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FEASIBILITY OF HORIZONTAL SUBSURFACE FLOW AS AN ALTERNATIVE TECHNIQUE FOR WASTEWATER TREATMENT IN DEVELOPING COUNTRIES

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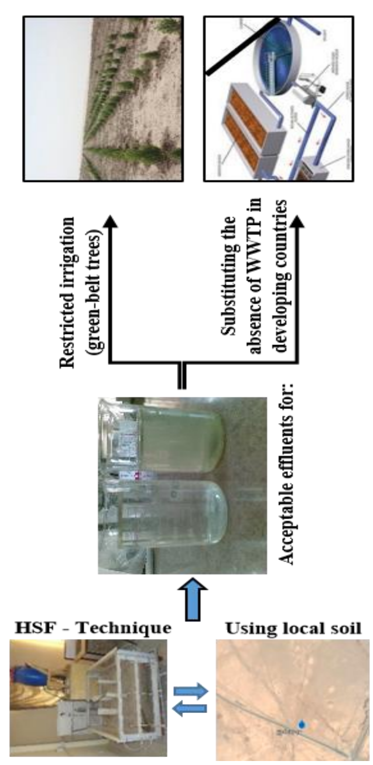
Graphical abstract



Abstract

Ramadi is one of the Iraqi cities which doesn't have a WWTP. The generated domestic wastewaters are treated by the individual septic tanks. Hence, most domestic wastewater is percolating into the subsurface water and groundwater causing their pollution. The tragedian water shortage scenarios predicted by other studies have motivated the looking for new water resources. The reuse of treated wastewater is one of these alternatives. Therefore, this study tries to investigate the feasibility of using such a cheap and easy controlled technique as a horizontal subsurface flow (HSF) for treating wastewater. A lab-scale reactor has been built up from acrylic, one half of its height was filled with soil that has been collected from a selected region. The reactor was charged with wastewater using batch feeding (30 L each run) and the study lasted for 3 months with an average of one run weekly including the acclimatization period. Results revealed the fairly contaminants' removal, where the average removal efficiency of COD, BOD_5, and TSS were 76%, 73%, and 90%, respectively. In conclusion, the HSF is a reasonable, low cost, less complicated treatment technology that could be adopted as an alternative water resource for irrigation of the green belt.

Keywords: Horizontal subsurface flow (HSF), low-cost treatment technique, wastewater reuse, effective alternative wastewater treatment technique, contaminants removal

1.0 INTRODUCTION

Iraq is one of the developing countries that has a 90% dependency on surface water sources to meet the population demands and for agricultural and industrial sectors [1]. The rest 2-9% of water resources is depending on the groundwater which is considered as the main source in the western desert and northern part of Iraq [2]. Owing to the population increasing, establishing many dams on the Tigris & Euphrates rivers by the neighbour countries of Iraq, less annual precipitation rates, and less popular awareness with economic ways in irrigation and water conservative, these water resources are in depletion trend. Hence, looking for new water resources are essential. The reuse of treated wastewater is one of these alternatives. Furthermore, many urban/suburban districts in Iraq do not have wastewater treatment plants (WWTPs) but they depend on the individual septic tank technique for getting rid of the generated wastewater. This technique has a negative impact on the soil characteristics and subsurface or groundwater where wastewater flow-in. Ramadi city (120 km to the west of Baghdad) is the centre of Anbar province which is surrounded by two water streams. One of them is the Euphrates river and the other is a channel that feeds the Al-Habannia Lake called Al-Warrar stream. The city has two systems for handling wastewater; individual septic tanks and storm water networks that had been trespassed by human activities through disposing of their generated wastewater. There is another method that has been used for lowering the water table in most residential and industrial areas called drainage channels. All water/wastewater gathered by storm water networks and drainage channels is discharged into these two streams without any treatment. These point sources contribute significantly to rising river and lake pollution levels. Ramadi does not have a WWTP as other many cities in Iraq. Political disorders, failure in strategic planning, corruption, security unstable, cost and limited experiences, and other reasons forced not to own the city for a wastewater treatment plant. The horizontal subsurface flow (HSF) is one of such an economic, less labours' skills needed, and an environmentally sound alternative technique [3].

The term "Constructed Wetlands (CW)" is commonly used as a suffix to the type of water flow, therefore, this treatment technique could be classified into two types; free water surface constructed wetlands (FWS CWs) and subsurface flow constructed wetlands (SF CWs). The SF CWs, depending on the flow direction, are divided into two other treatment types; horizontal subsurface flow (HSF CWs) and vertical flow (VF CWs). CW is classified also according to the used vegetation type, where there are three types; emergent macrophyte wetlands, submerged macrophyte wetlands, and floating treatment wetlands (FTWs) [4]. This study dealt with unplanted CW, hence, the type of treatment technique acquired its name (HSF) from the type and direction of water flow throughout the designed lab-scale model. HSF CW is considered a promising technology and it has a long term performance (more than 20 years) with keeping a relatively high removal efficiency of organic matters and TSS [5]. This technology requires lower construction, operational, and maintenance costs than conventional WWTPs. The main recorded drawback of this technology its necessity for larger areas than other techniques such as lagoons and oxidation ponds [6]. This disadvantage less effective on the aim of this study because of land availability in the selected region of Ramadi city and it is uninhabited as well. Furthermore, other researchers studied the use of different types of media and make comparisons among them to choose the best media in terms of removal efficiency of the studied contaminants [3, 7]. Although the plastic and shredded tires pieces recorded better removal efficacy, they revealed that the gravel and natural soil have a good opportunity to remove the pollutants with demonstrated a sustainable operation performance exceeded 20 years [5].

This study is carried out to investigate the possibility of using the HSF technique for treating wastewater and producing effluents compiling with the standards of agriculture reuse wastewater and/or safely discarding wastewater. This technology could be considered a sustainable solution for Ramadi city by safely dispensing of produced wastewater and recycling it to irrigate the prospective green belt. HSF's technique motivated this research owing to its cost-effective, easily controlled, and low environmental impact technology. It could be an alternative technology for treating the generated wastewater from Ramadi city and substituting the absence of WWTP. The study is conducted by building up a lab-scale reactor that is filled with predominant soil at the Al-Jarayshi region which located to the north of Ramadi city.

2.0 METHODOLOGY

2.1 Model Building Up

The lab-scale model was built up from acrylic (10 mm thickness) with dimensions of 110*110*60 cm (Figure 1). The model was strengthened with a steel frame for resisting the side pressure of water and soil. The recharging pipe was fixed in the centre of the model and the effluents have been gathered from the drainage valves distributed on the 4 sides of the model. These valves were set at 15 cm above the base of the model. Two water tanks were used for maintaining a fixed water level order to get a constant discharge using a flowmeter.

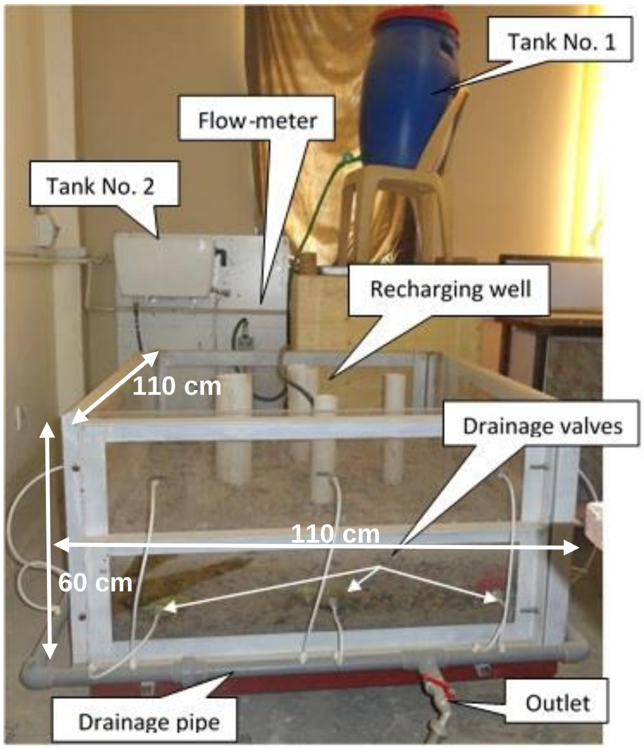


Figure 1 HSF model configuration

2.2 Soil Selection

The soil was provided from Al-Jarayshi district. The consideration of site selection was attributed to its unpeopled area, arid region, and a quarry of sub-base materials. The soil has a high porosity to facilitate water infiltration and it is described as a light grey poorly graded sand with gravel. Grain size distribution and percentages of coarse and fine matters are presented in Table 1 and Table 2, respectively. A soil sample was supplied to the model by three layers of 10 cm thickness. Each layer was compacted to get a bulk density of 18 kN/m^3 (as the in situ bulk density of selected soil).

Table 1 Grain size distribution of the selected soil

Sieve No.	4	8	16	35	50	100	200	**Pan**
Passing %	59.34	44.0	34.7	25.25	15.64	5.67	2.14	**0.0**

Table 2 Percentages of coarse, fine matters, gypsum content, and total soluble salts in the selected soil

Fine %	Sand %	Gravel %	Gypsum%	Total soluble salts%
2.1	57.3	40.6	8.45	8.59

Wastewater was discharged in the middle point of the model using a perforated pipe. Water will flow diagonally to the end of the model's walls then treated wastewater was collected for sampling from the main outlet. A flow meter was installed to control the discharge of wastewater into the recharging point. The flow rate of 0.5 m^3/d was allocated according to the soil permeability of 0.1 cm/min.

2.3 Wastewater Characterization

Wastewater used in this study was collected from the students' accommodation septic-tanks. Its characterization was listed in Table 3. COD, BOD_5, TVS, and TSS were examined according to standard methods [8], TDS & EC were conducted using HANNA (HI 99301), Turbidity and pH were measured by Lovibond, TurbiDirect and HANNA (pH 211), respectively.

Table 3 Wastewater characterization

Parameter	Unit	Average (± SD)
BOD_5	mg/L as O_2	87.6 (±38)
COD	mg/L as O_2	223.0 (±73)
TDS	mg/L	1045 (±78)
TVS	mg/L	463 (±21)
TSS	mg/L	770 (±290)
EC	(µs/cm)	2058 (±142)
Turbidity	NTU	106.8 (±40)
pH	---	7.84 (±0.2)
Temperature	°C	19.04 (±4)

2.4 Acclimatization

The model was filled with tap water to 15 cm which is the level of the drainage valves. Subsequently, an acclimatization period was performed before the model's start-up to simulate the real conditions in the site. This includes supplying wastewater into the model and receiving it without any tests. 360 L (60 L every week) of wastewater was charged during this period and lasted for 6 weeks. 30 L of wastewater was recharged to the centre of the model each run at the end of the acclimatization period. The wastewater flowed diagonally into the model. The treated water was collected from the model's sides to be analysed. The influent and effluent of each run were examined for their physical, chemical, and biological characteristics.

3.0 RESULTS AND DISCUSSION

3.1 HSF Performance

HSF concept was followed to remediate the primarily treated wastewater. HSF initiated after acclimatization accomplished. Seven runs (one each week) were conducted. Samples for influents and effluents were collected and analysed to investigate the performance of the HSF technique. The system revealed a good performance for relatively high removal efficiencies of COD, BOD, and turbidity which were 76, 73, and 67%, respectively as depicted in Table 4. This due to the integrated actions of biological, physical, and chemical processes. Meanwhile, the TSS parameter has a higher average removal efficiency (90%) than other parameters. This might be attributed to the physical action of the particle size distribution for the selected soil.

Table 4 Parameters investigated for influents, effluents, and the removal efficiencies

Item	Unit	Average of 7 runs		Average Removal %	Influent Values (mg/L)		Effluent Values (mg/L)	
		Influent	Effluent		Min.	Max.	Min.	Max.
COD	mg/L	223	53.6	76	96	307	16	112
BOD_5	mg/L	87.5	24	73	42	158	10	66
TSS	mg/L	770	77.6	90	484	1354	40	118
TDS	mg/L	1045	1496	- 43	970	1140	1260	1760
EC	μs/cm	2058	2922	- 42	1860	2220	2490	3460
Turbidity	NTU	106.8	35.7	67	66.5	165	8	158
pH		7.84	7.6	----	7.51	8.11	7.2	8.02
T	°C	19.04	18.7	----	13.9	25.4	13.1	25.2

Concentrations of the influents' COD, BOD_5, and TSS fluctuated from 96 to 307, 42–158, and 484 - 1354 mg/L, respectively, for the first six runs (lasted for 41 days). Whereas effluents were below 100, 40, and 120 mg/L, on a sequence as depicted in Figure 2(a, b, and c). The average removal efficiency for COD, BOD_5, and TSS for the first six runs were 80, 78, and 90%, respectively. The results of COD removal reveals compatibility with Alejandro's *et al.* findings [9], especially for the unplanted HSF model. Various studies showed a BOD_5 removal in the range of 67 - 83%, which is close to the related outcomes of this work [10, 11]. The degradation of organic matters, measured as BOD5 and COD, have been reasonably achieved even they have high concentrations as in the 6th run (Figure 2(a&b)). Hence, HSF produced an acceptable effluent concentration that meets the standards for restricted irrigation wastewater reuse. The most probable removal mechanisms of organic matters degradation are attributed to the physical properties of the soil media, which works as a filter layer as described by Jan Vymazal [12], and to the microbial activity that had built up during the acclimatization period as stated in previous studies [13, 14].

Suspended solids have been enmeshed by the soil particles, which lead to eliminating the TSS concentrations in the effluents from the HSF model. Around 90% of TSS removal had been obtained throughout the model operation time. This is consistent with other researchers' results [11, 15]. The same mechanism of TSS removal could be considered for turbidity contaminant remediation. The influent turbidity values (in the first six runs) were recorded in the range of 66.5 – 156 NTU. HSF had concealed the high turbidity influent values producing an acceptable purified effluent with an average removal efficiency of 86%. Meanwhile, other studies [16, 17] had presented a turbidity removal of 10% higher than that obtained in this study. The reason behind this differentiation might be attributed to the rhizosphere impact of planted constructed wetlands which adds an extra turbidity removal factor.

The concentrations of TDS and EC for the effluents were always higher than their influents in all investigated runs as illustrated in Figure 2(d and f), where the TDS and EC values increased by 43% and 42%, respectively. Wastewater that passed through the soil media acquired an extra salinity because of the high soluble salts in the selected soil (soil nature). Table 2, previously presented, elucidates that Al-Jarayshi's soil contains a high percentage (by weight) of the total soluble salts. An 8.59% from the soil weight represents total soluble salts, where 98% of these salts is gypsum. Since the gypsum follows two extremely different behaviours (very rigid in the dry condition and it is easy to be dissolved in the wet circumstances or there is a water table) [18, 19]. The mechanism of effluents salinity raising of this work is contrary to that stated in other studies [11, 20, 21], where they are attributed salinity increasing to the evapotranspiration.

From Figure 2(g), there is no significant difference between the influent and effluent pH. Since the HSF system used is an unplanted model, hence the nitrification reactions (a process that decreasing pH value) might be limited during the treatment process. Where the presence of plants is enhancing the nitrification process by 26% for high COD/N ratio's (8:1) influents as described by Wang et. al [22]. That means the selected soil has the capability to handle the wastewater ignoring pH variation.

As this study was conducted in the period from February to April, therefore influents' temperatures were ranged from 15 to 25 °C (Figure 2(h)). Figure 2 (h) shows that the temperature was not affected during the treatment process, where there are no chemical reactions that might appear during the treatment to add any thermal energy to the effluents. The minimum influent temperature (15 °C) produced a COD removals compatible with the Triantafyllos' T. *et al.* recommendation [7].

It is a worthy note, the seventh run revealed higher effluent contamination concentrations than other runs. Because the 7th run was conducted the second day after the 6th run, i.e. there is no idle time (6 days) between two successive runs as usually adopted for previous runs. This situation enhanced the increase of organic loading rate by 7 and 10 times than the average of the sixth previous runs for COD and BOD_5 respectively. Therefore, the intermittent operation for this system (HSF) is recommended [22].

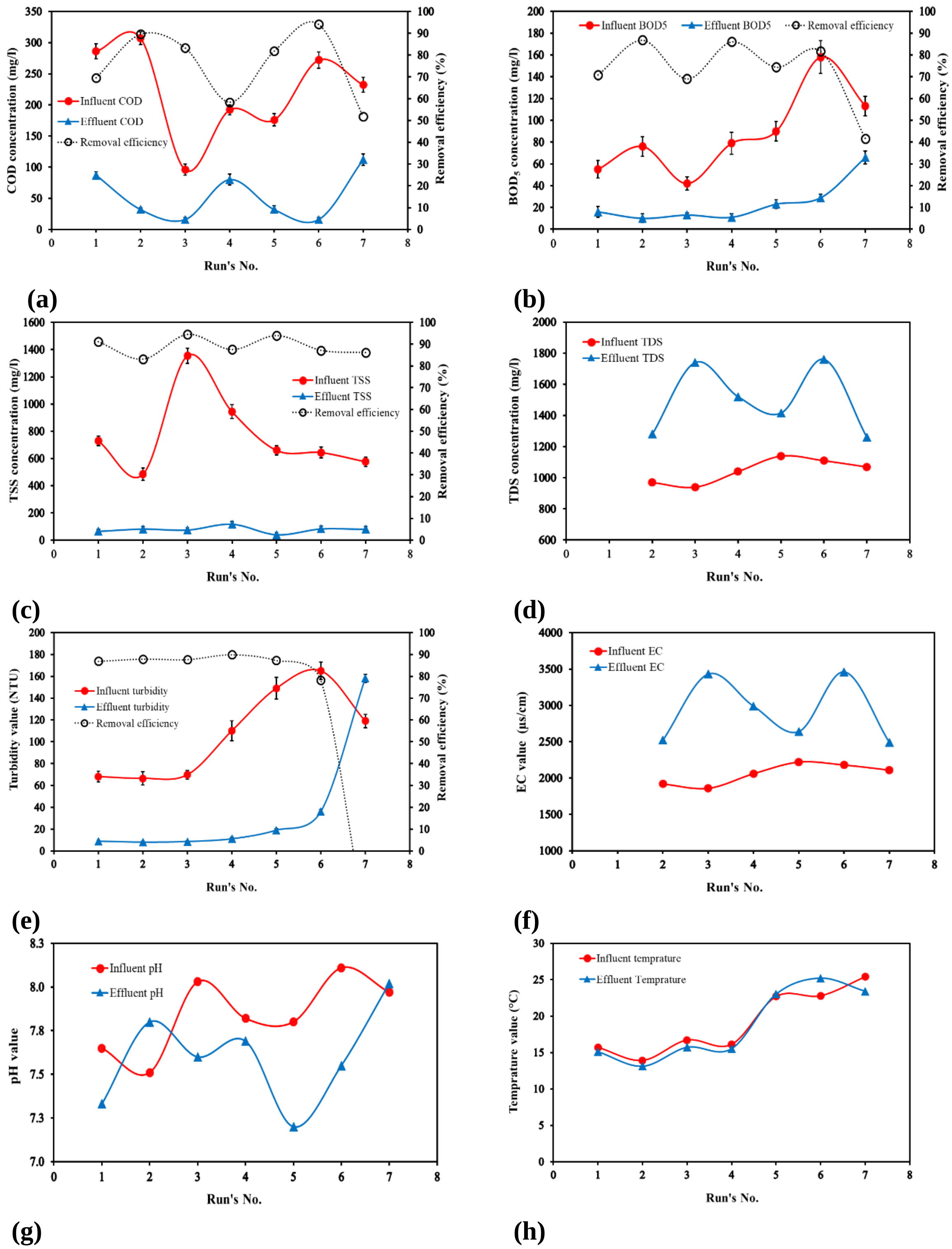


Figure 2 Influents, effluents, and removal efficiencies for the measured contaminants and parameters; (a) for COD, b) for BOD_5, (c) for TSS, (d) for TDS, (e) for turbidity, (f) for EC, (g) for pH, and (h) for Temperature

3.2 The Effect of Organic Loading

The organic loading rate (OLR) was 3.3 g(COD).m^{-2}.d^{-1} (±1.9) as an average for the six runs, whereas it was 21.1 g(COD) m^{-2} d^{-1} for the seventh run. The OLRs for the six runs were lower than 12 g(COD) m^{-2} d^{-1} which is recommended by USEPA (2000) for HSF constructed wetlands [9]. This interprets the acceptable removal of COD, BOD_5, TSS, and turbidity contaminant parameters as illustrated in Figure 2. Meanwhile, OLR in the seventh run was higher than that suggested by USEPA, therefore it was recorded lower removal efficiency for the aforementioned contaminants. Figure 3(a & b) elucidates the trend of removal efficiency (in terms of COD and BOD_5) related to OLR increasing, where higher OLR means lower removal. The mass removal rate (MRR) was calculated in terms of COD and BOD_5 and presented versus OLR in Figure 3(c & d). They have linear trend lines of high R^2 (0.963 and 0.956 for COD and BOD, respectively), i.e. the OLR has a significant effect on COD and BOD removals.

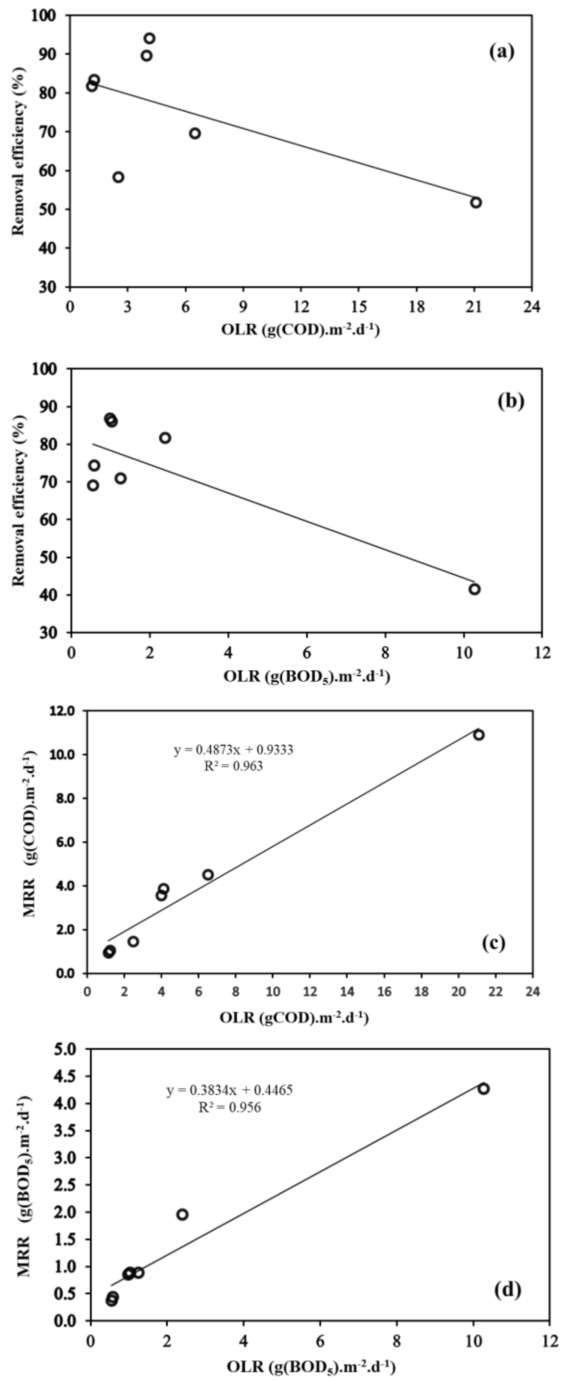


Figure 3 The effect of organic loading rate on HSF performance

It is a worthy note that the turbidity value of the effluent was higher than the influent for the 7th run comparing to the previous runs (Figure 2(e)). The most reliable effect for this result is due to the high OLR applied during the last run (21 g(COD).m^{-2}.d^{-1}/10.3 g(BOD_5).m^{-2}.d^{-1}), whereas these values were less than (6.5 g(COD).m^{-2}.d^{-1}/2.4 g(BOD_5).m^{-2}.d^{-1}) for earlier runs as shown in Figure 3. The period between 7th & 6th runs was one day, this situation led to manifold the OLR by around 3 times for COD and 4 times for BOD_5 with respect to the maximum OLR values of other previous six runs. High OLR raised the COD & BOD_5 concentrations in the effluent of the system, which prone to increasing the organics colloidal and producing high effluent turbidity.

3.3 HSF Effluent Quality

HSF system produced such a relatively acceptable effluents' characteristics, where the average concentrations of COD, BOD_5, TSS, TDS, pH, and Turbidity were 53.6, 24, 77.6, 1496 mg/L, 7.6, and 35.7 NTU respectively. Owing to the unavailability of Iraqi legislation for wastewater reuse, according to our knowledge, the neighbouring country's standards were considered. The Palestinian standards of wastewater reuse for unrestricted irrigation have been adopted in this study's results comparison. All parameters that earlier stated are complying with the Palestinian standards (Table 5) [23]. EC average value of 2922 µs/cm for HSF final products put them under moderate restriction wastewater reuse group [24].

This study demonstrates the applicability of the HSF technique to produce acceptable effluents that could be used for unrestricted irrigation purposes. HSF will take a vital role in wastewater treatment as an alternative cost-effective treatment plant to cope with the absence of conventional WWTP in Ramadi city. Al-Jarayshi district, where the soil is selected from, is classified as arid area. If the HSF treatment plant is constructed near this area, then the treated wastewater could be used to irrigate the planted green belt to repel the desertification spreading.

Table 5 Water quality standards for wastewater reuse for unrestricted irrigation [23]

Parameter	Unit	Max. Value
Temperature	°C	25
pH	pH Unit	6 – 9
BOD5	mg O2 / L	60
COD	mg/L	200
Dissolved Oxygen	mg/L	> 0.5
Total Dissolved Solids	mg/L	1500
Total Suspended Solids	mg/L	50
Turbidity	NTU	50
Sulphates	mg/L	500
Oil and grease	mg/L	5

3.4 Proposed Usage of HSF Effluents

Various reasons could affect the water abundancy in Iraq, even it has two big rivers (Tigris and Euphrates), such as population increasing, the lack of water resources, dams establishing on Tigris and Euphrates's tributaries by Iraq's neighbour countries, and the climate changes. some researchers predicted Many tragic scenarios, one of these scenarios is proposed by Al-Ansari *et al.*, 2013 [1]. Where Iraq country will be facing severe water resource scarcity by the year 2040. They recommended that Iraq should search for other additional water resources to cover the escalating water demand. The reuse of treated wastewater is one of the suggested solutions. The wastewater recycling for irrigation purposes requires an establishment of a legislations by the Iraqi government.

In the case of establishing the HSF treatment plant in Al-Jarayshi district, its effluents could be used in different ways, for instance not limited to, road washing, artificial recreational lagoons, and restricted irrigation purposes. In this research, it suggested the usage of treated wastewater to irrigate the prospective surrounding green belt. Eucalyptus is the most suitable candidates plants that could stand with the severe desert weather conditions and saline waters (such as effluents produced from HSF in this study) [25] so as olive [26] and date palms [27, 28].

4.0 CONCLUSION

Al-Jarayshi region has a desert nature that could increase the effect of dust in the area. A green belt planting is recommended to prevent the air dust spreading and reduce the effect on human respiration system. To provide an irrigation source for this green belt, a reasonable, low cost, less complicated technology (HSF) was suggested to treat and recycle the generated domestic wastewater for this purpose, especially in case of WWTP absence. Where the local soil is appropriate to establish such a treatment technique (HSF) and to provide effluents that are compatible with the reused wastewater for restricted irrigation. HSF technique could achieve an excellent sustainable solution for the developing countries. Furthermore, this study revealed that even though Iraq has two big rivers, it needs to manage its water resources and looking for new innovative water sources to overcome the predicted water shortage. The reuse of wastewater is an alternative essential solution, especially for the agricultural sector, and this solution leads to the necessity of legislating acts that manifest the reused wastewater types for irrigation purposes in Iraq.

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