JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2026, 27(10), 383–394
https://doi.org/10.12911/22998993/225544
ISSN 2299–8993, License CC-BY 4.0

Received: 2026.05.03
Accepted: 2026.08.14
Published: 2026.09.01

Evaluation of the performance of natural wetlands for heavy metal removal

Nazhad Majeed Fattah[1*], Khalid Tayeb Muhammad[2], Kosar Hikmat Hama Aziz[3]

[1] Department of Environment Science, University of Sulaimani, Tasluja Street 1 – Zone 501 Sulaimania, As Sulaymaniyah, Iraq
[2] Department of Natural Resources, University of Sulaimani, Tasluja Street 1 – Zone 501 Sulaimania, As Sulaymaniyah, Iraq
[3] Department of Chemistry, University of Sulaimani, Tasluja Street 1 – Zone 501 Sulaimania, As Sulaymaniyah, Iraq
* Corresponding author's e-mail: nazhad.kareem@univsul.edu.iq

ABSTRACT

One of the most efficient and low-cost plans to remove or reduce pollutants is the use of natural wetlands. In this study, a typical riverine type of natural wetland on the flow course of Chaqan river in Sulaimani / Iraq, was studied to evaluate the natural wetland components regarding the removal of heavy metals, namely Fe, Ni, Cd, Pb, Cr, Cu, Mn, and Zn. Samples of roots and shoots of three types of natural aquatic plants viz *Phragmites Australis, Xanthium Strumarium, Persicaria Hydropiper* were collected at the two different seasons, besides the control samples for each type of the plants and soil. The laboratory tests of the water samples showed that the concentrations of all studied heavy metals were reduced in the water samples of the wetland outlet, except Manganese and Iron where their concentration values increased in the water samples of the outlet in wet season. Results indicated that the highest removal efficiency of the plants was in wet season, and the highest value of phytoremediation generally observed at the plant shoots. The highest values of removal efficiency for the three studied plants in both dry and wet seasons showed the following sequence; *Xanthium Strumarium* > *Persicaria Hydropiper* > *Phragmites Australis.* Among the studied components of the wetland, the natural plants generally took the first highest order following the soil which acquired the second rank and the water was at the third sequence.

Keywords: assessment, effectiveness, components, wetland, wastewater treatment.

INTRODUCTION

Continuously increasing population requires more food and water, and this in turn requires more agricultural practices, hence leading to the reduction of the limited existent water resources. To decrease the crises of water resources scarcity, reuse of wastewater has increased worldwide, especially for the purpose of irrigation as well as conserving environmental quality. Wetlands are highly effective natural wastewater purification system that can be relied on as a low-cost method. A wetland is a separate semi-aquatic ecosystem the groundcovers of which are swamped or saturated in water, either eternally, for years or decades, or only seasonally, (Keddy, 2010). Wetlands are important to humans, as they achieve a range of functions, they offer ecological, hydrological and socio-economic functions (Dixon, 2003); moreover, they are sources of rivers, storm water control, flow of water and acts as purification systems (World Conservation Monitoring Centre, 1995). Wetlands also act as a preservation bowl of nutrients from the catchment area, toxic waste and sediments (Enger and Smith, 2000). Natural wetlands (NWs) and constructed wetlands (CWs) express nature-based treatment processes aimed at the removal of organic and nutrients from municipal wastewater, (Attili and Al-Saeed, 2020). Using the knowledge and the practice with the assimilative capacity of natural wetlands, the construction of man-made wetland systems (constructed wetlands) for wastewater treatment has therefore been suggested, (Dordio, et al., 2008). Wetlands are sole ecosystems described by specific features that discriminate them from other environments. The main characteristics of wetlands are hydrology (standing water, shallow water), soil which is known as hydric soil due to its prolonged saturation, and vegetation (grasses, sedges reeds and other plants that thrive in saturated soils), (Eyvaz and Albahnasawi, 2023). Growing vegetation takes up nitrogen and phosphorus from the water and soils as well as boosts further biomass growth sustaining wetland vegetation. The dense vegetation runs slow movement of incoming wastewater over a large surface, enabling filtration and settlement of particulate matter and related nutrients, (Katharine, et al., 2021).

Dhanya and Jaya (2014) confirmed that the use of natural wetlands for wastewater treatment has been proposed as an intermediate technological solution for managing wastewater. Studies have shown that natural wetlands are capable of providing high levels of wastewater treatment (Hammer and Bastian, 1989). According to (Cunningham et al., 2001), wetlands improve water quality by acting as natural water purification systems, removing silts and absorbing nutrients and toxins. Wetland vegetation absorbs nutrients and toxic substances from inflowing water thereby improving the quality of water downstream, (Kinyua, 2011). Wastewater was directly discharged to surface water, fostering the development of natural wetlands due to biosolid and nutrient accumulation tracked by the emergence of vegetation. The wastewater would be treated naturally, and the ecosystem was preserved, even with a low discharge load (Brix, 1995).

Wetlands offer an interesting alternative to technology-intensive treatment systems in certain localities, Patience and Klemas, (1993). Moreover, such systems provide critically important ecological habitats, (Drayer and Ritcher, 2016), operate as a protective buffer against storms by storing water and decreasing floods, and against erosion damage (Umgiesser et al., 2010). The water purification capability of wetlands, in particular, has long been recognized. Natural wetlands usually improve the quality of water passing through them, acting as "living filters" and serving as transitional zones between terrestrial as well as aquatic systems (Mitsch and Gosselink, 2000; Sundaravadivel and Vigneswaran, 2001). Wetlands purify water through flow velocity reduction, microbial degradation of organic matter, microbial transformation, as well as nutrient retention and uptake by plants (Moreno-Mateos and Comin, 2010; Vymazal, 2007).

There are several processes known to be taking place in wetland environments, having a role in reducing metal concentration and neutralizing the acidity of influent water. These processes include physical, chemical and biological processes, (Gazea, and Kontopoulos, 1996). Heavy metals are metallic elements with a high atomic weight and a density of at least five times that of water. They are non-biodegradable and unable to decompose. As a result, they are always dangerous compounds (Paul, 2017; and Goher et al., 2019). Large amounts of heavy metals, such as Cd, Cr. Ni, Pb and Zn are often present in sewage sludges and wastewaters. These metals pose a potential threat to the environment when applied to agricultural lands. On the other hand, Huda et al. (2022) showed that due to their potential for toxicity, bioaccumulation, and persistence, heavy metals are regarded as one of the most dangerous pollutants in the environment. Shibbmbu et al. (2016) mentioned that the natural wetland was able to considerably reduce the heavy metals in the municipal effluent during its passage in the wetland.

The Chaqan river is one of the main branches of the large Tanjaro river in Sharazoor fertile plain that is flows into Darbandikhan Lake. The water quality of the Chaqan river is related to several problems that make the water undesirable for drinking or irrigation. These problems include the lack of water quantities that are received from Chaqan watershed and reception of high quantity of municipal, agricultural and industrial pollutants that are discharged daily from Saidsadiq District and the surrounding places without any previous treatment process. Wastewater treatments require high costs, therefore, finding a typical riverine type of natural wetland on the flow course of the Chaqan river is of great importance for studying the river pollution by heavy metals, in addition to the extent of contaminant removals in this river via the water purification functions of natural wetland components. The objectives of the study were as follows: 1) To determine the heavy metal concentration and its changes with season in the studied wetland. 2) To compare the heavy metal removal efficiencies of three types of aquatic plants in the natural wetland. 3) To evaluate the performance of wetland characteristics in removing heavy metal pollutants.

MATERIALS AND METHODS

Location of the study area

The studied wetland located at the southeast of Said-Sadiq District in Sulaimani Governorate, Iraq, at the site of (35°19'29" N - 45 51 23 E). The studied wetland has been designated on the river of Chaqan after passing through Said-Sadiq District and before it enters Tanjaro River. The wetland chosen considering the ideal characteristics of the wetland. The wetland surface area was (1344.84) m^2 and the average depth was (0.34) m, Figure 1.

Climate

The climate of the studied area is subtropical climate, classified within semi-arid region, the summers are sweltering, arid, and clear and the winters are cold, dry, and partly cloudy. Over the course of the year, the temperature typically varies from 1.1 to 40 °C. The average annual rainfall is 657.25 mm (Mazn, 2022).

Analysis of water, soil and vegetation samples

In this study, the seasonal variation in water quality has been considered, due to the variation in hydrological variables during the wet and dry season. Beyene et al. (2014) showed that the research in tropical water bodies should deal with seasonality. Water samples were taken at the input and output of the wetland as well as at two points inside the wetland. Temperature, pH and Ec were measured on the wetland site for two seasons (August, 2024 and February, 2025). The water samples were transferred via a cold box to the laboratory for conducting the physiochemical analysis.

Hydric soil samples (sediment) were collected in the bed of the river at input, inside and output of the wetland, also a soil sample was taken outside the wetland, and it was considered a control sample.

Three replications were taken for each vegetation sample composed of roots and shoots of three types of natural plants, namely; *Phragmites Australis*, *Xanthium Strumarium,* and *Persicaria Hydropiper*, where the studied plants had been grown inside the wetland. Three types of each plant shoot and root were collected from three sites inside the wetland. The shoots and root samples were washed with tap water and distilled water and the weight was recorded. The samples were dried at 67 °C for dry matter yield. The root and shoot parts of the vegetables were separated from the plants, chopped into small pieces, and air-dried to constant mass. A Retsch grinder was used to grind all samples to fine powder. The same process of harvesting was conducted to the control samples of the three plant types which were planted inside the pots, where the soil of the pots was taken around the wetland and the plants were irrigated with distilled water. Laboratory analysis was conducted for each plant sample regarding the (pH, Ec, Fe, Ni, Cd, Pb, Cr, Cu, Mn, and Zn). The analysis methods of the water, soil and vegetation samples were as follows:

The pH was measured using a pH meter model (WTW 330i-Germany), Ec was measured by an Ec

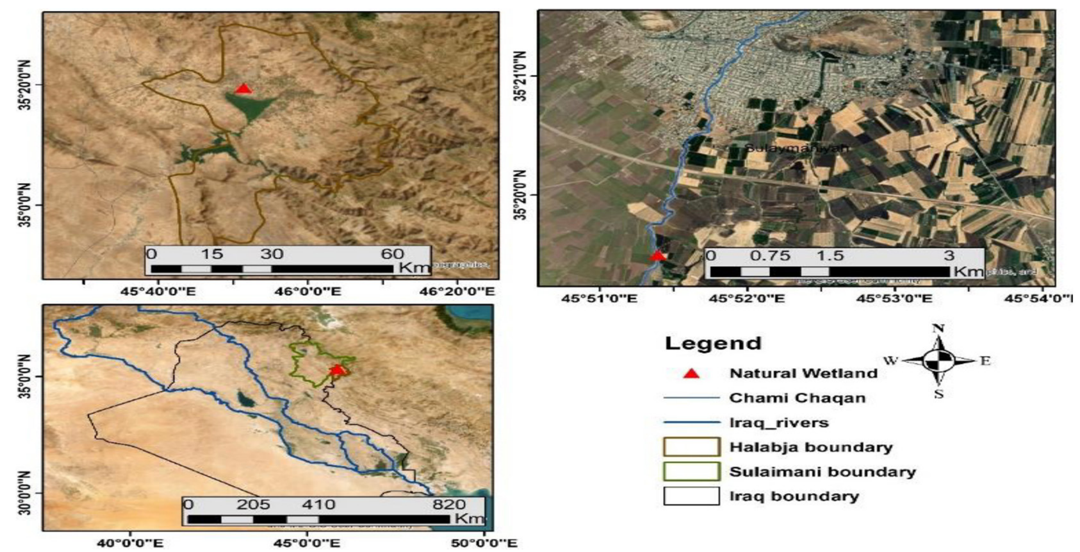

Figure 1. Location map of the studied wetland

meter model (HANNA INSTRUMENTS-EC-METERS/EC TESTER).In turn, Pb, Mn, and Zn were determined using a Hanna-WWT-Romanya Spectrophotometer. Cd, Cr, Cu, Ni and Fe were determined by Atomic Absorption Spectroscopy – Germany.

Removal efficiency percent of the wetland components was calculated as follows;

$$Removal\ efficiency\% = \\ = \left[\frac{(Ci - Cf\ )}{Ci}\right] \times 100 \quad (1)$$

where: *Ci* – initial metal concentration, (for water it represents the metal concentration in the inflow, whereas for plants and soil it represents the metal concentration in control samples of soil and control samples of each type of plants); *Cf* – final metal concentration, (for water it represents the metal concentration in the outflow of the wetland, for plants it represents the metal concentration in the sample of each type and each part of the plant took from those grown inside the wetland, and for soil is the metal concentration in the samples of the hydric soil inside the wetland).

Water discharge

The discharge of input and output of the wetland were measured using Manning method of open channel flow, and as follows:

$$Q = \frac{1}{n} R^{2/3}\, S^{0.5}\, A \quad (2)$$

where: Q – discharge in m^3/sec, n – Manning's channel roughness, R – hydraulic radius in meter, S – bed slope of the channel in m/m, A – cross sectional area of the channel in m^2.

Hydraulic radius is defined as the ratio of the channel's cross-sectional area of the flow to its wetted perimeter (the portion of the cross-section's perimeter that is "wet"):

$$R = \frac{A}{P} \quad (3)$$

where: R is the hydraulic radius (m), A is the cross-sectional area of flow (m^2), P is the wetted perimeter (m).

The wetted perimeter is the perimeter of the cross-sectional area that is "wet", it is the length of line of the intersection of channel wetted surface with a cross sectional plane normal to the flow direction (Knighton, 2014).

$$P = \Sigma\, \ell i \quad (4)$$

where: ℓi is the length of each surface in contact with the aqueous body in (m).

Statistical analysis

The study was performed in randomized complete block design (RCBD) with three replications. The collected data were arranged in factorial ANOVA, analyzed using the XLSTAT computer program, and Duncan's Multiple Range Test ($p \leq 0.05$) was used for comparison of means.

RESULTS AND DISCUSSION

Input and output discharges

The discharges of the input and output of the studied wetland were taken using Equation 2 in the two dry and wet seasons, as it was shown in (Table 1). From that table, it appeared that the discharges of both input and output of the wetland reduced in the wet season from that of dry season, this is attributed to the fact that the water use increased in dry season much more than in wet season, as long as the great part of the studied river discharge contains wastewater, so the amounts of wastewater will be greater in dry season. During the studied wet season, the rainfall magnitude was small, so that the floods and spring water discharges were not caused by the rise in discharge in the wet season.

Wetland water quality

The water quality of the input and the output of the studied wetland is shown in (Table 2) for both dry and wet seasons. It appeared from the mentioned table that the values of heavy metal concentration in the water of wetland output were reduced in comparison to their values in the input, except Manganese and Iron where its concentration value increased in the water samples of the output at wet season. This is due to the wetland characteristic effects, especially plants and soil, in terms of removing heavy metals of the wastewater inside the wetland. However, the increase of Mn and Fe in the output water it wet season may be attributed to wetlands acting as

Table 1. Input and output discharges of the studied wetland

Date	Input Q, m^3/s	Output Q, m^3/s
Dry season, 22.8.2024	0.240	0.223
Wet season, 22.2.2025	0.221	0.198

a sink in hot seasons through oxidation and deposition, in addition to releasing metals in the wetter seasons, hence the two mentioned metals were easily flushed out, (Krueger, 2020). These results agreed with those from (Maria, 2024). On the other hand, low pH is another factor, it promotes the solubility of both Iron and Manganese. The study conducted by Sundaravadivel and Vigneswaran (2001) interpreted that the rainfall may have eroded soil material outside the wetland and then deposited this in the wetland, thus contributing to high concentrations of Mn in the wetland, which were subsequently easily removed with the output flow. In this study, the values of all of the measured heavy metals were below the permissible values according to FAO / WHO [12], (Table 2).

pH

According to Ayers and Westcott (1985) [2], the normal range of pH for irrigation purposes begins from (6.5 to 8.4). Table 2 shows the pH values of the wastewater for input, inside and of output of the studied wetland. It was found that the value of pH for input water is much higher than its value in the outlet and for both studied seasons. However, inside the wetland, the pH value in wet season was greater than the value of pH in dry season; this is because the pH was affected by the temperature of the water, where the pH value increases with decrease of the temperature, due to the decrease of autoionization of water, the process that decreases the hydrogen ions, causing the pH value to rise. On the other hand, the pH lowering in the natural wetlands can be attributed to several factors, primarily related to the breakdown of organic matter and the release of acids, plus the waterlogging and low oxygen conditions, decreasing the pH value.

Electrical conductivity

Electrical conductivity (EC) was measured for wastewater samples and it varied during the study period. In dry season, it ranged from 0.096545 ds/m for input discharge to 0.064545 $ds.m^{-1}$ for the output discharge. In turn, in the wet season, the value was 1.191 $ds.m^{-1}$ for input discharge and 0.85 $ds.m^{-1}$ for output discharge, while inside the wetland the mean value ranged from 0.132333 $ds.m^{-1}$ of dry season to 0.094444 $ds.m^{-1}$ for the wet season, see Table 2. The increasing value of the Ec in the wet season is attributed to the fact that the water mainly contains the salts that come from the agricultural fields of the surround areas of the wetland by runoff water which increases the Ec value to a higher value than in dry season, which the water contains mainly from domestic wastewater and less soluble salts. In turn, the increase of Ec inside the studied wetland was due to the stagnant water or water with longer retention times that can accumulate more dissolved solids over time, which in turn increases the EC of the water.

Table 2. Parameter values of the wastewater samples for the studied wetland at two different seasons in ($mg \cdot L^{-1}$)

Parameter	Dry season 22.8.2024			Wet season 22.2.2025			WHO /FAO maximum permissible value ($mg \cdot L^{-1}$)
	Input	Inside the wetland	Output	Input	Inside the wetland	Output	
pH	6.9	6.65	6.6	7.45	7.24	6.8	8.4
Ec, $ds \cdot m^{-1}$	1.062	0.9005	0.71	1.191	1.058	0.85	3
Fe	0.06	0.015	0.01	0.11	0.11	0.14	5
Ni	0.024	0.014	0.009	0	0	0	0.2
Cd	0.002	0.0015	0.001	0.002	0.001	0	0.01
Pb	0	0	0	0.02	0.015	0.009	5
Cr	0.017	0.012	0.01	0.01	0.01	0.01	0.1
Cu	0.044	0.001	0.001	0.01	0	0	0.2
Mn	0.058	0.019	0.002	0.012	0.105	0.2	0.2
Zn	1.2	0.955	0.9	0.19	0.1	0.06	2

Evaluation of the removal efficiency of the wetland components

Removal efficiency of the natural plants inside wetland

The removal efficiency percent of each of the wastewater, soil and plant samples were calculated using Equation 1. Table 3 represents the removal efficiency values of heavy metals of plant samples with studied seasons, it was shown that the values of removal efficiency were higher in wet season except the removal efficiency values of Cd and Zn; the results were attributed to the fact that the studied aquatic plant active growth stage starts from February to April, so the nutrient uptake increased in wet season, where the studied wet season was on 22.2.2025. On the other hand, the high accumulation of Cd and Zn in dry season returned to that the transfer of these two heavy metals from soil to plant were highly promoted at a warmer temperature.

It appeared from Table 4 that *Xanthium Strumarium* gave the highest value of removal efficiency except Fe and Pb, followed by *Phragmite Australis* except Ni and Mn, the removal efficiency of these two metals were higher in the case of *Persicaria Hydropiper*. In turn, *Persicaria Hydropiper* took the third rank of removal efficiency values for the remaining heavy metals.

It can be noticed from Table 5 that the plant shoots have the highest removal efficiency values for all studied heavy metals, except Cd, Pb and Cu, where the root removal efficiency of these heavy metals was greater than of shoot parts, and this is because of the mobility of these three heavy metals from root to shoot was lower than for the rest of the studied heavy metals. In respect to the roots and shoots effects with seasons, it is worth mentioning that the plant roots studied gave the highest value of the removal efficiency in wet season, whereas in dry season the shoots gave the highest value of removal efficiency. Table 6 shows that significant differences appeared between plant shoots and roots in wet season, ($p \leq 0.05$).

Table 7 demonstrated that the plant type of *Xanthium Strumarium* in wet season has the highest removal efficiency values for all studied heavy metals, except Mn removal, where its value was higher in dry season. Significant difference achieved between the plant types and seasons ($p \leq 0.05$), except the case of *Phragmite Australis* and *Persicaria Hydropiper* in wet season.

In general, the results of removal efficiency values in both dry and wet seasons gave the following sequence; *Xanthium Strumarium* > *Persicaria Hydropiper* > *Phragmites Australis.* In respect to the *Xanthium Strumarium* phytoremediation role, this finding agreed with that found by (Khalid, 2018).

It was evidenced from Table 9 that the roots of *Xanthium Strumarium* in wet season exhibited the highest value of removal efficiency among the other roots and shoots of the studied plant types, Figure 2, followed by the shoots of *Persicaria Hydropiper* in wet season, while the shoots of the *Xanthium Strumarium* in wet season took the third place, Figure 3, and the roots of *Xanthium Strumarium* at dry season took the fourth place, Figure 4; however, the shoots of *Phragmites Australis* in dry season took the fifth rank, Figures 5, 6. The remaining values of removal efficiency of the roots and shoots for the types of plants studied were as shown in the afore-mentioned table.

Removal efficiency of water, soil and plant of the studied wetland

From results shown in Table 10, it appeared that the plant removal efficiency values regarding the studied heavy metals took the highest values for most of the studied heavy metals, and the soil removal efficiency comes in the second rank, whereas water removal efficiency values took the third rank.

Significant differences were noticed among the treatments ($p \leq 0.05$) according to the post hoc test results (Duncan multiple range test). Significant differences were also noticed among the treatments with seasons. It is worth mentioning that the plant treatment gave the best response to the removal of heavy metals compared to the soil and water characteristics of the wetland, this is due to the high nutrient uptake capability of the

Table 3. Statistical analysis of plant removal efficiency with seasons

Season	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Dry	88.911 b	52.392 b	99.762 a	75.887 b	66.355 b	92.587 b	80.000 b	98.963 a
Wet	92.613 a	83.042 a	85.799 b	98.035 a	95.768 a	95.399 a	93.066 a	98.562 b

Table 4. Statistical analysis for removal efficiency of three studied types of plant

Plant type	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Phragmites A.	91.711 a	61.212 c	80.842 b	97.482 a	80.492 b	93.428 b	80.476 c	98.981 a
Xanthium S.	90.004 c	75.863 a	98.828 a	67.119 c	89.316 a	98.246 a	94.965 a	99.416 a
Persicaria H.	90.572 b	66.075 b	98.670 a	96.282 b	73.376 c	90.304 c	84.158 b	97.890 b

Table 5. Removal efficiency of the studied plant roots and shoots

Parameter	Dry season 22.8.2024			Wet season 22.2.2025			WHO /FAO maximum permissible value (mg. L^{-1})
	Input	Inside the wetland	Output	Input	Inside the wetland	Output	
pH	6.9	6.65	6.6	7.45	7.24	6.8	8.4
Ec, ds.m^{-1}	1.062	0.9005	0.71	1.191	1.058	0.85	3
Fe	0.06	0.015	0.01	0.11	0.11	0.14	5
Ni	0.024	0.014	0.009	0	0	0	0.2
Cd	0.002	0.0015	0.001	0.002	0.001	0	0.01
Pb	0	0	0	0.02	0.015	0.009	5
Cr	0.017	0.012	0.01	0.01	0.01	0.01	0.1
Cu	0.044	0.001	0.001	0.01	0	0	0.2
Mn	0.058	0.019	0.002	0.012	0.105	0.2	0.2
Zn	1.2	0.955	0.9	0.19	0.1	0.06	2

Table 6. Statistical analysis of the removal efficiency of the studied plant roots and shoots with seasons

Season	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Dry	88.911 b	52.392 b	99.762 a	75.887 b	66.355 b	92.587 b	80.000 b	98.963 a
Wet	92.613 a	83.042 a	85.799 b	98.035 a	95.768 a	95.399 a	93.066 a	98.562 b

Table 7. Removal efficiency values of the studied plant types in dry and wet seasons

Season × Plant type	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Dry × *Phragmites A.*	88.409 c	49.832 f	99.645 a	96.840 c	69.220 e	95.076 c	65.684 e	98.933 b
Dry × *Xanthium S.*	85.005 d	56.000 d	99.741 a	36.667 e	79.447 d	98.355 a	95.721 a	99.659 a
Dry × *Persicaria H.*	93.319 b	51.343 e	99.899 a	94.155 d	50.397 f	84.329 e	78.594 d	98.298 c
Wet × *Phragmites A.*	95.014 a	72.592 c	62.039 c	98.125 a	91.764 c	91.780 d	95.268 a	99.030 ab
Wet × *Xanthium S.*	95.002 a	95.725 a	97.916 b	97.572 b	99.184 a	98.137 a	94.208 b	99.174 ab
Wet × *Persicaria H.*	87.824 c	80.808 b	97.440 b	98.408 a	96.356 b	96.278 b	89.722 c	97.482 d

plants, where the plants remove heavy metals through the processes of rhizofiltration, phytoaccumulation and phytostabilization. The soil is more capable than water in regard to absorbing ions, molecules, or contaminants to the surface of soil particles (clay/organic matter) (Table 8).

Water acts as removal means by reducing the concentration of heavy metals through dilution, it also serves as a medium to facilitate chemical precipitation, enhancement of adsorption and ion exchange. In addition, the natural water bodies have an inherent capacity to absorb and dilute pollutants, particularly when the water flow rate is high enough to disperse contaminants before they can settle into sediments.

When the season taken into consideration, as presented in Table 10, the studied plants gave the highest values of removal efficiency in wet season, except for the removal efficiency of Cd and Cu, see Figure 7. Between the water and soil, the highest removal efficiency of soil were for Ni, Pb, Cr, Mn, and Zn in wet season; in contrast, the

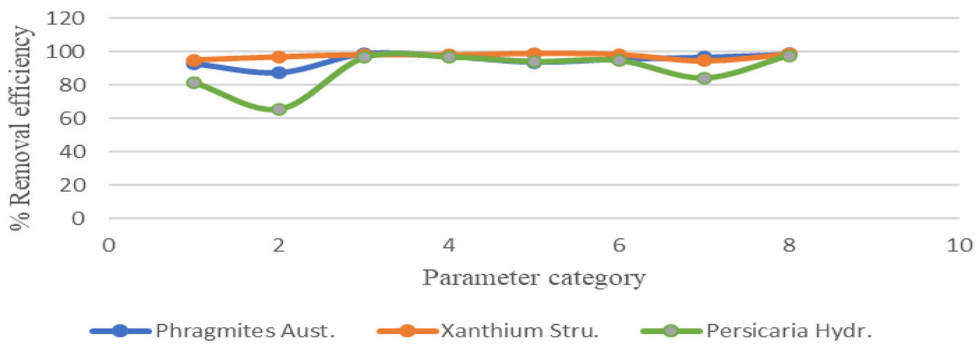

Figure 2. Comparison among the roots of the studied plants in respect to the heavy metal removal efficiency in wet season

Table 8. Statistical analysis of the removal efficiency of the studied plant roots and shoots of each plant type with season

Season × plant type × × plant part	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Dry × *Phragmites A.* × Root	84.676 f	16.667 l	99.767 a	94.286 e	46.032 g	93.506 f	33.333 g	97.961 cde
Dry × *Phragmites A.*× Shoot	92.141 d	82.998 e	99.524 a	99.394 ab	92.409 c	96.646 c	98.034 a	99.905 a
Dry × *Xanthium S.* × Root	96.640 a	69.074 g	99.533 a	73.333 g	88.525 e	98.872 a	94.921 c	99.529 ab
Dry × *Xanthium S* × Shoot	73.370 h	42.927 j	99.948 a	0.000 h	70.370 f	97.838 b	96.522 b	99.788 a
Dry × *Persicaria H.* × Root	90.029 e	25.424 k	99.840 a	88.696 f	1.587 h	94.783 e	62.667 f	97.913 cde
Dry × *Persicaria H.* × Shoot	96.609 a	77.261 f	99.958 a	99.615 a	99.207 a	73.875 h	94.521 cd	98.683 bcd
Wet × *Phragmites A.* × Root	92.917 d	87.500 d	99.079 ab	97.500 d	93.929 b	95.833 d	96.800 b	98.700 bcd
Wet × *Phragmites A.*× Shoot	97.111 a	57.683 i	25.000 d	98.750 bc	89.600 d	87.727 g	93.736 d	99.360 ab
Wet × *Xanthium S.*× Root	95.315 b	97.222 a	98.542 b	98.286 c	99.278 a	98.625 a	94.667 cd	98.786 bc
Wet × *Xanthium S.*× Shoot	94.689 bc	94.228 c	97.291 c	96.858 d	99.090 a	97.649 b	93.750 d	99.562 ab
Wet × *Persicaria H.* × Root	81.562 g	65.921 h	96.667 c	97.061 d	94.259 b	94.878 e	84.444 e	97.763 de
Wet × *Persicaria H.*× Shoot	94.086 c	95.695 b	98.214 b	99.756 a	98.452 a	97.679 b	95.000 c	97.200 e

Table 9. Statistical analysis of the removal efficiency of the studied wetland characteristics

Agent	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Plant	90.747 a	67.688 a	92.745 a	86.970 a	81.022 b	94.060 b	86.543 a	98.522 a
Water	41.667 c	31.250 c	75.000 b	27.500 c	20.588 c	98.863 a	48.275 c	46.710 b
Soil	72.165 b	50.328 b	69.642 c	73.525 b	87.833 a	67.863 c	79.045 b	33.625 c

Table 10. Statistical analysis of the removal efficiency of the studied wetland characteristics with seasons

Agent	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Plant	90.747 a	67.688 a	92.745 a	86.970 a	81.022 b	94.060 b	86.543 a	98.522 a
Water	41.667 c	31.250 c	75.000 b	27.500 c	20.588 c	98.863 a	48.275 c	46.710 b
Soil	72.165 b	50.328 b	69.642 c	73.525 b	87.833 a	67.863 c	79.045 b	33.625 c

highest removal efficiency of water was achieved for Fe, Ni, Cu and Mn in dry season, Figure 8. This is attributed to the increase of temperature enhances the process of chemical reaction. In the case of plants, the highest removal efficiency in wet season was attributed to the active growth stage of plants in the studied wet season, on 22.2.2025.

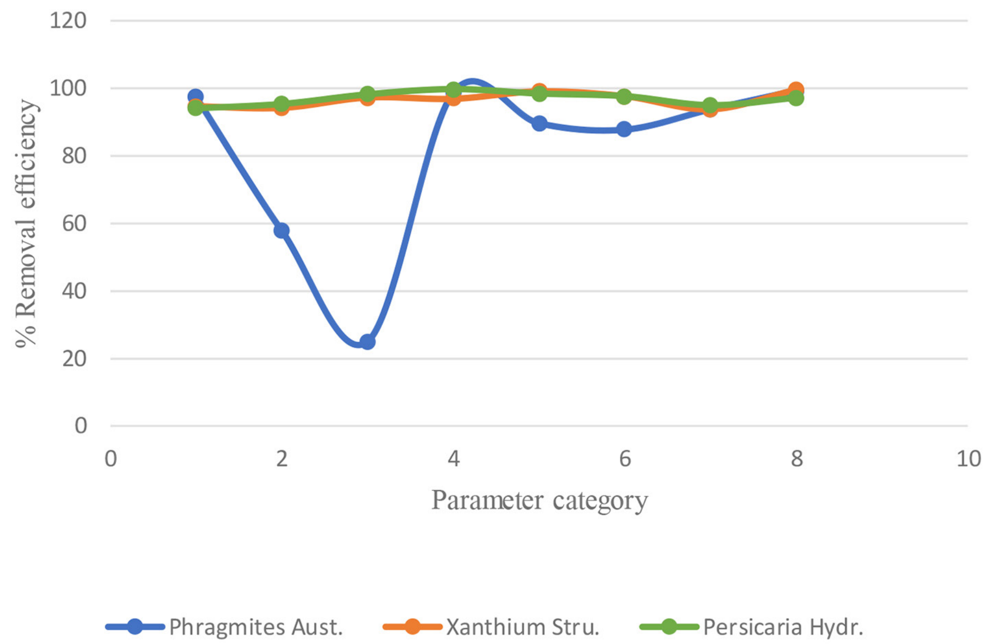

Figure 3. Comparison among the shoots of the studied plants in respect to the heavy metal removal efficiency in wet season

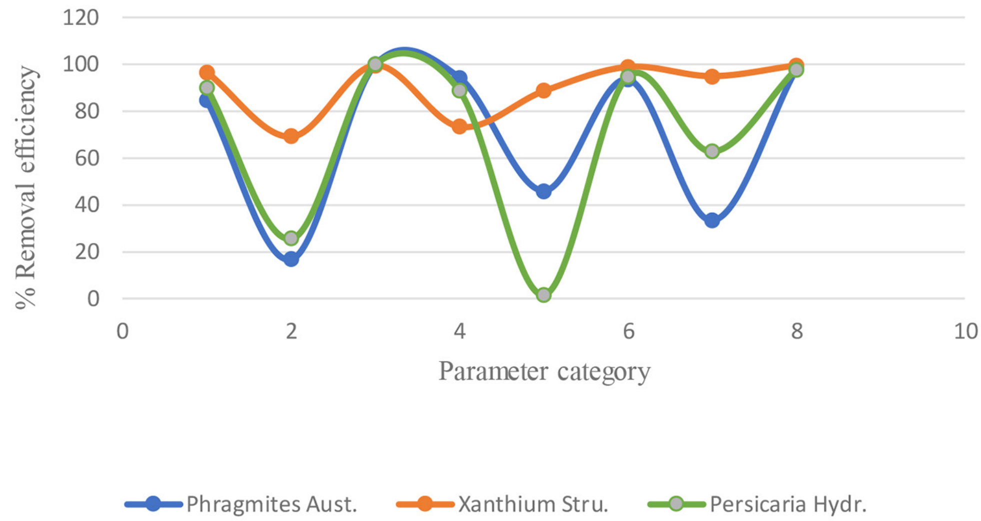

Figure 4. Comparison among the roots of the studied plants in respect to the heavy metal removal efficiency in dry season

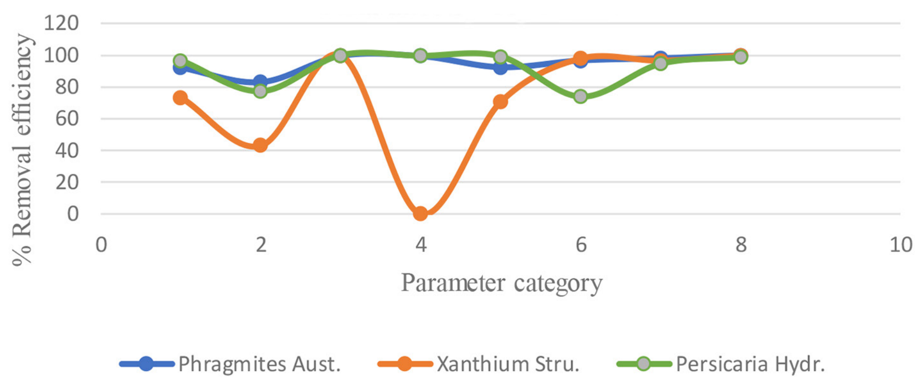

Figure 5. Comparison among the shoots of the studied plants in respect to the heavy metal removal efficiency in dry season

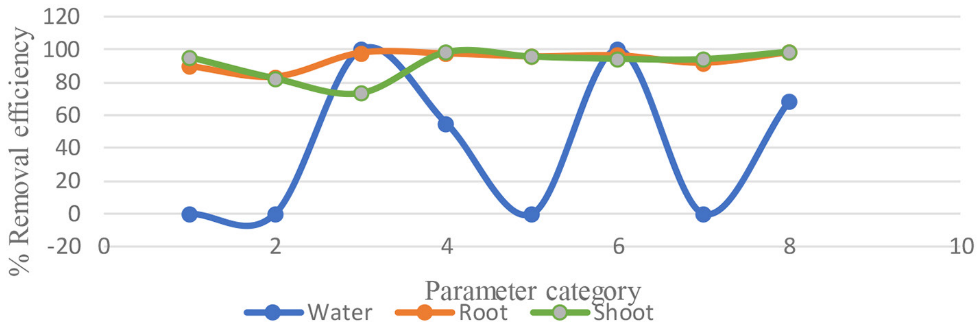

Figure 6. Comparison among the shoots of the studied plants in respect to the heavy metal removal efficiency in dry season

Table 10. Statistical analysis of the removal efficiency of the studied wetland characteristics with seasons

Season × Agent	Fe	Ni	Cd	Pb	Cr	Cu	Mn	Zn
Dry × Plant	88.93 b	52.39 d	99.76 a	75.89 c	66.36 d	92.59 d	80.00 c	98.96 a
Dry × Water	83.33 c	62.50 b	50.00 e	0.00 f	41.18 e	97.73 b	96.55 a	25.00 e
Dry × Soil	74.93 d	53.57 c	72.73 c	77.22 b	91.81 b	77.18 e	78.44 d	41.00 c
Wet × Plant	92.56 a	82.99 a	85.73 b	98.05 a	95.68 a	95.53 c	93.09 b	98.08 a
Wet × Water	0.00 f	0.00 f	100 a	55.00 e	0.00 f	100 a	0.00 e	68.42 b
Wet × Soil	69.40 e	47.09 e	66.56 d	69.83 d	83.85 c	58.55 f	79.65 c	26.25 d

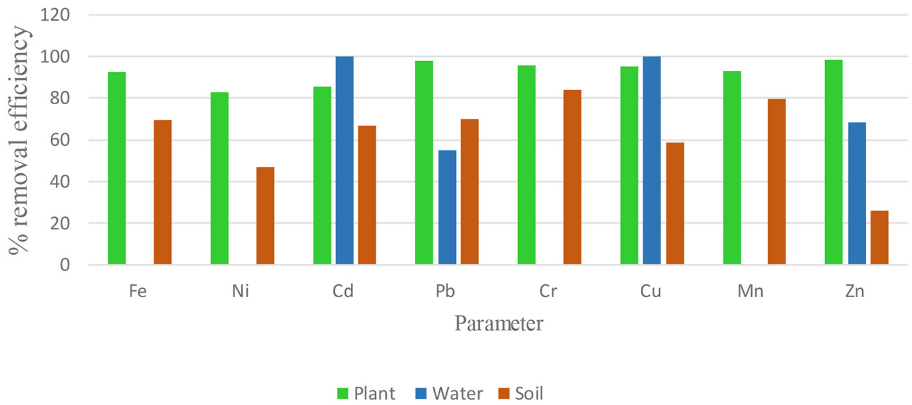

Figure 7. Removal efficiency percent of plant, water and soil in wet season

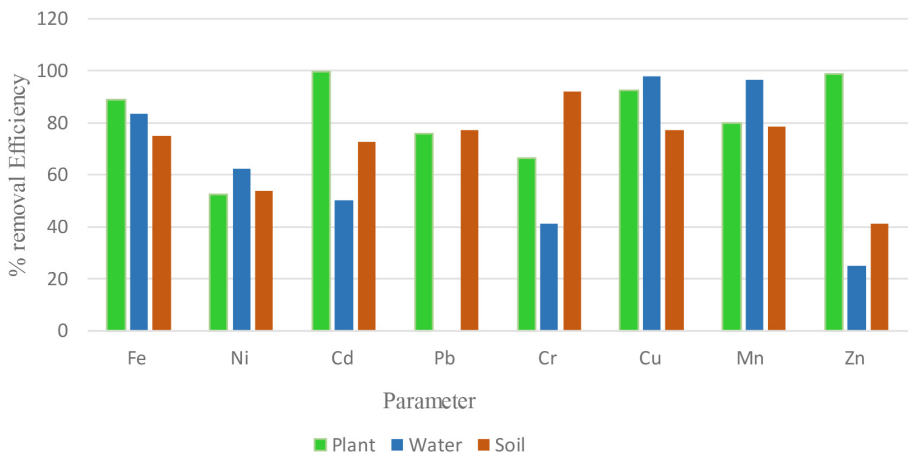

Figure 8. Removal efficiency percent of plant, water and soil in dry season

CONCLUSIONS

The results displayed that the concentration of all the studied heavy metals was reduced in the water samples of the wetland outlet, except Manganese and Iron where their concentration values increased in the water samples in wet season. The highest removal efficiency of the plants was in wet season, and the highest value of phytoremediation was generally observed in the shoots of the studied plants. Overall, the highest values of removal efficiency for the three studied plants in both dry and wet seasons exhibited the following sequence; *Xanthium Strumarium* > *Persicaria Hydropiper* > *Phragmites Australis.* Significant differences among the studied components of the wetland for removing heavy metals were found, where the natural plants took the first highest order, followed by the soil which acquired the second rank, and the water was at the third place.

REFERENCES

1. Attili, O. A. (2022). Efficacy of natural wetlands along Wadi Zomer as a sustainable phytore-mediation alternative for industrial effluents from Nablus West, Palestine. *Desalination and Water Treatment, 275*, 245–252. https://doi.org/10.5004/dwt.2022.28930
2. Ayers, R. S., Westcot, D. W. (1985). *Water quality for agriculture* (Vol. 29, p. 174). Rome: Food and agriculture organization of the United Nations.
3. Beyene, A., Awoke, A., Triest, L. (2014). Validation of a quantitative method for estimating the indicator power of, diatoms for ecoregional river water quality assessment. *Ecological Indicators, 37*, 58–66. ttps://doi.org/10.1016/j.ecolind.2013.09.025
4. Brix, H. (1995). Treatment wetlands: an overview. Oczyszczalnie hydrobotaniczne. *Miedzynarodowa Konferencja Naukowo-Techniczna, Gdansk, 167*, 176.
5. Cunningham, W. P., Cunningham, M. A., Saigo, B. W. (2001*). Environmental science: A global concern* (Vol. 412). New York: McGraw-Hill.
6. Dhanya, G., Jaya, D. (2014). Waste water treatment efficiency of vetiver grass in constructed wetlands. *J Aquat Biol Fish, 2*, 119–125.
7. Dixon, A. (2003). Indigenous management of wetlands. King's SOAS studies in development geography. https://doi.org/10.4324/9781315182018. http://www.jgiass.com.
8. Dordio, A., Palace, A. J., Pinto, A. P. (2008). Wetlands: Water living filters?. https://www.novapublishers.com/catalog/product_info.php?products_id=7901 http://hdl.handle.net/10174/6485
9. Drayer, A. N., Richter, S. C. (2016). Physical wetland characteristics influence amphibian community composition differently in constructed wetlands and natural wetlands. *Ecological Engineering, 93*, 166–174. https://doi.org/10.1016/j.ecoleng.2016.05.028
10. Enger, D. E., Smith, F. B., (2000). *Environmental science. A study of interrelationships (7th edition).* Chapter 15 water management. Western Washington University. https://doi.org/10.4324/9781003463917
11. Eyvaz, M., Albahnasawi, A. (2023). *Introductory Chapter: Wetlands–Characteristics, Functions, and Values*. In Wetlands-New Perspectives. IntechOpen. https://doi.org/10.5772/intechopen.111469
12. WHO, F. (2022). Manual on the development and use of FAO and WHO specifications for chemical pesticides. https://doi.org/10.4060/cb8401en
13. Gazea, B., Adam, K., Kontopoulos, A. (1996). A review of passive systems for the treatment of acid mine drainage. *Minerals Engineering, 9*(1), 23–42. https://doi.org/10.1016/0892-6875(95)00129-8
14. Goher, M. E., Ali, M. H., El-Sayed, S. M. (2019). Heavy metals contents in Nasser Lake and the Nile River, Egypt: an overview. *Egyptian Journal of Aquatic Research, 45*(4), 301–312. https://doi.org/10.1016/j.ejar.2019.12.002
15. Hammer, D. A. (1989). Constructed wetlands for wastewater treatment. *Critical Reviews in Environmental Science and Technology*. https://doi.org/10.1080/20016491089253
16. Ali, H. H., Fayed, M. I., Lazim, I. I. (2022). Use of aquatic plants in removing pollutants and treating the wastewater: A review. *Journal of Global Innovations in Agricultural Sciences, 10*(2), 61–70. https://doi.org/10.22194/JGIAS/10.985
17. Cross, K., Tondera, K., Rizzo, A., Andrews, L., Pucher, B., Istenič, D.,..., Mcdonald, R. (2021). Nature-based solutions for wastewater treatment. IWA publishing. https://doi.org/10.2166/9781789062267
18. Keddy, P. A. (2010). *Wetland ecology: principles and conservation.* Cambridge university press. http://dx.doi.org/10.1017/CBO9780511778179
19. Kinyua, G. J. (2014). *Effectiveness of natural wetland in waste water treatment: a case study of Tibia Wetland, Limuru Municipality, Kenya*. Master's thesis.
20. Khalid, N., Noman, A., Aqeel, M., Masood, A., Tufail, A. (2018). Phytoremediation potential of Xanthium strumarium for heavy metals contaminated soils at roadsides. *International Journal of Environmental Science and Technology, 16*(4), 2091–2100. https://doi.org/10.1007/s13762-018-1825-5
21. Knighton, D. (2014). *Fluvial forms and processes: a new perspective.* Routledge.
22. Krueger, K. M., Vavrus, C. E., Lofton, M. E., McClure, R. P., Gantzer, P., Carey, C. C., Schreiber, M. E. (2020). Iron and manganese fluxes across the sediment-water

interface in a drinking water reservoir. *Water Research, 182*, 116003. https://www.sciencedirect.com/science/article/pii/S0043135420305406

23. Mazn, G. H., (2022). S*tudy of rainfall characteristics in Sulaimaniyah Governorate/KRI; Case study of Basara Basin.* Master thesis submitted to University of Sulaimani).
24. Maria M., Nikolaos D., E, Zagana, and Avramidis P. (2024). *Investigation of the Origin of Elevated Amounts of Iron and Manganese in a Dam Reservoir.* Department of Geology, University of Patras, 26504 Patras, Greece. https://doi.org/10.3390/geosciences14120336
25. Mitsch, W. J., Gosselink, J. G. (2000). *Classification, Characterization and Comparison of Aquatic Ecosystems in the Landscape of Adilabad District, Telangana, Deccan Region,* India. Wetlands john Wiley & sons. Inc., New York, New York.
26. Moreno-Mateos, D., Comín, F. A. (2010). Integrating objectives and scales for planning and implementing wetland restoration and creation in agricultural landscapes. *Journal of Environmental Management, 91*(11), 2087–2095. https://doi.org/10.1016/j.jenvman.2010.06.002
27. Patience, N., Klemas, V. (1993). Wetland functional health assessment using remote sensing and other techniques, literature search and overview. http://www.st.nmfs.noaa.gov/tm/sefc/sefc319.pdf.
28. Paul, D. (2017). Research on heavy metal pollution of river Ganga: A review. *Annals of Agrarian Science, 15*(2), 278–286. https://doi.org/10.1016/j.aasci.2017.04.001
29. Shibambu, C. S., Gumbo, J. R., Gitari, W. M. (2017). Field study on heavy metal removal in a natural wetland receiving municipal sewage discharge. *International Journal of Sustainable Development and Planning, 12*(1), 1–10. https://doi.org/10.2495/SDP-V12-N1-1-10
30. Sundaravadivel, M., Vigneswaran, S. (2001). Constructed wetlands for wastewater treatment. *Critical Reviews in Environmental Science and Technology, 31*(4), 351–409. https://doi.org/10.1080/20016491089253
31. Umgiesser, G., Zonta, R. (2010). Classification and physical attributes of wetlands and their interaction with pollutant inputs. *Natural Environment Science, 88*, 79–87.
32. Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. *Science of the total environment, 380*(1–3), 48–65. https://doi.org/10.1016/j.scitotenv.2006.09.014
33. World Conservation Monitoring Centre (WCMC). (1995). *Endangered lands. World book international, Chicago.*