. According to the results, it was observed that, the pH values are typically met with the Iraqi standards in terms of their suitability for irrigation.

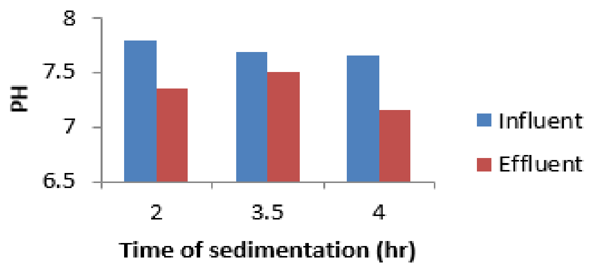

Figure 2. pH of the wetland influent and effluent water samples

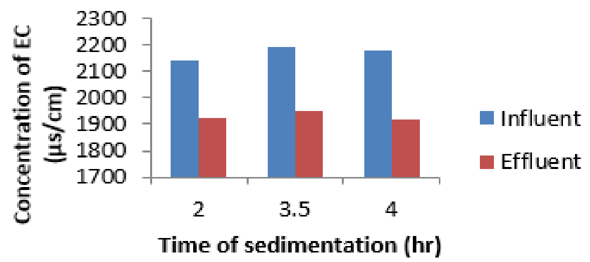

Figure 3. EC of the wetland influent and effluent water samples

3.3 Electrical Conductivity

Electrical Conductivity (EC), indicating salts content, is the ability of an aqueous solution to conduct electric current. As shown in Figure 3, the values of the treated wastewater fall within Egypt's allowable limits for reclaimed water reuse standards (Egypt Decree 2013) [27]. A slight decrease in the EC values of the treated effluent may be attributed to the effect of the sedimentation tank in removing solids, including salts, and the aerobic/anaerobic treatment in CW that decreases some nutrient effecting EC.

3.4 Total Suspended Solids

Total Suspended Solids (TSS) have a negative effect on aquatic species and wildlife, making them a crucial water quality metric [26]. Improving water quality and the functioning of the wetland ecosystem are primarily dependent on removing TSS from water and allowing it to settle in the wetland sediment bed.

The average measurement of TSS in water samples collected from wetlands at the influent and effluent during the study period is displayed in Figure 4. It is noteworthy that, in terms of their suitability for irrigation, the TSS values of the treated effluent are generally met with the Iraqi standards.

3.5 5-day Biochemical Oxygen Demand

5-day Biochemical Oxygen Demand (BOD_5) represents the amount of oxygen consumed by bacteria during the biodegradation of organic matters, as well as the oxygen necessary to oxidize various compounds in the water, such as ammonia, sulfides and ferrous iron. The amount of oxygen being consumed can be found via the BOD_5 test [30]. Figure 5 shows that the final treated effluent was significantly improved regarding TSS content that it became close to limit permitted by Iraqi quality standards (40 ppm).

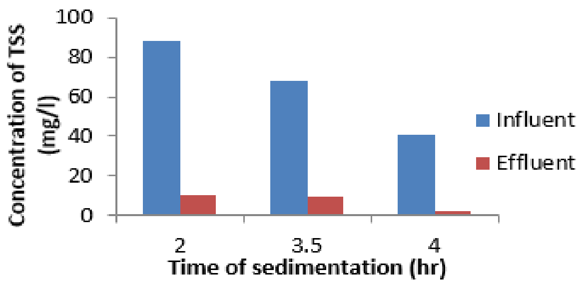

Figure 4. TSS of the wetland influent and effluent water samples

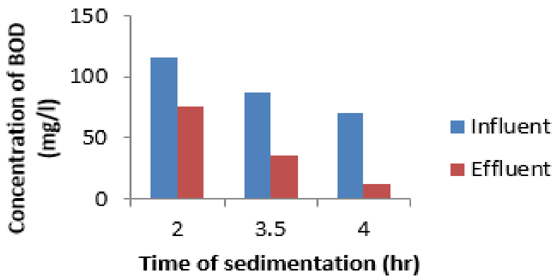

Figure 5. BOD_5 of the wetland influent and effluent water samples

3.6 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is the mass of oxygen used per liter of solution required to oxidize all oxidizable matters present in the solution. It is directly proportioned with the level of water sample pollution. It is considered as one of the most important quality control parameters in wastewater treatment facilities [31]. Figure 6 demonstrates a significant improvement in the treated final effluent that it became close to limit permitted by Iraqi quality standards (100 ppm).

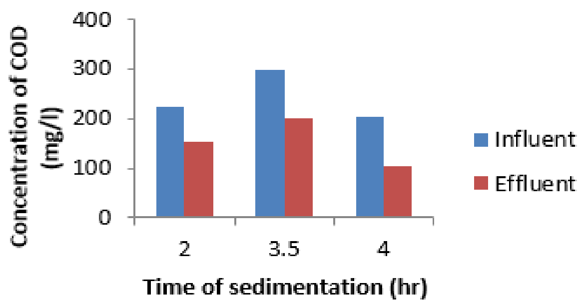

Figure 6. COD of the wetland influent and effluent water samples

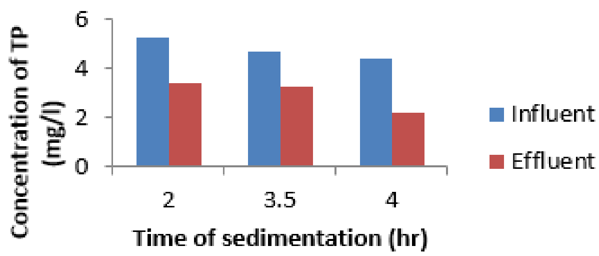

Figure 7. TP of the wetland influent and effluent water samples

3.7 Total Phosphorous

Total Phosphorous (TP) is usually the nutrient that determines plant outgrowth. TP can be suspended or dissolved in water in aquatic environments. Since it is the form that plants are most accustomed to, it may serve as an indicator of probable problems of excessive growth of plant and algae in relatively short term. Figure 7 demonstrates a significant improvement in the wetland final treated effluent regarding TN content. The content of TP in treated effluent matched the permissible level of the reclaimed water reuses standards of Egypt [27].

3.8 Total Nitrogen

Total Nitrogen (TN) is one of the main pollution indicators of wastewater and, depending on its form, can be toxic to aquatic life, influencing the amount of dissolved oxygen in receiving streams, and may cause eutrophication. Nitrogen can be found in wastewater as organic and inorganic [32]. It is obvious that the TN was within the permissible level of the reclaimed water reuses standards for Egypt. Figure 8 demonstrates the results with a significant improvement in the treated effluent regarding TN content. It is noteworthy that the final effluent properties fall within Egypt permitted bounds for the reuse of reclaimed water [27].

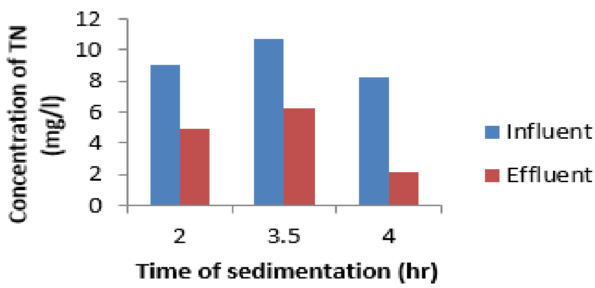

Figure 8. TN of the wetland influent and effluent water samples

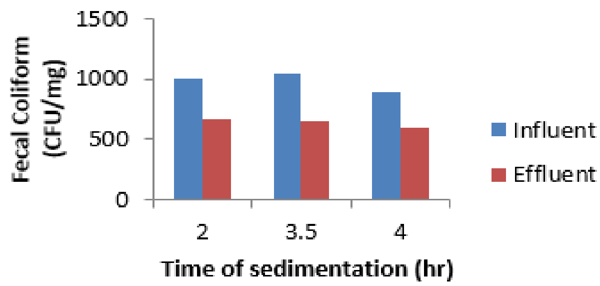

Figure 9. Fecal-coliform of the wetland influent and effluent water samples

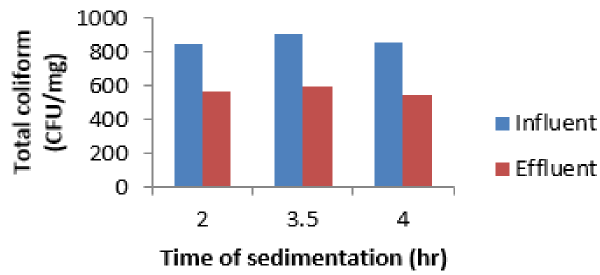

Figure 10. Total fecal-coliform of the wetland influent and effluent water samples

Table 4. Results of parameters considered in computing WQI with the Iraqi standards

Parameter	PH	EC	TSS	BOD_5	COD	TP	TN
Standard	8.5	2000	40	40	100	3	15
Test 1	7.5	1922	10	75	171	3.35	6.25
Test 2	7.44	1925	9	30	200	3.338	5.57
Test 3	7.37	1919	6.5	64	139	3.3	6.16
Test 4	7.25	1948	2.5	48	104	2.52	2.54
Test 5	7.16	1945	7	12	120	2.182	2.14
Test 6	7.32	1918	8	16.2	182	2.882	4.04

3.9 Fecal-coliform and total fecal-coliform

Municipal wastewater classification into foul (black) and greywater has shown to be an effective method for preventing the pollution of greywater, lowering the amount of fecal and total fecal polluted wastewater, and lowering the treatment costs [33]. Following final effluent treatment, the wetland shows a notable improvement, as shown by results represented in Figures 9 and 10.

Table 5. Water classification groups based on the CCME WQI value [34]

Classification	Values	Description
Excellent	95 to 100	There is almost no threat to or deterioration of the water quality, making it nearly identical to its pristine or natural state.
Good	80 to 94	There is little threat or impairment to the protected water quality, and conditions hardly ever deviate from ideal or natural levels.
Fair	65 to 79	Although generally safe, water quality can occasionally be threatened or compromised; conditions can occasionally deviate from ideal or natural levels.
Marginal	45-64	Water quality is frequently in jeopardy or compromised; conditions frequently deviate from ideal or natural thresholds.
Poor	0-44	Water quality is nearly always in jeopardy or compromised; conditions typically deviate from ideal or natural thresholds.

3.10 Determining the WQI

To determine whether the treated water is suitable for irrigation purposes, quality index for the wetlands under investigation is computed on the basis of the results set of the treated effluent as listed in Table 4 for 7 parameters with the corresponding limits values of the Iraqi standards adopted.

To compute WQI for the treated effluent, values of f_1, f_2, f_3 and NSE are first calculated as:

$$f_1 = \frac{3}{7} \times 100 = 42.86 \tag{7}$$

$$f_2 = \frac{12}{42} \times 100 = 28.57 \tag{8}$$

Excursion = 0.875, 0.6, 0.2, 0.71, 1, 0.34, 0.04, 0.2, 0.82, 0.117, 0.113, 0.1.

$$NSE = \frac{5.115}{42} = 0.122 \tag{9}$$

$$f_3 = \frac{0.122}{0.01 \times 0.122 + 0.01} \times 100 = 10.876 \tag{10}$$

Then, the CCMEWQI is calculated as:

$$CCMEWQI = \left[100 - \left(\frac{\sqrt{42.86^2 + 28.57^2 + 10.876^2}}{1.732}\right)\right] = 69.9 \in (65 - 79) \tag{11}$$

The value computed for the CCMEWQI is 69.6 considered fair within the range 66–79 according to the CCMEWQI ranges listed in Table 5.

4. CONCLUSIONS

The VSSFCW investigated improved the characteristics of the wastewater in terms of pH, EC, TSS, BOD_5, COD, TP, and TN. Some parameters in the treated wastewater agreed with the Iraqi standards (IQS-2012) like; pH (7.16 to 7.5), EC (1919–1948 μS/m), TSS (7 to 10 mg/L) and TN (2.14 to 6.25 mg/L). The other parameters were slightly higher than the limits like; BOD_5 (12 to 75 mg/L), COD (104 to 200 mg/L) and TP (2.182 to 3.35 mg/L). However, the WQI computed according to CCMEWQI is 69.6 considered fair within the range 66 – 79 and can be used for irrigation directly or after dilution with clean water. The findings of the present study prove capability to adopt the VSSFCW for municipal wastewater treatment at areas with similar conditions in Iraq. Future research is required about long-term impacts of using such treated wastewater in irrigation on soil conditions and crop yield.

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