Non–Vegetated Constructed Wetland with Graded Sand Bed System for Hazardous Landfill Leachate Treatment and Heavy Metals Removal

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Abstract
Three pilot scale non-vegetated constructed wetland with graded sand bed systems (N-VCWGS) were investigated for the treatment of hazardous landfill leachate and heavy metals removal. The reactors were filled with graded sand media. The pilot systems were operated at the same Hydraulic Retention Time (HRT) of 5 days. The results showed that the N-VCWGS which consists of three reactors (CW3) was very efficient for the removal of heavy metals. The removal efficiency was 63% for iron (Fe+3), 89% for copper (Cu+2), and 68% for manganese (Mn+2). The results showed that it was very efficient in ammonia removal with efficiency 84%, total suspended solids removal efficiency was 48%, and 62% removal efficiency for volatile suspended solids. The results approved that vegetation is not essential for heavy metals removal and hazardous landfill leachate treatment, but it has an important role in Chemical Oxygen Demand (COD) removal due to the higher microbial activities and aeration in root zone.

Keywords: Constructed wetland, hazardous landfill leachate, industrial wastewater treatment, heavy metals removal.

Introduction

The industrial production of Alexandria city is 40% of the total industrial production of Egypt. There are more than 1900 industrial institution in Alexandria include food processing, chemicals, petrochemical, pharmaceuticals, hydrocarbons, construction, cement, metals, light and electronics manufactures [1]. The increase of industrial activities has increased the amount of the produced hazardous wastes. Hazardous waste landfills were established for the environmental disposal of hazardous wastes [2]. Landfill leachate is a highly contaminated liquid [3], [4], generated due to the percolation of rainfall through waste materials, or due to the inherent water content resulting from chemical and biological reaction in wastes. Leachate components depend on the waste type that is disposed within the landfill and reactions taking place in it. Hazardous landfill leachate has high chemical oxygen demand (COD), ammonia nitrogen (NH_4-N), heavy metals, and alkalinity [5]. So that, hazardous landfill leachate treatment and contaminants removal before the safe disposal is considered an important environmental issue in our societies [6], [7]. Al-Nasreya hazardous waste treatment center in Alexandria produces highly concentrated, toxic and corrosive landfill leachate contains toxic heavy metals such as copper, zinc, iron, nickel and manganese and inorganic pollutants at high concentrations. It became a potential pollution source threats human health, air, soil, and groundwater. Several technologies are used for hazardous landfill leachate treatment, such as: precipitation, adsorption, oxidation, evaporation, reverse osmosis [8], [10]. Among the existing currently used wastewater treatment technologies, constructed wetland is considered the most economic and effective technology for its low cost, energy, land, operation and maintenance requirements [11], [14]. Constructed wetlands are widely used for many wastewater types treatment [15], [16], and achieved high treatment efficiency and heavy metals removal [17], [19]. The three main factors that affect the performance of constructed wetland systems include the granular media used, hydraulic retention time (HRT), and vegetation type [11], [17].

Many researchers investigated the role of vegetation in constructed wetland system for heavy metals removal and treatment. In several cases, researchers found that vegetation is not essential for wastewater treatment and heavy metals removal, and sometimes it may has negative effects on the performance of the system such as: [20] he found that the performance of non-vegetated constructed wetland was better than the vegetated constructed wetland in heavy metals removal for urban runoff wastewater. This was due to the decreased pH value resulted from the vegetation, which in turn inhibited heavy metals removal process. He also found that heavy metals removal mechanism depended mainly on filtration. Giovanni De Feo also found that vegetation did not affect chemical oxygen demand (COD) and suspended solids removal. As well, filtration process significantly controlled the treatment process for municipal solid waste landfill leachate. Additionally, it was reported that, the difference in the treatment efficiency between vegetated and non-vegetated constructed wetland ranged from 1.9 to 8.9% [12]. Therefore, this research was made for investigating two objectives: the first one was to compare among three different constructed wetland systems for the treatment of hazardous landfill leachate as well as heavy metals removal using the same granular media and under constant hydraulic retention time (HRT). The second objective was to investigate if the vegetation is essential for achieving higher performance or not.

Materials and Methods

A. Laboratory System Design and Operation Conditions

Three pilot scale rectangular reactors were prepared as non-vegetated constructed wetlands with graded sand bed systems (N-VCWGS). Each reactor has the same working volume of 58 liters. Three different constructed wetland systems (CW) were constructed using these three reactors. The first system consists of only one reactor (CW1). The second system was made of two consecutive reactors (CW2), and the third system comprised of three consecutive reactors (CW3). The schematic diagram for the three constructed wetland systems is shown in Fig. 1. The consecutive reactors were placed in declining levels to provide a natural flow for water under gravity. All reactors media was graded sand. Water hose was used for leachate flow through the consecutive reactors. Systems were opened and exposed to ambient temperature. Experimental work was pursued for two months with 5 days' hydraulic retention time (HRT).

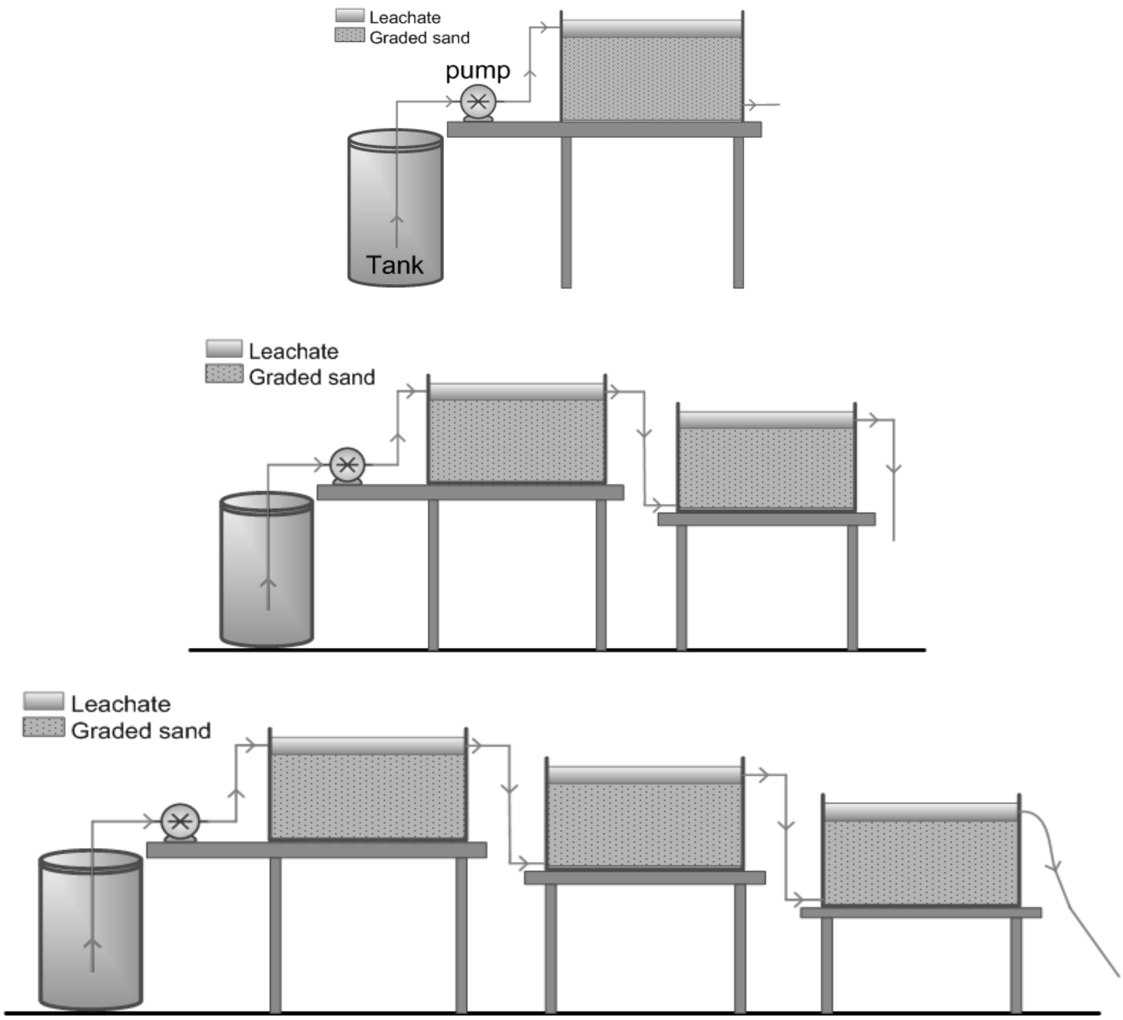


Figure 1: Schematic diagram for the three non-vegetated constructed wetland with graded sand bed systems.

B. Hazardous Landfill Leachate

The influent for the three systems was the generated leachate from Al-Nasreya hazardous waste landfill. The leachate characteristics are presented in Table (1).

Parameter	Unit	Range	Average
PH-value	—	8.28 – 9.07	8.78
Total COD	mg/l	2665 – 4772	3529
Soluble COD	mg/l	2100 – 4752	3247
TSS	mg/l	505 – 1360	1360
VSS	mg/l	110 – 910	523
TDS	mg/l	44200 - 84600	62104
VDS	mg/l	5120 - 40600	27723
TKJ-N	mg/l	58 – 334	102
NH_4-N	mg/l	14 – 239	84
NO_3	mg/l	5 – 17	10
Cu^{+2}	mg/l	0.12 – 6.44	3.7
Ni^{+2}	mg/l	6.6 – 8.4	7.5
Fe^{+3}	mg/l	3.4 – 11.5	6.2
Zn^{+2}	mg/l	2.72 – 12	6.4
Mn^{+2}	mg/l	5.71 – 15.66	9.8

Table 1: Al-Nasreya Hazardous Landfill Leachate Characteristics and Heavy Metals Concentrations.

C. Sampling and Experimental Work

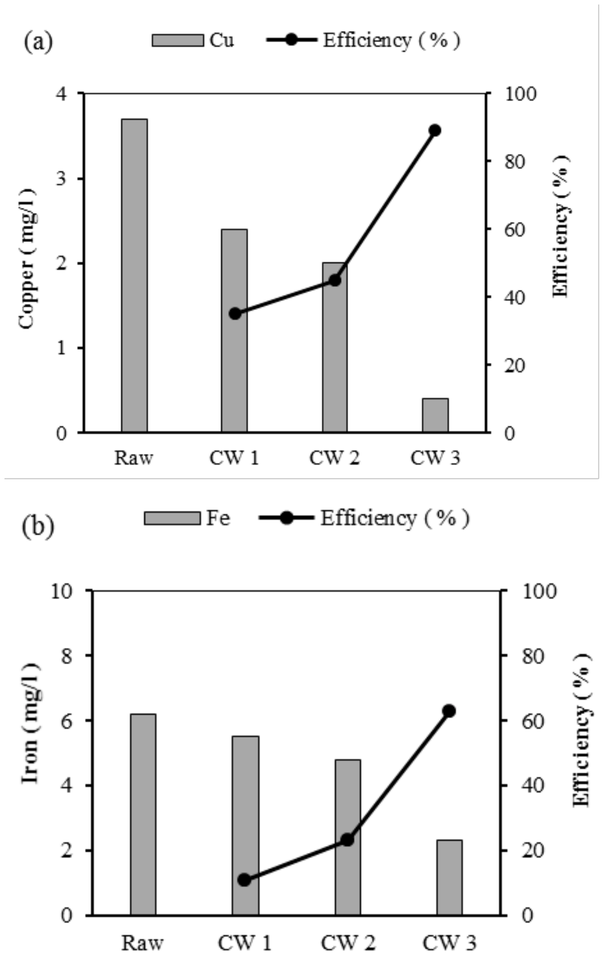
Samples from the influent and effluent of each reactor were taken three times a week. Samples were analyzed for the following physicochemical parameters: pH, total and soluble chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total suspended solids (TDS), and volatile suspended solids (VDS) according to APHA (2005) [21]. Heavy metals: copper (Cu^{+2}), manganese (Mn^{+2}), iron (Fe^{+3}), zinc (Zn^{+2}), and nickel (Ni^{+2}) concentrations in the influent and effluent of each reactor were measured.

Results and Discussion

A. Heavy Metals Removal

Fig. 2 shows the obtained experimental results for heavy metals concentrations in the influent and effluent of the N-VCWGS and the efficiency of heavy metals removal for each system. The results show that the N-VCWGS were very efficient for Cu^{+2}, Fe^{+3}, and Mn^{+2} removal and moderate efficient for Zn^{+2} and Ni^{+2} removal. From the results, the third system (CW3) which consists of three reactors was the most efficient system for heavy metals removal. In particular, the removal efficiency of Cu^{+2} was 89% for CW3, 45% for CW2, and 35% for CW1 as shown in Fig. 2 (a). Where, the removal efficiency for Fe^{+3} was 63%, 23%, and 11% for CW3, CW2, and CW1, respectively as shown in Fig. 2 (b). Furthermore, the Mn^{+2} removal efficiency of 86%, 72%, and 66% have been achieved for CW3, CW2, and CW1, respectively as shown in Fig. 2

(c). As well, moderate removal efficiency was obtained for Zn^{+2} of 37%, 13%, and 5% for CW3, CW2, and CW1, respectively as shown in Fig. 2 (d). The removal efficiencies of Ni^{+2} were 25%, 15%, and 14% for CW3, CW2, and CW1, respectively as shown in Fig. 2 (e). Significantly, the removal of heavy metals was mainly due to filtration, adsorption, and metal sulfides precipitation processes [11], [22]. In particular, the anaerobic conditions in the bottom layers of the graded sand in submerged non-vegetated constructed wetlands enhances sulfate-reducing bacteria (SRB) activity, which oxidizes the sulfate compounds presented in hazardous landfill leachate to produce sulfides and increase the alkalinity. In turn, the produced sulfides react with the heavy metals in dissolved or particulate forms resulting in metal sulfides which precipitate on sand [11], [22]. Taking into consideration that the toxicity of the produced metal sulfides is very low compared to the high toxicity of heavy metals [23].



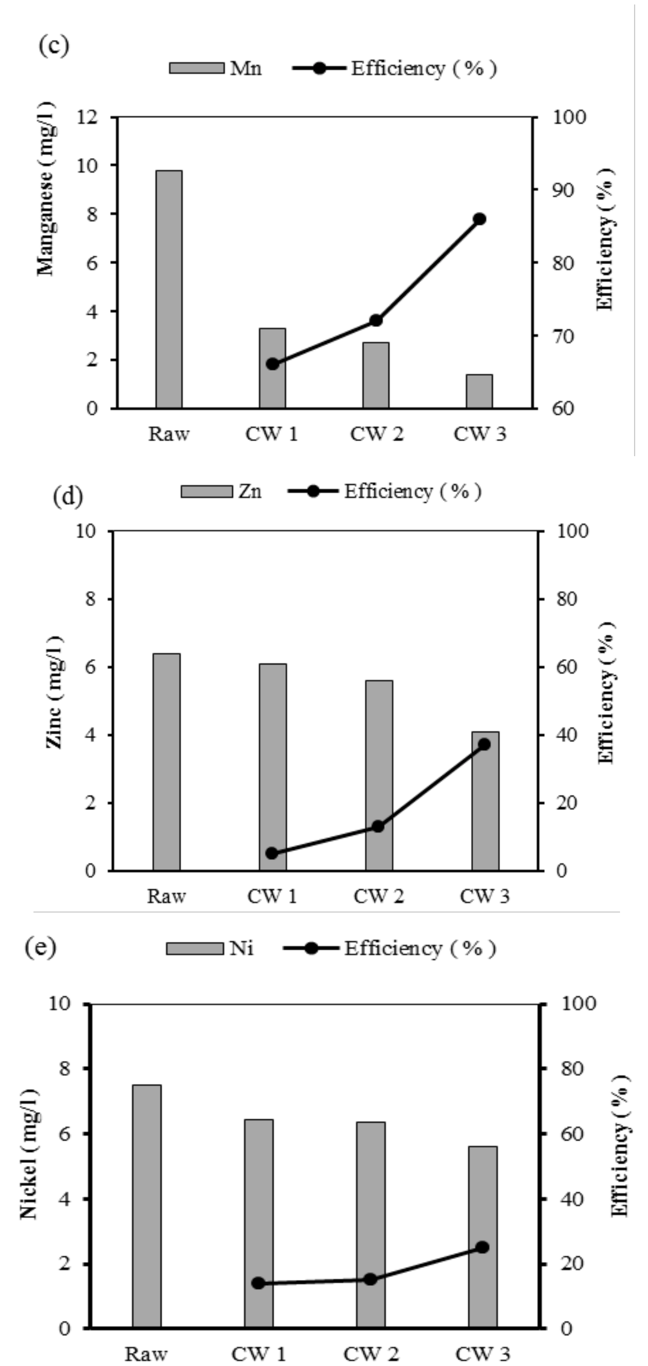


Figure 2: Heavy metals concentrations for the raw hazardous landfill leachate and the effluent of N-VCWGS and the removal efficiency of each system.

B. pH Value

As shown in Fig. 3, pH value was 8.78 for raw hazardous landfill leachate which increased respectively to 8.9, 9.1, and 9.2 in CW1, CW2, and CW3. This was due to the production of metal sulfides which are strong alkaline. The increasing of pH value causes reducing of heavy metals solubility which makes the wastewater less toxic and less harmful to the environment [24].

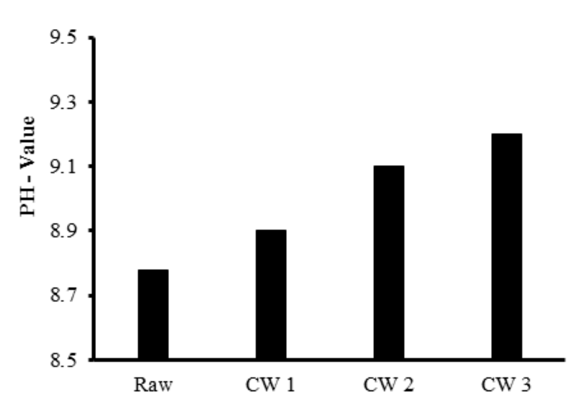


Figure 3: pH values for raw hazardous landfill leachate and each reactor effluent.

C. COD Removal

The total and soluble chemical oxygen demand concentration in raw hazardous landfill leachate were 3529, 3247 mg/l, respectively. The N-VCWGS show low removal efficiency for both total and soluble COD. The total COD removal efficiency was 24%, 10%, and 7% in CW3, CW2, and CW1, respectively, and 22%, 10%, and 5.5% for soluble COD as shown in Fig. 4. The low removal efficiency of the three systems can be attributed to the absence of vegetation resulting in very low microbial activities in sand pores, and due to the low porosity of sand resulting in poor oxygen transfer through sand bed pores [25].

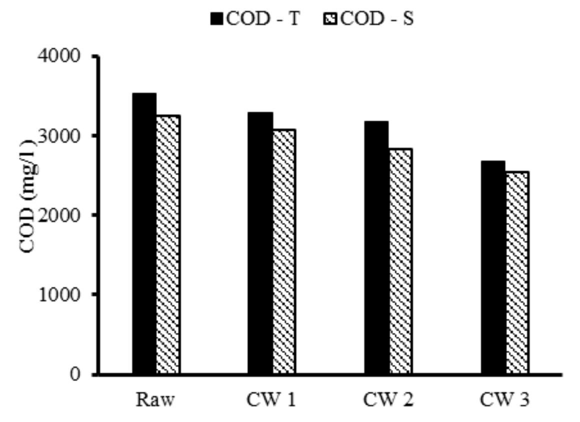


Figure 4: COD values for influent and each reactor effluent.

D. Nitrogen Removal

As shown in Fig. 5, the results show that N-VCWGS achieved high efficiency of nitrogen removal. The highest removal efficiency was for CW3 of 40% and 84% for TKN and ammonia, respectively. The removal efficiency of TKN and ammonia decreased to 28% and 47% for CW2 and 13% and 31% for CW1, respectively. As for nitrates, it increased from 10 mg/l for raw hazardous leachate landfill to 13, 15.5, and 19 mg/l for CW1, CW2, and CW3, respectively resulting from nitrification.

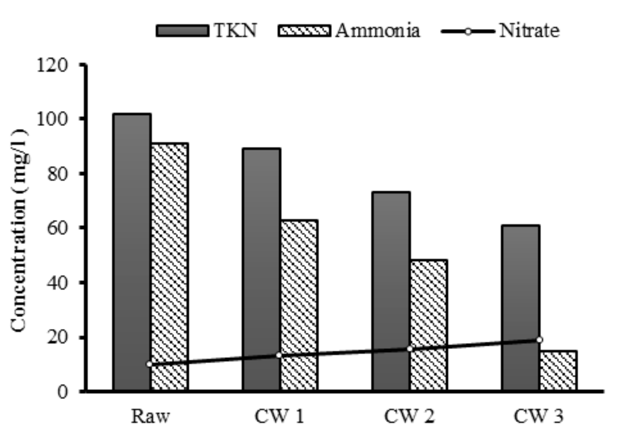


Figure 5: TKN, ammonia, and nitrates for influent and each reactor effluent.

E. Suspended Solids Removal

Fig. 6 shows that CW3 was the most efficient system for both suspended and volatile solids removal with 48% and 62%, respectively whereas, the removal efficiency decreased for TSS and VSS to 45% and 55% for CW2, and 21% and 35% for CW1, respectively.

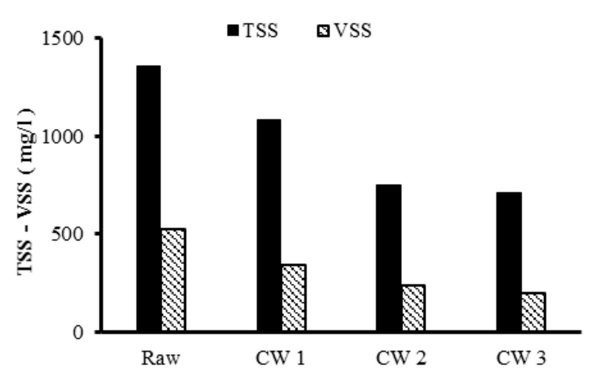


Figure 6: TSS and VSS values for influent and each reactor effluent.

Conclusion

In summary, the present study confirms the high performance of non-vegetated constructed wetlands with graded sand bed for Al-Nasreya hazardous landfill leachate treatment and heavy metals removal. The results proved that vegetation is not essential for heavy metals, nitrogen and solids removal. However, it is considered essential for COD removal due to the high microbial activities in the root zone. Also vegetation enhances aeration in sand pores due to the plants ability to transfer oxygen from surrounding atmosphere to root zone. Moreover, the results showed that the non-vegetated constructed wetland system which consists of three reactors was the most efficient system for hazardous landfill leachate treatment and heavy metals removal.

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