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RESEARCH PAPER

Phytoremediation of Oil Refinery Wastewater Using Different Constructed Wetland Designs, Erbil, Iraq

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A B S T R A C T:

Petroleum refinery generates a great deal of hazardous and toxic pollutants that contaminate the receiving environment. In this study, different outdoor constructed wetland (CWs) designs, namely; horizontal (HSSF-CW), vertical (VSSF-CW) and hybrid (HSSF + VSSF-CWs), planted with Southern cattail (*Typha domingensis Pers)* were evaluated for removal of lead (Pb) and zinc (Zn) from petroleum refinery effluents (KCPS-Erbil-Iraq from February to May 2022). Results revealed that the maximum removal rate of both implanted constructed wetlands (i.e., HSSF-CWs and VSSF-CWs) able to reduce Pb and Zn to an acceptable level. Meanwhile, the implanted hybrid-CWs (HSSF + VSSF-CWs) were showed more intensive reduction of Pb and Zn. However, the maximum percentage removal rate of metals in the implanted hybrid-CWs reached (96.14% Pb and 98.87% Zn) over 45 days and highest metal uptake values of (13.40 mg/plant and 44.4 mg/plant) were calculated for Pb and Zn, respectively. On the other hand, *T. domingensis* species accumulated higher quantities of Pb and Zn in their shoots rather than roots ($BAF_{shoot/root}$ >1 and TF <1), credited as strong excluders.

KEYWORDS: HSSF-CW; VSSF-CW; hybrid-CW, refinery effluent; lead; zinc
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1.INTRODUCTION :

Contamination of water supplies by hazardous substances caused by the release of petroleum refinery wastewater, however, has turned into a worldwide issue due to the adverse impacts on the health of humans as well as the fauna and flora that consume water systems (Ansari et al., 2015). As a result, special attention should be paid to the handling and preservation of natural freshwater that will continue to be the primary source of both residential and agricultural water supplies, especially in semi-arid developing nations such as Iraq's Kurdistan region (KRI) (Gaf and Ganjo, 2012).

Petroleum refinery wastes produce a large amount of waste sludge that is high in toxic heavy metals and pollutes the soil and water (Masoumi et al., 2016).Metals that are toxic to vegetation, wildlife, and humans over a certain level for each substance (Bolisetty et al., 2019).

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Zinc (Zn) is a critical compound and a micronutrient required for essential physiologic and biological processes involved in plant life. It is a component of several enzymes along with proteins, so all plants may collect it through the soil solution. Lead (Pb) has not referred to physiological or biological performance and is thus not required for growth of plants. High Pb levels can harm plants by reducing chlorophyll synthesis, resulting in stunted growth (Sricoth et al., 2018).

The cultivation of aquatic species of plants for phytoremediation has been shown as an economical and environmentally friendly tool (Ebrahimbabaie et al., 2020). Constructed wetlands (CWs) are among current technique that is becoming a progressively important part of phytoremediation (Qi and Zhao, 2020). CWs are intended to mimic a lot of the procedures that take place in natural wetlands, but in a more regulated situation (Hussain et al., 2018). When compared to traditional systems, CWs are more efficient and have considerably reduced funding costs; they also require a smaller amount of land, labour, and strength (Ansari et al., 2015). Multiple kinds of constructed wetlands are currently being paired into hybrid systems to improve therapy achievement for contaminants elimination (Odinga et al., 2014). The majority of them are constructed in horizontal subsurface flow systems (HSF-CWs), however vertical subsurface flow systems (VSF-CWs) are getting more common due to their higher removing capacity (Schück and Greger, 2020). CWs are made up of a few areas that have been filled with a base material that promotes plant growth.

Aim this study is phytoremediation of oil refinery wastewater by using constructed wetland , were use different outdoor constructed wetland designs (CWs); (HSSF-CW), (VSSF-CW) and (HSSF + VSSF-CWs), planted with southern cattail (*Typha domingensis)* evaluated for removal of lead (Pb, not vital for plant) and zinc (Zn, vital for plant) elements in petroleum refinery wastewater. Southern cattail was harvested after 45 days and tested for survival of the plant, rate of growth, metal accumulation, metal uptake, and removal capacity in different CW designs.

2. Materials and methods

2.1 Plant preparation and selection

T. domingensis is an emergent plant that was gathered in wetland habitats obtaining refineries discharges of wastewater from the Khurmala Central Processing Station (KCPS) in Erbil, Iraq in february to May 2022 (Lat. 35°58'50.17"N and Lon. 43°46'0.01"E).Plants that were homogeneous and in good health were gathered. Plant specimens identified by Professor Dr. Abdullah Shakur Sardar (Plant Taxonomist), University of Salahaddin-Erbil, College of Education, Biology department. To remove any bonded soil, all plant samples had been completely rinsed through distilled water multiple times afterward using deionized water (DI). Before the beginning of the investigations, specimens were placed in outdoor polyethylene square containers and acclimatized within the wastewater in natural conditions over 45 days for adapting and promoting vigorously develop of plants (Khwakaram and Ganjo, 2010). The initial amount of dry biomass, as well as the Pb and Zn levels found in roots and shoots, had been calculated before the study.

2.2 Experimental design and schedule

A polyethylene pre-treatment tank (as a physical treatment unit and/or as a primary settler) was set up (capacity = 3000 liter) at 2 m above the ground level (**Figure 1**). The tank was filled with wastewater from the Khurmala refinery. The effluent from the tank was then distributed via 1 Inch PVC tubes over three serial constructed wetlands (of three replicates each), along with a control (included none plant product, i.e., non-aquatic plant's remedy), as below:

1) Horizontal (HSSF-CWs),
2) Vertical (VSSF-CWs), and
3) Hybrid (HSSF + VSSF-CWs).

Each constructed wetland was set up in a 110-litre containing ten cm of cobblestone (0.2-0.5 cm sized particles) at their bottom, next to a 30 cm second quartz layer water stone (2.0 mm sized particles) (**Figure 2**)

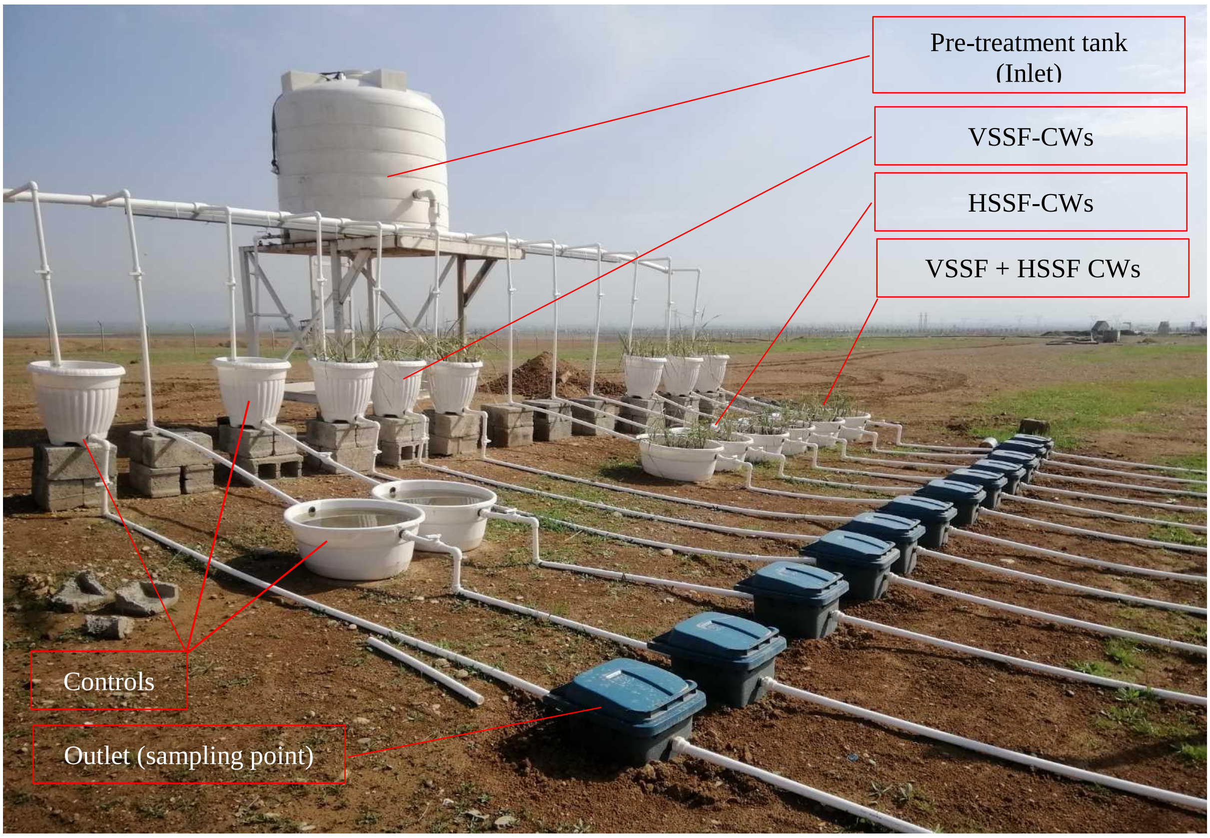
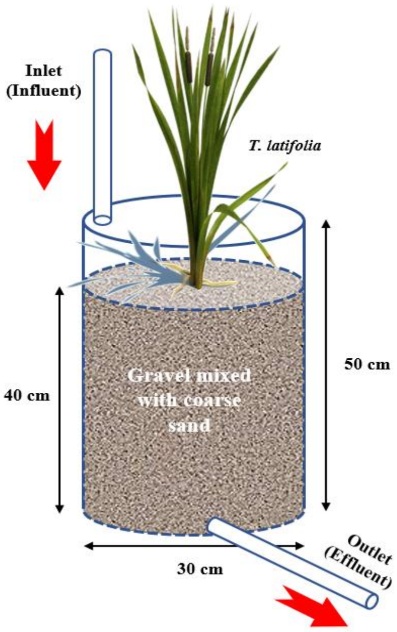
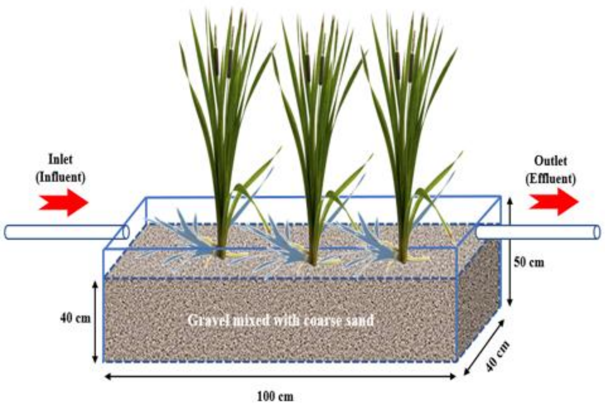


Figure (1): Experimental design





A) Vertical SSF-CW **B) Horizontal SSF-CW**

Figure (2): Design of Subsurface Flow Constructed Wetlands (CWs)

The sandy material and cobblestone, or a base, were rinsed multiple times with reverse osmosis water to eliminate small soil fragments before being acids washed via 10% HNO3 (TraceMetal Grade). The medium was then air-dried after being washed multiple times with distilled water till the pH reached neutral. The CWs' substrate stored undetectable levels of Zn and Pb. The constructed wetlands received the influent by self-acting (no peristaltic pump, only gravity force), periodic batches loading (i.e., mechanical loading),

(8-10/day) dosages (for the transfer of oxygen improvement), and a two-day resting time For example, HRT (hydraulic retention time) (Hussain et al., 2018).
Southern cattail plant species were transplanted in equal numbers immediately into the sand. The mechanisms have been tested for 15 days to assess growth of plants and stability of the system. The research timetable included three phases, which are summarized in Table (1) below:

Table (1): The experiment phases and schedule

Phase	Duration	Assay
Phase (1) Acclimation	45 days	Analyses of initial dry biomass and metal content in plant parts (root and shoot)
Phase (2) Monitoring	45 days	Monitoring of metal content (Pb and Zn) in the raw wastewater and outlets of the constructed wetlands (on biweekly intervals)
Phase (3) Post Sampling	After 45 days	Plant and substrate collection (analyses of metal uptake indices, i.e., BAF, TF, MU etc.)

2.3 Sampling and metal analyses

Water samples were taken from each untreated (inlet) and treated (discharge) of various remedy units. Water samples were collected in a 1-litre pre-acid-washed quartz bottles. Each sample was kept in a cool and dark place till they arrived at the laboratory.

The heavy metal concentrations, Pb and Zn in samples of water have been measured using flame atomic absorption spectrophotometry (FAAS; Buck Model 210/211 AAS 220 GF graphite furnace and 220 AS auto sampler, USA), as stated by (APHA, 2017). The samples of water were filtered via 0.45 m filters before analysis to eliminate particulates. To reduce the adsorption of metal on the bottle walls, four ml of concentrated HNO3 (TraceMetal Grade) was incorporated into one-litre suction-filtered water sample. Aqua regia was used for digesting water samplers (HNO3 67%: HCl 37% = 3) (Sricoth et al., 2018, Ebrahimbabaie et al., 2020).

Pb and Zn levels in the tissues of plants (roots and shoots) and sand samples were measured using the method described in (Khalid and Ganjo, 2020), through (FAAS; ICP-MS Model 4500 Elan DRC, Perkin Elmer Company, USA).

2.4 Growth rate, metal uptake and contaminant removal indices

Plants have been counted at the end of the operation to assess mortality rates; the rate of survival of the plant was determined by dividing the final surviving number by the planted amount. In the growing situation, plants had been visually examined for any indications of toxicity (Arora et al., 2019). The metal uptake indicators were computed through the formulas stated in (Sricoth et al., 2018, Ebrahimbabaie et al., 2020). growth rate (GR) was used to assess the growth of plants among species (Meeinkuirt et al., 2016):

$$GR = DBP_{ah}-DBP_{bp} / T_{ah}-T_{bp} \quad (1)$$

In which DBP_{ah} is the dry biomass produced right after harvesting, DBP_{bp} is the dry biomass produced before planting, and T_{ah} (days) and Tbp (days) are the cultivation intervals prior to and after harvesting, calculated over 45 days, the GR result has been turned to (% GR) percentages of growth rate (Meeinkuirt et al., 2016):

$$\text{Metal uptake} = Metal_{pp} \times DB_{pp} \quad (2)$$

$Metal_{PP}$ denotes the amount of metal found in a plant's part (root or shoot), and DB_{pp} denotes the dry biomass produced by the root or shoot tissues.

The percentage of the removal rate of contaminants is employed to differentiate the amount of contaminants eliminated for aquatic plants developed in wastewater (Liu et al., 2016)

$$R = (C_i-C_f) / C_i \times 100 \quad (3)$$

Which R denotes the contaminant removal rate (%) C_i the initial contaminants level and C_f the final contaminants amount.

Removal capacity denotes the plant's overall ability to eliminate contaminants from wastewater for the investigation (Liu et al., 2016):

$$RC\ (mg/\ day/\ g) = (C_i-C_f) \times VDB \quad (4)$$

In which RC denotes the rate of removal capacity (mg/day/g), C_i is the initial contaminants level, C_f is the final contaminants level. Also V is the volume; D is the number of days, and B the biomass average.

Translocation factor (TF) is a key index for determining metal transfer from the plant's below-ground to above-ground sections (Meeinkuirt et al., 2016):

$$TF = MC_{shoot} / MC_{root} \quad (5)$$

Where $MC_{shoot}/_{root}$ is the amount of metal in a plants part (root or shoot).

The bioaccumulation factor (BAF) is a measure of the possibilities for heavy metal moving throughout various parts of a plant. The plant part ought to hold metal basically in roots for the process (Dogan et al., 2015); whereas accumulation of metal happens primarily in shoots in a plant extraction approach (Zou et al., 2012):

$$BAF_{PP} = C_{PP} / C_{WW} \qquad (6)$$

Where BAF_{PP} is the biological concentration value for plant parts (PP) (i.e., root or shoot), C_{PP} is the plant part's metal level, and C_{WW} is the metal quantity in the wastewater.

2.5 Statistical analysis data

The results were shown as means ± standard deviation (Mean ± SD). SPSS software (version 25) (SPSS Inc., Chicago, IL, USA) was used for analyzing the data. One-way ANOVA with Duncan's multiple range test was used for assessing and comparing significant differences ($P \leq 0.05$) among various remedies.

3. Results and discussion

3.1 Plant growth

The studied species of plant i.e., southern cattail (*T. domingensis)* grew rapidly and survived completely in all treatments, without any obvious morphological indications of toxicity (e.g., chlorosis and stunting), indicating adapting to and tolerances of the extremely polluted oil refinery wastewater. However, the highest growth rate of 248% was recorded in the third replicate of the hybrid-CWs (Table 2). southern cattail possesses extended roots with thick hairs on their roots and a fibrous and pressed root structure, which is a distinguishing feature. This species is deemed highly invasive in Kurdistan region government (KRI). The investigated plant was classified as belonging to the excellent dry biomass category, indicating a typical feature of this native species of plant in its natural environment; however, aquatic species are quite simple to reproduce and develop quickly, building up a large biomass in a short period of time (Das et al., 2014). The entire plant biomass commitment is critical in phytoremediation study because it serves for understanding plant tolerance for adverse environmental limitations (Arora et al., 2019).

Table 2: Survival and growth rate of *T. domingensis* Pers implanted in different CW design experiments

System	Treatment/Replicate	Survival rate (%)	Growth rate (%)
Control		100	300
Vertical SSF-CW	First	100	113
	Second	100	111
	Third	100	120
Horizontal SSF-CW	First	100	123
	Second	100	120
	Third	100	125
Hybrid-CW	First	100	243
	Second	100	240
	Third	100	248

3.2 Initial Zn and Pb in the refinery effluent

The variation in concentration mean values of metals and the effectiveness of various phytoremediation treatment parts throughout the research time are shown in Table (3). The initial mean metal concentrations in the refinery influent were 2.20 and 2.37 mg/l recorded over 45 days for Pb and Zn, respectively, which exceeded safe levels, when compared with safe limits recommended by Iraqi standards (2009)(Aziz and Sabbar, 2013) of 0.1 and 2.0 mg/l prescribed for Pb and Zn, respectively in oil refinery effluents.

Table 3: The changes in the mean value of a metal concentrations with (mean ±SD), over the study period (n = 3).

System	Treatment	Metal concentration (mg/L)	
		Pb	Zn
Influent (raw wastewater)	Untreated	$2.20^{a}\pm0.011$	$2.37^{a}\pm0.31$
Pre-sediment tank	Physical	$2.09^{ab}\pm0.09$	$2.20^{a}\pm0.21$
Vertical SSF-CW	Unplanted	$1.69^{ab}\pm0.08$	$1.00^{b}\pm0.25$
	Planted	$0.28^{c}\pm0.26$	$0.13^{c}\pm0.10$
Horizontal SSF-CW	Unplanted	$1.72^{ab}\pm0.09$	$1.13^{b}\pm0.35$
	Planted	$0.28^{c}\pm0.26$	$0.15^{c}\pm0.09$
Hybrid-CW	Unplanted	$1.62^{b}\pm0.08$	$0.92^{b}\pm0.16$
	Planted	$0.08^{c}\pm0.22$	$0.09^{c}\pm0.07$

Permissible level (Iraqi standard 2009)(Aziz and Sabbar, 2013) of Pb & Zn in oil refinery wastewater is 0.1 & 2.0 mg/l, respectively.
Values with the same letter don't differ significantly ($P > 0.05$).

3.3 Physical (Pre-sediment tank)

Throughout the study period, the physical treatment sections (i.e., Pre-sediment tank) displayed no significant variations (P > 0.05) in elimination of both contents Zn and Pb (Table 3). Maximum percentage removal rate by the physical treatment of Pb and Zn was 4.86 and 6.96 %, respectively (Figure 3 and Figure 4). This might be linked to the medium initial level of metals in the oil refinery influent; additionally, no coagulators were utilized in the pre-sediment tank in the current research for preventing chemical interferences; however,(Bolisetty et al., 2019) claimed that physical units have a greater efficient at removing metals at smaller quantities when there are little metal ions in the solution.

3.4 Constructed Wetland Designs

The Vertical SSF-CW indicated small variations ($p < 0.05$) in Pb and Zn contents (0.28 and 0.13 mg/l, respectively) over the study period, with percentage removal rate of 23.18% in unplanted and 65.91% in planted VSSF-CWs recorded for Pb removal and 21.44% in unplanted and 52.91% in planted VSSF-CW calculated for Zn removal (Table 3; Figure 3: Figure 4).

The HSSF-CW performed sufficiently well to remove lead and Zinc in the refinery wastewater(0.28 and 0.15 mg/l, respectively), with a Pb percentage removal rate of 22.05% in unplanted and 66.14% if planted HSSF-CW and Zn percentage removal rate of 20.72% in unplanted and 58.32% (Table 3; Figure 3: Figure 4).

Meanwhile, the hybrid-CWs showed more intensive decrease in Pb and Zn, whereas, the mean value of concentrations of metals of concern reduced to 0.08 and 0.09 mg/l recorded for Pb and Zn, respectively, over 45 days, compared to the initial content of 2.30 and 2.37 mg/l, calculated for Pb and Zn, respectively, with Pb percentage removal rate of 26.45% in unplanted and 96.14% in planted hybrid-CWs and Zn percentage removal rate of 28.61% in unplanted and 98.87% in planted hybrid-CWs (Table 3; Figure 3: Figure 4).

The base material plays a role in the treatment of contaminants both immediately and in an indirect manner, the substrates play a direct role in the deposition and filtering of suspended particles, as well as the absorption of heavy metals and organic compounds (Mandal et al., 2016) and informally act as a microbe's bonding and root system promote (Hussain et al., 2018). Nonetheless, the technologies of constructed wetlands for treating wastewater has not reached its full potential, and numerous issues remain in terms of ideal handling and long-term viability (Ansari et al., 2015). Heavy metal concentrations are a major impediment to employing and enhancing phytoremediation in polluted aquatic environments (Ite and Ibok, 2019). The majority of metal pollutants are deposited in the beneath of wetland regions (Bonanno and Giudice, 2010). This suggests the utilization of rooted emergent species of plants that are more effective in phytoremediation (Zou et al., 2012).

Similar conclusions were made (Khalid and Ganjo, 2020) using different aquatic plants and constructed wetlands. CW treatment is essentially depending on a variety of physical and biological procedures such as filtration, precipitation, adsorption, predation, decomposition, nitrification, and so on.; hence, hybrid-CWs are capable of removing metals more efficiently compared to other types of CWs (Laghlimi et al., 2015). Although, there's very little knowledge accessible on the removal of pollutants strategies as well as process dynamics in outside CWs. Generally, in this study hybrid-CWs showed much more removal activity than other treatments because it connects vertical and horizontal treatments. (Truu et al., 2015) explained throughout such a complicated system, multiple removal processes (volatilization, photochemical oxidation, settling, adsorption, and biodegradation) may occur concurrently, while plants can participate by immediately contaminants uptake and gathering, phyto-volatilization, and metabolism changes, or by developing favourable conditions for pollutants remediation with the system itself. Same comparable observations were made by (Hussain et al., 2018) Who showed that the ability and efficiency of sand substrates (i.e., filter bodies) for removing heavy metals detected in CWs is linked to the input initial level of metal and the rate of flow importation, i.e., periodic batches, putting doses/day and resting period, along with to the substratum depths. Heavy metals like zinc may be totally eliminated by chemical precipitations when employing lime treatment (Ansari et al., 2015). The similar approach, yet fails to provide complete elimination of lead, a contaminants from water until pre- or follow-up treatments (e.g., decreasing the solution via soda ashes or sodium sulphide) are used (Das et al., 2014).

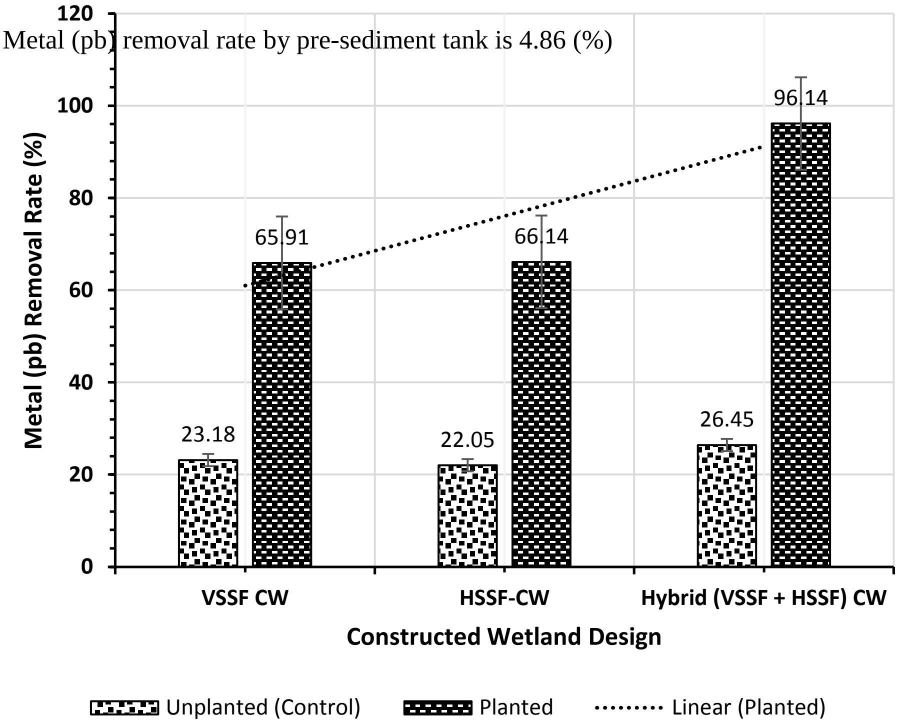


Figure 3: Percentage removal rate (%) of lead (pb) by different constructed wetland designs over 45 days (*n*=3).

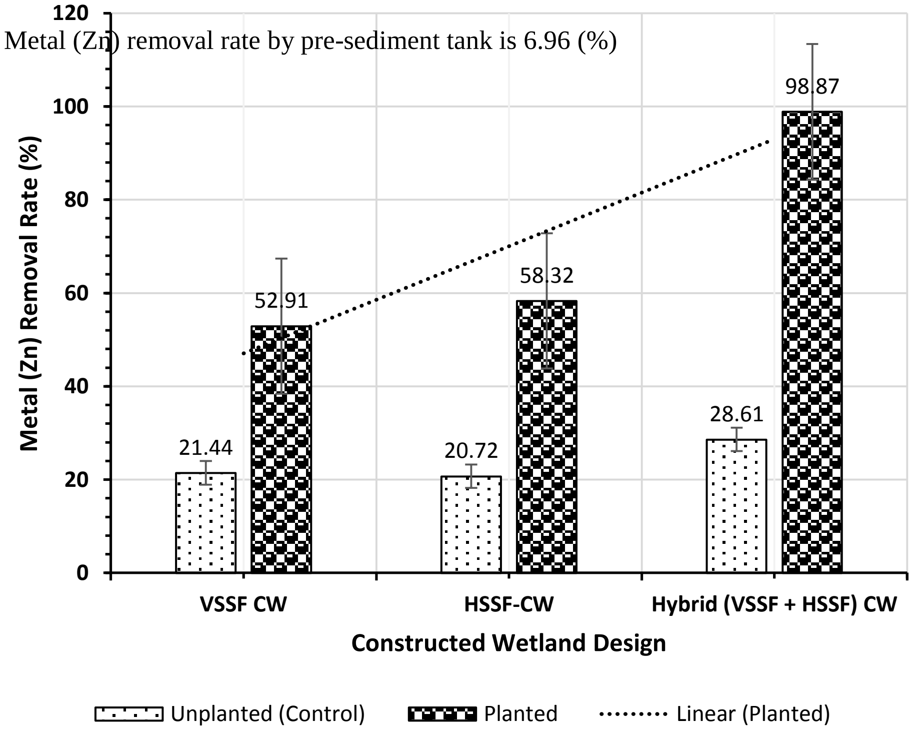


Figure 4: Percentage removal rate (%) of zinc (Zn) by different constructed wetland designs over 45 days (*n*=3).

3.5 Bioaccumulation Factor (BAF), Translocation Factor (TF), Metal Uptake (MU)

Bioaccumulation factor (BAF) and translocation factor (TF) are the two most reliant indices for determining metal phytoremediation capacity and considered one of the most essential indicators for the phytoremediation process (Mendez and Maier, 2008). In this research, bioaccumulation factors, BAF (BAF_{root} and BAF_{shoot}), translocation factor (TF) and metal uptake (MU) values were also ascertained in the studied plant *Typha domingensis* Pers tissues (i.e., root and shoot), as well, implanted in different CW designs (Table 4 and Table 5).

Generally, present results showed that southern cattail had consumed a large amount of Pb and Zn in the shoots rather than roots. However, bioaccumulation factor values in the shoot in all treatments were greater than (1)

(BAFshoot >1), while translocation factor values were less than (1) (TF <1), accordingly southern cattail is credited as strong excluders.

The plant in different CWs had Pb uptake values greater than (1) (MU >1), but always Pb values were high in their shoots rather than roots, this reveals that southern cattail is strong excluder for Pb in their shoots. Zinc (Zn) uptake values were always greater than (1) (MU >1) and relatively accumulated the same patterns of Zn in either shoots or roots, and showed suitability for Zn phytoextraction in both roots and shoots (Table 4 and Table 5).

On the other hand, constructed wetland experiment results, showed that; the performance of the VSSF-CW and HSSF-CW separately showed slight decrease (P> 0.05) in bioaccumulation of Pb and Zn from wastewater, whereas, the bioaccumulation rate for all metals of concern were severely increased in the hybrid-CWs (VSSF-CW + HSSF-CW). This was evident from a decrease of all chemophysical parameters as mentioned above, however they were more intensively reduced to below permissible levels, and the most replicated CWs (hybrid wetlands) was the most potent treatment unit with a high singnificant difference (P<0.05) compared with the control, on one hand, and VSSF and HSSF CWs experiments on the other hand.

Generally, metal uptake (MU) in plant parts was high and concentrated mostly in root and shoot tissues, but translocation through the root to shoot was insufficient (TF<1). Metal uptake and build-up in the experiment plant followed separate patterns; the metal uptake ratio reflects both plant dry biomass and concentration of metals (Table 2 and Table 4).

Even maximum metal uptake for lead (Pb) was 13.4 mg/plant shoot and 8.4 mg/plant roots at hybrid-CWs and 9.8 mg/plant shoot and 10.25 mg/plant root at VSSF-CWs, whereas it was 8.6 mg/plant shoot and 6.2 mg/plant root in HSSF-CWs. Furthermore, maximum metal uptake for Zinc (Zn) was 44.40 mg/plant shoot and 18.04 mg/plant root at hybrid-CWs and 38.1 mg/plant shoot and 15.63 mg/plant root at VSSF-CWs, while it was 42.26 mg/plant shoot and 19.9 mg/plant root at HSSF-CWs (Table 4). It is important to note that both metals were distributed differently throughout the plant tissues, and significant variations between the tested plant ($P < 0.05$) were found in the different experimental constructed wetland designs (Table 4 and Table 5).

Sivaramakrishnan et al. (2018) stated that, Plants that have a BAF root higher than one (>1) and a BAF shoot with a TF smaller than one (1) have an opportunity to be utilized for the process. The current finding is consistent with previous studies showing the static character of metals from water, soil, and sediments to parts of aerial structures. (Ahmad and Ganjo, 2020). The plant southern cattail may immobilize heavy metals through build up by roots via root hairs, adhesion onto root surface, or settling throughout the rhizosphere. The same result was reached by (Yadav et al., 2018, Khalid and Ganjo, 2020).

Table 4: Mean value of metal uptake, bioaccumulation factor (BAF), and translocation factor (TF) with (mean ±SD) of the studied plant in different constructed wetlands (n = 3).

Metal	CW Design	Metal uptake (mg/plant)		BAF		TF
		Shoot	Root	Shoot	Root	
Lead (Pb)	VSSF-CWs	$9.80^{b} \pm 0.7$	$10.25^{a} \pm 1.1$	$2.04^{b} \pm 0.03$	$1.7^{ab} \pm 0.04$	$0.84^{a} \pm 0.1$
	HSSF-CWs	$8.60^{b} \pm 0.8$	$6.2^{b} \pm 2.2$	$1.51^{b} \pm 0.6$	$1.09^{b} \pm 0.2$	$0.72^{b} \pm 0.04$
	Hybrid-CWs	$13.40^{a} \pm 0.8$	$8.40^{ab} \pm 2.6$	$3.27^{a} \pm 0.1$	$2.05^{a} \pm 0.1$	$0.63^{b} \pm 1.1$
Zinc (Zn)	VSSF-CWs	$38.10^{b} \pm 2.0$	$15.63^{b} \pm 1.9$	$11.97^{b} \pm 7.0$	$4.9^{b} \pm 0.6$	$0.41^{b} \pm 0.8$
	HSSF-CWs	$42.26^{a} \pm 3.6$	$19.90^{a} \pm 3.4$	$13.99^{b} \pm 0.8$	$6.59^{a} \pm 1.4$	$0.47^{a} \pm 1.1$
	Hybrid-CWs	$44.40^{a} \pm 1.2$	$18.04^{b} \pm 1.6$	$22.60^{a} \pm 0.7$	$9.18^{a} \pm 0.6$	$0.41^{b} \pm 1.8$

Values with the same letter don't differ significantly (P > 0.05).

Table 5: Removing capacity of metals by *T. domingensis* in different constructed wetland designs over 45 days.

Metal	Removal capacity (mg/day/g)			
	Unplanted (control)	Planted Constructed Wetlands		
		VSSF-CW	HSSF-CW	Hybrid-CW
Pb	0.000	5.209	8.146	14.279
Zn	0.000	11.248	13.671	17.077

4. Conclusion

Based on the Iraqi standards set for oil refinery effluents, Khurmala Oil Refinery wastewater was rated as extremely poor with very bad quality. In the study, the utilisation of hybrid-CWs, planted with southern cattail species to removing Pb and Zn from oil refinery wastewater, in the field (outdoor) studies, has been recognized as an appealing choice. southern cattail survived 100% of the time and showed significant tolerances for adverse environmental conditions. The hybrid-CW's achievement was sufficient to remove Pb and Zn from the refinery effluents compared to VSSF-CW and VSSF-CW designs. Lead (pb) uptake values were greater than (1) (MU >1), but always the metal values were higher in their shoots rather than roots, this reveal to that southern cattail is strong excluder (i.e., strong phytostabilizer) for pb, but in its shoots. The plant southern cattail accumulated relatively similar patterns of Zn in roots and shoots, and showed suitability for Zn phytoextraction. More research is needed to determine how much heavy metals aquatic species of plants could bio-accumulate, as well as the leading to the processes for heavy metal breakdown.

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