Evaluate the performance of horizontal flow wetlands as an option for tertiary treatment of secondary sedimentation basins

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Abstract. Constructed wetlands (CWs) are simple low-cost wastewater treatment units that use natural processes to improve the effluent water quality and make it possible for its reuse. In this study, the horizontal flow system was used for tertiary treatment of wastewater effluent from secondary basins at Al-Rustamiya wastewater treatment plant / old project / Baghdad / Iraq. The Phragmites Australis plant was used for wastewater treatment, and the horizontal subsurface flow system was applied. The experimental study was carried out in February 2020 to October 2020. The parameters were monitored for a period of five weeks. Concentration-based average removal efficiencies for HSSF-CW were COD, 53%; \( \text{NO}_3 \), 41.3%; \( \text{PO}_4 \), 52% and TSS, 54.2%. Thus, constructed wetland can be considered as a sustainable alternative to the tertiary conventional treatment of wastewater, thus making it possible for reuse.

Key Word: Constructed Wetlands, Subsurface Flow, Wastewater, Phragmites Australis. Wastewater Parameters, Tertiary treatment.

1. Introduction

In Iraq, there are eleven major wastewater treatment plants with a total capacity of 650,000 m\(^3\)/day and usually, they are located near the river banks of Euphrates, Tigris, Kahla, Diala, Husseinya, Diwaniyah, and Shatt Al- Basrah. Adopted treatment scheme processes in the plants consisted of traditional steps and can be arranged as preliminary, primary, and secondary treatment systems [1]. These systems required many requirements such as facilities, sanitary collection, as well as treatment and disposal of wastewater to decrease and/or remove the concentration of familiar components like BOD\(_5\), COD, total suspended solids (TSS), and nutrients to ensure that the final effluents will not cause additional pollution. The main advantages of those techniques are the best control on the treatment process and, also, the required area for construction of this project can be acceptable. Traditionally, the spread of the rural population in many villages and the high cost of wastewater conveyance system and treatment beside their own properties and conditions would require decentralized wastewater treatment plant [2].

Constructed wetland utilization can provide sustainable wastewater treatment because they rely on natural processes and are less expensive to build, operate and maintain when compared with
conventional sewage treatment systems. The filtered water is suitable for reuse and reaped plants can have commercial value. All these are aids for the use of this wastewater treatment technology in developing countries facing socioeconomic challenges [3] CWs are subdivided into two types based on water flow: (1) surface flow (SF) or free water surface flow wetlands, where wastewater is flowing horizontally over the wetland substrate; (2) subsurface flow (SSF), in which the wastewater flows horizontally or vertically through the highly permeable substrate (gravel, rock or soil). These systems treat different types of wastewater like domestic wastewater [4] acid mine drainage [5], urban sewage [6], agricultural wastewaters, landfill leachate, urban storm water (States 2000) and industrial wastewater [7].

Apre-treatment with conventional processes is usually desirable before discharge into a wetland because of the potential solids or oxygen demand overload that create nuisance conditions within a wetland receiving raw or inadequately treated wastewater [8]. Fresh water resources have become insufficient to meet demand with the increasing world population, which leads to a global challenge represented in the scarcity of fresh water, and wastewater is one of the most serious problems to public health in most countries of the world, because most of these countries do not have an integrated sanitation network. Some channels are used to drain them, which leads to great pollution and the spread of many diseases, if the wastewater contains a very large amount of organic compounds and huge numbers of aerobic and anaerobic microorganisms, so if the wastewater is thrown without treatment into the river, it will cause a great environmental problem [8].

The negative impact of the lack of interest in wastewater treatment is reflected in the national income and the country's economy, and for the purpose of treating the aforementioned damages, it is necessary to treat wastewater to benefit from it for economic purposes. Treatment of wastewater with natural systems is a very practical and effective method, especially in remote and isolated communities because it relies on cheap treatment methods such as treatment with artificial wetlands, which are plants treatment plants and are engineered (unnatural), as the polluted water passes through the wetland basin planted with plants and is filled with a gravel or sandy medium or a combination of both. It works to reduce the concentrations of pollutants in wastewater [9] and uses certain plants that have the ability to remove or reduce pollution levels through metabolic processes Carrie out by the plant and lead to the removal, seizure or analysis of pollutants and this is called name (phytoremediation) [10] which represents one of the types of biological treatment (Bioremediation). The reed plant (Phragmites Australis) is one of the aquatic plants most used in bioavailability due to its great ability to absorb many nutrients from the bottom and the water column, and its possession of rhizomes that provide a larger surface area for the destruction of pollutants by bacteria, as well as the reeds to sort enzymes that are able to withstand the organic matter in the water. And its ability to secrete antibiotics capable of killing pathogens in the water [11].

The role of the reed plant (Phragmites Australis) is summarized in that its roots play the role of the host for aerobic bacteria and primates, as the plant absorbs oxygen from the air and then moves it to the roots below and injects it into the growth environment, and then this oxygen oxidizes the organic materials in the wastewater, thus reducing the pollutants Organic and odours [12].

From here, the importance of the study was shown in attempts to overcome the problems facing the wastewater treatment sector in general and the traditional treatment system in particular, and to find an appropriate solution for a healthy environment through the application of the subsurface horizontal treatment system (HFS) while determining the efficiency of the reed plant in improving the purification of wastewater Health and trying to reach a semi-natural system that depends on what is available in the local markets in the treatment of liquid waste and its application on the ground. Likewise, using modern, environmentally friendly technology that does not have side effects and is low in cost, knowing the efficiency of the reed plant in treating wastewater to the extent that it is allowed to be discharged into water bodies or reuse, and comparing the results of this method with traditional and reliable methods.
Therefore, these technologies must be robust and capable of operating with minimal maintenance or supervision are of great value for the local population and are expected to be the only feasible alternative for conventional wastewater treatment [13].

2. Material and Methods

2.1 Case study description

The capital of Iraq, Bagdad, has the highest level of sanitation in the country. Baghdad did not have a major treatment system until 1963. In 1963, a major trunk sewer and tributary network was built east of the Tigris River and the first major treatment plant was built: Al-Rustamiya (stage 0) and later extended (stage 1). Extension of stage 2 in 1980. As part of the major expansion of the sewage treatment capacity. Al-Rustamiya plant is the oldest and biggest sewage treatment plant in Iraq; it locates in the south of Baghdad city. Al-Rustamiya old project considered the waste water collected through the sewage network of Al-Rusafa part. The plant is located on the banks of the Diyala River south of Baghdad, in the Al-Rustamiya area, at the end of Baghdad's main line carrier sewage project serving the Baghdad area between the Army Canal to the east and the Tigris River to the west, from northward Adhamiya and down to south AL-Rustamiya area. Survey estimated population covered by this service today at about two million people, Figure 1. The selection of this site to construct the pilot facility for the present study was related to a number of considerations such as; Similarities in objectives and environmental conditions between a wastewater treatment plant (WWTP) and a constructed wetland, as well as the existence of a laboratory building to achieve the planned measurements. In addition, the facility is unique in that it is located near a wastewater treatment plant, allowing all pilot scale systems to receive the same municipal wastewater in quantities required by the operation process. The raw wastewater, which was provided to the constructed wetland units, was taken from the effluent collection point in the three primary basins to ensure that the amounts of suspended solids were as low as possible. More wastewater was released directly to the river and more pollution contribution was introduced [14].

The key pollutants that affect the selection of the treatment process are suspended solids, organic material (BODs, COD), phosphorus, in addition to the pathogenic organ, viruses, bacteria [15]. The degradation and mineralization of organic matter occurs in both the bed substrate and the biofilms on reed plants [16], Vegetation has a minor function in the transformation and mineralization of nutrients and organic pollutants where the roots of the plants can be provided a bulky surface area for attachment of microorganisms that played the main role of organics degradation [17]. Plants roots also prevent wastewater from taking preferential paths in the substrate [18]. In the subsurface CW systems, media material is an important factor because it could avoid clogging to ensure a sufficient hydraulic conductivity [19].
2.2. Experimental design and layout

The treatment systems consist of horizontal subsurface flow wetland system planted with Phragmites Australia. The wetland units (Figure 2) included one planted horizontal flow (HFP) system. The CW units have size (length of 75 cm, width of 180 cm and depth of 75 cm). The basin was made of iron (ductile) from the inside, while the outside is covered with wooden boards. The basin was installed next to the secondary sedimentation basins of the old Al-Rustamiya project. With a slope of 10 cm, then a plunger was placed in the secondary sedimentation basin or the purpose of drawing sewage into the factory wetland basin, and a meter was set to control the amount of discharge required to enter the wetland basin, and there is a valve by which the required discharge amount is installed to 10 L/min and also a valve was placed at the end of the sink. After completing the process of erecting the basin, the basin is filled from the bottom to the top with a layer of medium sized gravel with a height of 10 cm, then a distance of 10 cm is left from all sides of the basin for the purpose of isolating the gravel from the sand by a metal clip, and then distributing the gravel quantities to the sides of the basin as well as the sand in addition to the sequence, the thickness of the agricultural sand layer is 50 cm the sides of the basin are only filled with gravel with a characteristic of 60 cm. Plastic tubes six of type PPR with a length of 75 cm are drilled on all sides with a diameter of ½ inch. Four of the tubes are spread over the sides of the sink and two of them are in the middle of the sink. These tubes are placed inside the gravel layers. Through these tubes, samples are taken for the purpose of completing the required checks. Wastewater is slowly provided to the soil through a plastic tube of type PPR perforated with a diameter of 10 mm on all sides and a distance of one inch between one hole and another. In the form of sprinklers, this tube is placed in the upper part of the basin. The waste water flows horizontally through in the soil towards the exit area. The plant originates on 15 February 2020, when the wild cane plant, which was taken from the work site that was growing in the aeration tanks and initial sedimentation condition, was planted 10 plants were planted and the distance between one plant and the other was 20 cm rom. The germination period lasted for about two months.
2.3. Types of Constructed Wetland Systems

According to the way of water flow through the wetland basins, CWs can be classified into:

(1) subsurface flow wetlands
(2) surface flow wetlands.

In the first type, water flows underground through the porosity of the granular medium, while in the second type, under atmospheric pressure conditions (free surface flow), water flows over the granular medium [20]. Subsurface flow CWs can also be subdivided into horizontal flow or vertical flow systems. In the horizontal subsurface flow system (HSFS), the wastewater is maintained at a constant depth and flows horizontally below the surface of the granular medium. In vertical subsurface flow system (VSFS), the wastewater is distributed over the surface of the wetland and trickles down through the granular medium CWs [21] can also be a combination of (VSFS) and (HSFS) in order to fulfill higher treatment efficiency by using the advantages of individual systems [22]. HSFS, thus, more attention shall be given to this type. CWs are rare in Iraq. The recorded performance for pollution removal is relatively poor. Therefore, wetland treatment is considered as the aim of this study. Hence performance data that will guide the design and operation of wetland systems in an invitation to efficiencies for irrigation and diverse applications is desirable. They withstand an immersion environment, and bear high levels of salinity and pollution.

2.4 Vegetation

Phragmites Australis, (common reed) as a native plant that is widely available in vast quantities through the environment of Iraq especially in the natural marshes located at the southern regions having the following properties:
- A large external surface is provided for the bacteria, yeast and fungi needed to break down the pollutants.
- Provide a high level of oxygenation to ensure anaerobic processes in the treatment area, and has deep roots.
- Living all around the year.
- Rapidly growing and spreading.

The broad root system also creates channels for the passage of water and provides the means for the secondary restructuring of the reed base layer system. Phragmites Australis was selected for the plantation process in constructed wetlands furthermore its availability within the primary and aeration tanks of Al-Rustamyia treatment plant.

The reed plant (phragmites Australis) was cultivated in the wetland basin, and the number of cultivated plants did not exceed 10 plants, and the distance from one plant to another was 15 cm. This means that choosing a reed plant may be an appropriate decision because it will reduce the maintenance required of the ponds and that the plant is already adapting to the same type of wastewater that is being treated in the current pilot facility.

3. **Results and Discussion**

The main objective usually expected from wetland system is that, the quality of the discharged water is accepted and meets the local regulation. The pilot plant was designed to give, when reed plants are mature, the following parameters, COD, TSS, $\text{NO}_3$, $\text{PO}_4$.

3.1. **Phragmites Australia monitoring**

The gravel that used for building purposes was chosen as the bed material for Phragmites Australis implementation, their densities have been increased dramatically within all the vegetated CW units from 10 plants/m² at plantation in February 2020 to reach 120 plants/m² after 8 months from plantation process and then to reach 120-140 plants/m² in October 2020. Their average height was more than 1.8 m. This type of reed has good growth ability and, during the summer season, it seems that the foliage branches of common reeds suffered and looked to be yellow and dry. The optical condition may be due to temperature rising which was around 50 °C or because of pollutants accumulation in plant tissues. Previous studies pointed out that this problem could be solved by trimming stems and added them to the experimental unit for nature reproduces.

3.2. **Statistical analysis.**

The Statistical Analysis System- SAS (2012) program was used to detect the effect of difference factors in study parameters. Least significant difference –LSD test was used to significant compare between means in this study.

3.3. **Organic materials (COD) removal**

Effluent and Influent COD concentrations for wetland unit was measured during the monitoring period and plotted in Fig.3. Higher COD removal rates might be related to physical processes such as filtration, sedimentation, and adsorption that can be achieved in CW unit in addition to biological degradation. The Figure 3 shows the effect of the Phragmites Australis plant in reducing the values of the chemical oxygen requirement. It was found that the large removal of the chemical oxygen requirement indicates the high ability of these plants to oxidize the organic materials present in the treated water [23]. The chemical oxygen requirement is a good measure of polluted water, especially polluted with industrial pollutants, if it reflects the amount of oxidized organic matter [24].
During the monitoring period, the conditions of the effluent from the tertiary treatment showed varying values reaching a maximum of 30 mg/L and a minimum of 79 mg/L of Chemical Oxygen Demand. In all collected samples, as shown in Table 1. The lowest removal efficiency rates were verified in 1 July (20.2%) and the highest removal efficiency in 21 July (77%).

| Date      | Influent Concentration (mg/l) | Effluent Concentration (mg/l) |
|-----------|-------------------------------|------------------------------|
| 1/7/2020  | 150                           | 60                           |
| 7/7/2020  | 99                            | 79                           |
| 14/7/2020 | 60                            | 30                           |
| 21/7/2020 | 299                           | 70                           |
| 28/7/2020 | 175                           | 52                           |
| 9/8/2020  | 50                            | 30                           |

3.4 Nutrients removal

The nitrogen compounds are of importance beside the organic materials; the inorganic forms of nitrogen (i.e. NO₃) were measured within the CWs treatment units as an indicator of nutrients present in treated wastewater during the observation period. The NO₃ concentration in influent and effluent for the unit is presented in Table 2, which means that CWs treatment units achieved an acceptable percentage of treatment so that ammonianitrogen concentrations in the treated water were acceptable with these standards [25]. During the monitoring period, the conditions of the effluent from the tertiary treatment showed varying values reaching a maximum of 2 mg/L and a minimum of 0.6 mg/L of Nutrients. In all collected samples, the lowest removal efficiency rates were verified in 9 August (33%) and the higher removal efficiency in (14, 21) July (50%).
The Figure 4 shown the great reduction in plant experiment pond, which was recorded the Phragmites Australis plant was successful in lowering the nitrate values during the trial period. The reason for the decrease in nitrate is due to the fact that the reed plant in a horizontal system provides high conditions for reduction and intensive growth of microorganisms in nitrogen conversion or by direct transcription before the plant[26]. Aquatic plants represent the important methods for treating high concentrations of nutrients and reducing a high percentage of nitrates that give the plants ideal properties for their use of nutrients in the wetland system, making them fast growth, and suitable for high nutritional value to achieve a good yield. (Ensuring the survival and sustainability of the plant). Then it gives a high processing purity [27]. This is because the organisms found in living organisms are plant growth microorganisms. Then it takes root and helps it grow the plant [28].

Table 2. Inflow and out flow NO₃ concentrations in HFP wetland systems

| Date     | Influent Concentration(mg/l) | Effluent Concentration(mg/l) |
|----------|-------------------------------|------------------------------|
| 1/7/2020 | 2.3                           | 1.5                          |
| 7/7/2020 | 3.1                           | 1.9                          |
| 14/7/2020| 1.2                           | 0.6                          |
| 21/7/2020| 4                             | 2                            |
| 28/7/2020| 1.5                           | 0.9                          |
| 9/8/2020 | 1.5                           | 1.01                         |

Figure 4. NO₃ concentrations in HFP wetland systems
3.5 Ortho phosphate-phosphorous removal

During the monitoring period, the conditions of the effluent from the tertiary treatment showed varying values reaching a maximum of 2.5 mg/L and a minimum of 0.6 mg/L of phosphorus. In all collected samples, as shown in Table 3. The lowest removal efficiency rates were verified in August (43%) and the Higher removal efficiency in July (63%). This was because the sprouts acclimatation period occurred at the beginning of the experiment. Phosphate is one of the important nutrients that plants need to grow and increase cellular activity. However, it is present in low concentrations. The active phosphate (Orthophosphates) is the dissolved inorganic form that is used by living organisms [28], despite its role as a basic nutrient for plants in aquatic ecosystems. Excess phosphate concentrations can cause and algae growth in the water body [29].

Table 3. Inflow and out flow $PO_4$ concentrations in HFP wetland systems

| Date       | Influent Concentration(mg/l) | Effluent Concentration(mg/l) |
|------------|------------------------------|-----------------------------|
| 1/7/2020   | 3                            | 1.1                         |
| 7/7/2020   | 1.2                          | 0.6                         |
| 14/7/2020  | 3                            | 1.2                         |
| 21/7/2020  | 2.2                          | 1.3                         |
| 28/7/2020  | 5                            | 2.5                         |
| 9/8/2020   | 3                            | 1.7                         |
3.6 Total suspended solids removal

During the monitoring period, the conditions of the effluent from the tertiary treatment showed varying values reaching a maximum of 45 mg/L and a minimum of 19 mg/L of Total Suspended Solid. In all collected samples, as shown in Table 4, these wetlands individually reduce TSS with efficiencies ranging from 37% to 65%. The Figure 6 shows the effect of the reed plant in the reduction of total suspended solids (TSS). The decrease in the values of total suspended solids in the wetland basin planted with reed plants is due to the reason for the reed plant’s ability to filter and precipitate total suspended solids, as these plants act as biological filters (Biofilter) by attracting these obstructive and dissolved materials with water and pushing them to the bottom and thus the water is purified and its transparency increases. [30] This is more than what the researcher found and the reed plant has a high efficiency to remove suspended solids by 70%. [31] He indicated that the estimation of total suspended solids is one of the criteria used in evaluating the efficiency of wastewater treatment. It was also found that there is no total removal of all total suspended solids (TSS) in conventional treatment plants units such as sewage sedimentation tanks, but it was found that they are effectively removed through the filtration and sedimentation processes by using aquatic plants such as reed plants in treatment ponds using wetlands [32] It serves to precipitate solid suspended materials and make them stagnant in the lower layer, as for the filtration process, the adhesion particles adhere to the upper surface of the submerged parts of the plant, forming a thin biofilm layer. It helps to attract microorganisms [33] In addition to that, the filtration and sedimentation processes It plays an important and major role to remove organic matter, nutrients and pathogens [34, 35].
### Table 4. Inflow and out flow TSS concentrations in HFP wetland systems

| Date       | Influent Concentration(mg/l) | Effluent Concentration(mg/l) |
|------------|------------------------------|-----------------------------|
| 1/7/2020   | 60                           | 35                          |
| 7/7/2020   | 71                           | 45                          |
| 14/7/2020  | 81                           | 28                          |
| 21/7/2020  | 61                           | 30                          |
| 28/7/2020  | 70                           | 34                          |
| 9/8/2020   | 38                           | 19                          |

### Figure 6. TSS concentrations in HFP wetland systems

4. Conclusions

The results obtained from running a pilot plant for more than 8 months showed that the plant was not only able to remove pollutants to the required level for the amount of wastewater, and also showed that the pilot plant was robust, did not require any maintenance and was characterized by low implementation costs. The wetland system does not require any electrical energy, does not use any chemical additives, does not produce odor or noise, and therefore it is considered environmentally friendly, as well as demonstrating the success of the Bioremediation efficiency in getting rid of the greater part of the organic matter present in wastewater. It also achieved phytoremediation. By using the Horizontal Flow System (HSF), high efficiency in wastewater improvement. And that the reed plant is considered a biological evidence for the presence of water rich in organic matter and nutrients, as well as a record of reduction of various environmental factors and that the treated water is acceptable in terms of removing the polluted organic load, suspended materials and salts as well as its nitrate and phosphate content.
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