Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.28930

275 (2022) 245–252
November

Efficacy of natural wetlands along Wadi Zomer as a sustainable phytoremediation alternative for industrial effluents from Nablus West, Palestine

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Received 13 April 2022; Accepted 23 September 2022

ABSTRACT

This paper investigated the effectiveness of natural wetlands (*Phragmites australis*) along Wadi Zomer in reducing the organic and inorganic pollution loads from diverse industrial discharges including occasional emergency discharges from Nablus West Sewage Treatment Plant (NWSTP), Palestine. A spatial variation of physicochemical parameters was monitored at four sampling stations (S1–S4) along Wadi Zomer downstream of NWSTP to evaluate the removal of some heavy metals (Fe, Cu, Zn, Cr, Ni) in water and sediment samples. In addition, an assessment of *P. australis* in heavy metals phytoremediation (leaves, stem, and root) was determined. The results showed that S2 (0 + 0.5 km) and S3 (0 + 3.0 km) reflected an increase in pollution loads due to illicit industrial discharge and sewer overflow discharge form NWSTP during emergency conditions. Biochemical oxygen demand (BOD) values varied significantly along the sampling sites from 6.64 mg/L (S1) to 437.10 mg/L (S3). The BOD at S1 and S2 in water samples were below the Palestinian Water Standard (PWS) compared to S3 and S4 with 437.1 and 333.9 mg/L, respectively. Water samples from all sites (S1–S4) showed a decreasing tendency in heavy metals concentrations (Fe > Cu > Zn > Cr > Ni) and were below the PWS limits, sediment samples followed the same decrease pattern for Zn, Cr and Ni content with Wadi Zomer flow course. The concentration of Fe (6,687 mg/kg) and Cu (1,384.7 mg/kg) were highest in the sediment samples (S1–S4); this might be due to non-point sources of pollution. The research demonstrated that phytoremediation, is a sustainable nature-based technology for the restoration of heavily polluted surface water bodies in Palestine.

Keywords: Heavy metals; Industrial wastewater; Natural wetlands; Phytoremediation; Wadi Zomer restoration; Water quality

1. Introduction

Water is one of the most important resources for all living things. Water is not only an essential element for agricultural food security, but plays a key role in the industry, agriculture, tourism and environmental conservation. The Israeli–Palestinian water conflict further aggravates an environment already characterized by water scarcity [1]. Water scarcity is raising the alarm in achieving sustainable development progress [2]. Increased human activities and using streams and rivers at large-scale resulted in poor water quality and ecosystem degradation [3]. The components of industrial wastewater differ from the municipal wastewater by the content of organic matter and nutrients [4]. Industrial wastewater is less biodegradable compared to other kinds of wastewater and contains hazardous substances, thus having negative effects on ecological service, economic and social development [5]. In Palestine, small streams and seasonal Wadis are subjected to pollution by raw industrial and partially treated municipal wastewater [6]. Industrial discharges contain organic and nutrient rich pollutants, exacerbated by toxic heavy metals, even at low concentrations [7–9]. Groundwater pollution occurs through chemicals present in wastewater where watersheds are at risk due to the increase in chemical

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Presented at the 1st Palestinian-Dutch Conference on Water, Sanitation and Hygiene (WASH), and Climate Smart Agriculture (CSA), 5–6 September 2022, Nablus, Palestinian Authority

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accumulation and this pollution continues for long periods even after it stops from the main source [10]. Thus, to avoid the occurrence of accumulation in the human body or groundwater, wastewater treatment could be accomplished by chemical, physical and phytoremediation methods [11]. Phytoremediation is a multi-service treatment method for treating contaminated water and soil by using specific types of plants ([12]. Natural wetlands (NWs) and constructed wetlands (CWs) describe nature-based treatment processes aiming at the removal of organic and nutrients from municipal wastewater. The use of NWs and CWs is an accepted eco-technology, especially beneficial to rural areas or industries that cannot afford expensive conventional treatment systems [13]. Both CWs and NWs, established at various scales, are constructed for domestic, industrial, municipal wastewater and leachate. Ever increased and stringent water quality rules and effluent standards urged policymakers to search for ecofriendly natural treatment systems including wetlands [14]. In Palestine, the water and environmental problems have increased in spatial distribution over the last two decades with improper practices and inadequate management of industrial and municipal wastewater streams. Agrifood industries (e.g., dairies, slaughterhouses, olive mills) discharge organic-rich liquid streams into public sewerage systems without prior pretreatment. Lack of sustainable management and poor financial resources are responsible for the gross pollution of the receiving water bodies, increased water borne diseases, loss of water value and enhanced political dispute with regional water agencies [15]. Previous studies [16] reported that five Palestinian Wadis, small streams with seasonal flows, are heavily polluted, but they did not explore the role of nature-based technologies to improve water quality and reduce public health and ecosystem hazards. According to Al-Sa'ed [17], organic and inorganic pollutants of various origins are heavily polluting almost all water bodies in Palestine. Al-Sa'ed [17] has developed a policy framework for receiving water bodies including groundwater, streams and water reservoirs, subject for incidents of industrial pollution loads (organic and inorganic substances). Illicit industrial discharges into transboundary watercourses caused political and economic disputes between the Palestinian Authority and Israeli water related agencies [17]. According to Yaqob et al. [18] 70 million cubic meter of wastewater, produced from the West Bank, flow towards the green line. Wadi Zomer produces almost 6 million cubic meter of wastewater annually, or 35% of the wastewater that crosses into the green line. Wadi Zomer receives additional liquid waste streams along its flow course from stone cutting factories, olive mills and runoff from agricultural areas [19]. Abu Ghosh et al. [20] reported that the watershed of Nablus West Sewage Treatment Plant (NWSTP) with increased number of industrial facilities (262) including olive mills (7) and stone cutting sites (75) could harm treatment processes, if raw industrial effluents are discharged without prior pretreatment. With increased understanding of the importance of protection and revitalization of heavily polluted surface water to groundwater, public and ecosystem health, the main goal of this study was to investigate the efficacy of natural wetlands in phytoremediation of industrial organic and inorganic pollutants along Wadi Zomer in Palestine. The specific objectives of the present study were to:

- Investigate the capacity of natural wetlands in removing organic and inorganic pollutants of industrial origin discharged from Nablus West into Wadi Zomer
- Determine the efficacy of natural wetlands in phytoremediation of heavy metals along the course of Wadi Zomer.

Phragmites australis and *Typha latifolia* are two natural wetland vegetation that are native to Palestine. *P. australis*, known as the common reed, is the broadly invasive wetland grass growing along the course of freshwater bodies like Wadi Zomer in Nablus Governorate, Palestine.

2. Materials and methods

2.1. Description of study area

The main channel of Zomer has a total length 44 km, 17 km of which inside the green line Historical Palestine [1]. The Palestinian part of the Wadi spans over 27 km from Nablus City to Tulkarm City [19]. This study covers 5 km in middle of the overall distance Palestinian part (Fig. 1). The average temperature ranges between 8°C to 14°C in winter and 21.9°C to 40°C in summer; the average relative humidity varies from 39% in May to 84% in January. Humidity is at its highest in the early morning and lowest in the early afternoon [21]. NWSTP, since its establishment in 2013, around 5.3 MCM of treated water, as water for nature, drained into Wadi Zomer in 2019. However, frequent illicit industrial discharges and uncontrolled septage disposal form a challenge, and call for urgent actions [20].

2.2. Experimental setup and sampling methodology

Samples were collected for a period of eight months (August to December 2019, and January to March 2020) through the flowing water in the Wadi. Four sampling stations were identified considering the diverse environmental flows in Wadi Zomer (Fig. 1). Sampling station S1 (0 + 0.0 km) represents the first site for water sampling, the outlet of Nablus West Sewage Treatment Plant (NWSTP). This the main tributary as baseline environmental flow, which meets incidental sewer overflows form NWSTP headworks, illicit industrial discharges and septage disposal into Wadi Zomer. Station S2, located about 500 m (0 + 0.5 km) far from S1, is the bridge near the main entrance to Beit Leed town. Here it is worth noting that the treated water from NWSTP is further mixed with domestic sewage from Beit Leed town. Station S3 (0 + 3.0 km), represents a water flow section without additional industrial activities or domestic sewage discharge into the Wadi but there could be drainage from the settlement near the third site. The final station S4 (0 + 5.0 km) receives mixed pollution loads from households and agrifood industries in the middle town of Anabta and some nearby village.

2.3. Analysis of water, sediment, and vegetation samples

Four water parameters were measured using field instruments (onsite) for the Wadi, in the four sampling stations.

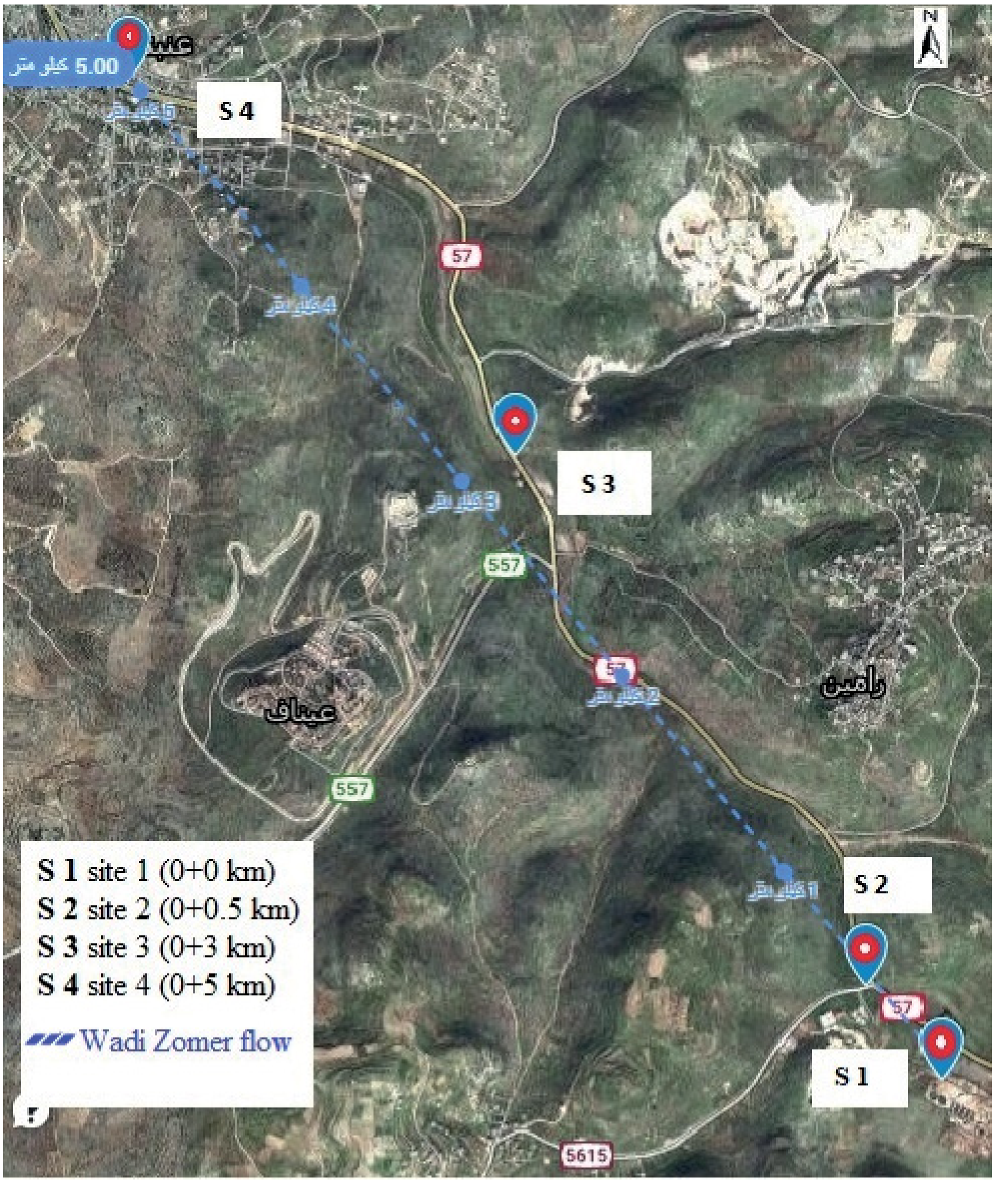

Fig. 1. Study area and sampling sites along Wadi Zomer (not to scale).

These parameters included temperature (T), pH and dissolved oxygen (DO) using WTW OXI 7310 (WTW, Germany), electric conductivity (EC) with Metler Toledo (Seven Excellence, USA). Directly after sampling, water and sediment from Wadi Zomer were subjected to analysis following the standard methods [22]. Major parameters total suspended solid (TSS), total phosphorus (TP) by ICP Avio 200 (Perkin Elmer, USA), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium (NH_4–N) by Spectrophotometer Lambda 25 (Perkin Elmer, USA) and nitrate (NO_3–N) by HPLC (Dionix Thermo, USA) in water and sediment in accordance with the standard methods [22]. Vegetation samples from leaves, stem and roots were analyzed for selective heavy metals (Zn, Fe, Mn, Cu, Ni, Pb, Cr). 1 g of dry weight of each sample was digested using the following digestion mixture (Conc. HNO_3, H_2SO_4, H_2O_2) in the ratio (1:3:3). ICP Avio 200 (Perkin Elmer, USA) measured the heavy metal concentration in various plant parts (leaves, stem and roots) and sediment. The results obtained are expressed in mg/kg [23] as dry weight.

2.4. Statistical analysis

The MS Excel and Graphpad prism version 8 software, for Windows version 10, was used to analyze the obtained results data. The mean and standard errors were used to assess the data accuracy. The mean of parameters (±SE) and one-way analysis of variance (ANOVA) was performed with the SPSS version 26 software package followed by a post hoc multiple comparison (Tukey's test) were calculated to compare the mean values of observation based on the sites under investigation. The differences in mean values obtained were considered significant if calculated *P*-values were less than 0.05. The correlation analysis was done to test the association between different parameters along testing sites along the Wadi Zomer.

3. Results and discussions

3.1. Wadi Zomer flow characterization

Physicochemical analysis of water samples in the studied four sites along the Wadi Zomer are presented in Table 1. The pH value was considered normal and it was within the normal range, the pH values showed insignificant variations along the sampling sites and ranged between 7.23 ± 0.04 and 7.61 ± 0.05. Bello et al. [24] reported that the *P. australis* preferred an acidic to neutral condition for both cadmium and lead remediation, but a pH performed better at pH 10 for nickel remediation. In all site but the first, the temperature ranged from 20.2°C to 22°C. In the first site, it was below than the normal average, as it is the first sampling site within the NWSTP fence (outlet), which is often covered from direct sunlight as an outlet pipe before discharge into Wadi Zomer. Temperature influences the solubility and, thus, the availability of oxygen in water [24].

Concerning DO content, the lowest value for DO was measured in site 1, while the highest value was recorded in site 4. According to the established criteria, the range must be below than 2 mg·O_2/l. This may be due to topographical distribution of monitoring stations and the time of sampling, and may change with season [25]. When studying the water quality of flowing rivers, Matamoros and Rodríguez [26] recorded a dissolved oxygen rise in the direction of the downstream flow. In surface water bodies that receive partially treated wastewater, Edokpayi et al. [10] reported a significant and increasing depletion of the DO. Regarding the EC, site 2 (main entrance to Beit Leed town) showed the highest EC values. This might be due to the presence of metal salts (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{-2} and HCO_3^-) leading to higher EC values [27,28].

The TSS varied significantly and ranged from 5.6 ± 0.9 mg/L to 109.1 ± 14.5 mg/L (Fig. 2). TSS level were generally above the PVL 227 standards [29] permissible limits (60 mg/L) except site 1.

Fig. 3 shows the nitrogen concentrations (NH_4–N, NO_3–N) in water samples along the Wadi Zomer. Ammonium-N was found at higher concentrations in all site exceeding the limits of PVL 227 [29] of 5 mg/L depicted in Table 1.

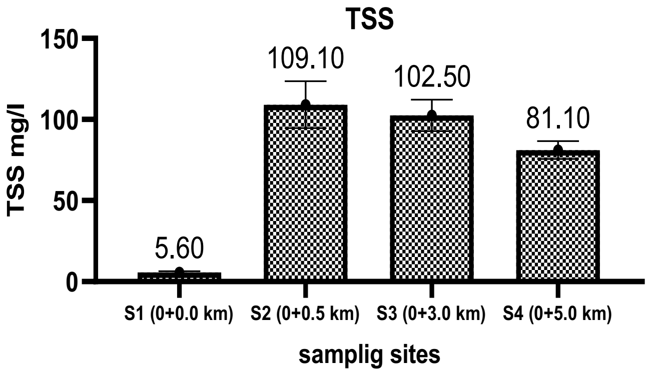

Fig. 2. Total suspended solid (TSS) in water samples at various sites of Wadi Zomer.

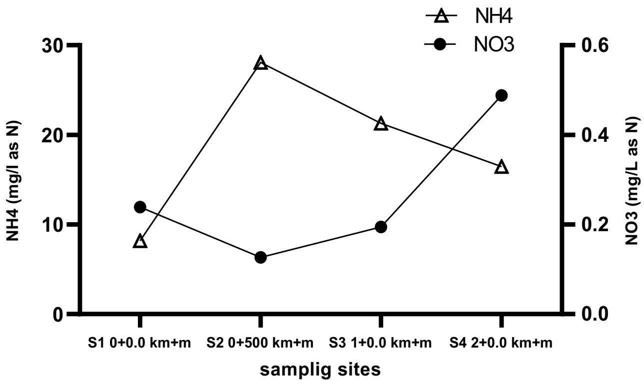

Fig. 3. Concentration of ammonium and nitrate at various sites along Wadi Zomer.

Table 1
Mean ± SD for parameter measured in water samples at all sites (*n* = 11)

Parameter	Site 1 (0 + 0.0 km)	Site 2 (0 + 0.5 km)	Site 3 (0 + 3.0 km)	Site 4 (0 + 5.0 km)	PVL227 (PSI, 2010)
pH	7.61 ± 0.05	7.4 ± 0.05	7.23 ± 0.05	7.24 ± 0.05	6–9
T	20.9 ± 0.7	21.2 ± 0.7	21.3 ± 0.7	21.4 ± 0.7	–
DO	0.02 ± 0.01	1.3 ± 0.12	2.1 ± 0.19	3.3 ± 0.23	<2
TSS	5.6 ± 0.9	109.1 ± 14.5	102.5 ± 9.7	81.1 ± 5.5	60
NH_4–N	8.2 ± 1.02	28.1 ± 1.95	21.3 ± 1.97	16.5 ± 1.07	5
NO_3–N	0.24 ± 0.06	0.13 ± 0.01	0.19 ± 0.01	0.49 ± 0.02	50
Total-P	4.9 ± 0.2	6.2 ± 0.3	5.6 ± 0.3	6.3 ± 0.2	15–20
EC (µS/cm)	1,407.3 ± 26.8	1,595.3 ± 27.4	1,508.6 ± 21.7	1,508.7 ± 33.2	–
COD	24.8 ± 3.6	122.2 ± 24.2	899.7 ± 605.9	708.1 ± 511.1	150
BOD	6.6 ± 0.7	57.6 ± 11.4	437.1 ± 300.8	333.9 ± 233.7	60

PLV: Palestinian values limit (PSI, 2010);
All units are in mg/L, otherwise stated.

The lowest value of ammonium was recorded at site 1 and the highest value in site 2. Nitrate (NO_3–N) level was below the limits (50 mg/L) of PVL 227 [29] for all sites. TP in all site were considered normal and ranged from 4.9–6.2 mg/L. TP levels were generally below the PVL 227 [29] permissible limits (15 mg/L) at all sampling sites.

BOD varied significantly along sampling sites and ranged from 6.6 to 333.9 mg/L. The study revealed that the water in site 1 and site 2 had BOD levels below PVL 227 [29] and that site 3 and site 4 had BOD levels 437.1, 333.9 mg/L respectively, above the maximum permissible limits given by the PVL 227. COD varied significantly along sampling and ranged from 24.8 to 899.7 mg/L. The study revealed that the water in site 1 and site 2 had COD levels below PVL 227 [29] and that site 3 and site 4 had COD levels (899.7 ± 605.9), (708.1 ± 511.1) mg/L respectively, above the maximum permissible limits given by the PVL 227. Low levels of BOD and COD in rivers indicate improvement in water quality, where high pollution levels may cause degradation in ecosystem health and fuel a regional political conflict.

3.2. Heavy metals content in water samples at four sampling sites

The results obtained from analysis of wastewater samples along the 5 km of Wadi Zomer are summarized in Table 2. The heavy metals analyzed are Zn, Fe, Cu, Pb, Ni, and Cr. The concentration of the heavy metals was in the flowing waters of the Wadi within the permissible Palestinian value limits (PVL227) [29]. Except the Cr in the site 2. High levels of Nickle exceeding PVL limits were recorded at site 2 and site 3. Dheri et al. [30] found that the high concentration of Cr was due to the discharge of untreated industrial water.

3.3. Heavy metals in stream sediment from all sampling sites

The results in Table 3 depicts the highest value was found in the sediment for Fe was 6,687 mg/kg and the lowest value 10.5 mg/kg for Ni. The concentration of Zn, Cu and Cr were at levels of 293.1, 1,384.7, and 52.7 mg/kg, respectively. Heavy metals in stream sediments was found to increase in order of Fe > Cu > Zn > Cr > Ni.

Anthropogenic activities have a negative impact on the environment, because they can release a diversity of pollutants including heavy metals through point sources. Manmade activities reflected in industrial and agrifood industrial activities could release heavy metals in wastewater causing heavy metals pollution in rivers from non-point sources [31,32]. The heavy metals can be considered as the results of industrial and from the outputs of agricultural manufacturing. A recent study by Khan et al. [33] showed that Cr in the sediment sample was (70 mg/kg) compared to our result that was (52.7 mg/kg) and zinc is found 780 mg/kg compared to our result that was 293.1 mg/kg. In this study, Fe recorded high concentration in sediment samples (6,687 mg/kg), close to reported data in sediments of Suez Gulf (7,497 mg/kg) [34]. Table 4 shows obtained results on the content of heavy metals in the sediment samples compared with published literature data.

Table 3
Concentrations of heavy metals in sediment (n = 3)

Metals	Zn	Fe	Cu	Pb	Ni	Cr
Sediment	293.13	6,687	1,384.77	BDL	10.53	52.77
Control	21.16	16.81	8.99	3.60	16.92	25.05

All units are in mg/kg;
BDL: below the detection limit.

Table 4
Metals concentration in sediment samples (mg/kg)-this study vs. literature data

Site	Cu	Pb	Zn	Cr	Ni	Fe	Sources
Odiel River	607	2,369	2,874	54.7	29.7	31,862	[57]
Haihe River	28.52	25.20	84	57.55	32.71	29,500	[58]
Yangtze River	30.7	27.3	94	78.9	31.8	33.394	[11]
Suez Gulf	33.2	70.44	159.4	32.04	71.44	74,97	[34]
This study	1,384.7	ND	293.1	52.7	10.5	6,687	This study

All units are in mg/kg dry weight sediment samples;
ND: not detected.

Table 2
Mean ± SD for heavy metals measured in water samples at all sites (n = 11)

Parameter	Site 1 (0 + 0.0 km)	Site 2 (0 + 0.5 km)	Site 3 (0 + 3.0 km)	Site 4 (0 + 5.0 km)	PVL227 PSI [29]
Zn	0.9 ± 0.8	0.2 ± 0.04	0.3 ± 0.03	0.12 ± 0.02	2
Fe	0.2 ± 0.1	1.8 ± 0.2	4 ± 0.6	1.6 ± 0.2	5
Cu	0.14 ± 0.002	0.12 ± 0.002	0.1 ± 0.004	0.07 ± 0.005	0.2
Pb	0.15 ± 0.005	0.06 ± 0.01	0.06 ± 0.01	0.04 ± 0.005	0.2
Ni	0.2 ± 0.009	0.3 ± 0.01	0.3 ± 0.02	0.1 ± 0.01	0.2
Cr	0.14 ± 0.005	0.22 ± 0.01	0.08 ± 0.02	0.04 ± 0.01	0.1

PLV: Palestinian values limit according to PSI [29];
All units are in mg/L.

Copper (Cu), which is regarded as a serious pollutant of aquatic ecosystems, was the second higher in concentration in this study. Nickel is a common pollutant resulting from various past industrial activities like the production of Ni–Cd batteries, illegal waste incineration, and illicit municipal wastewater discharges. High Ni concentrations (10.5 mg/kg) in the sediment, reflecting long-term accumulation of Ni metal in the sediment of Wadi Zomer.

3.4. Heavy metals in vegetation parts of P. australis

The results shown in Table 5 indicate the highest value was found in the plant leaves are Fe (326.3 mg/kg) and that the lowest value is for Ni (6.7 mg/kg). The concentrations for Zn, Cu and Cr were at levels of 80.3, 12.5, and 51 mg/kg, respectively, except that the Pb metals below the detection limits. Heavy metals in *P. australis* (leaves) was found to increase in order of: Fe > Zn > Cr > Cu > Ni. As shown in Table 5, the highest value was found in the plant stem are Fe 435.1 mg/kg and the lowest value for Cr 1.6 mg/kg. The content for Zn, Cu, Ni, and Pb were at levels of 73.3, 11.9, 6.4, and 4.9 mg/kg, respectively, the metal of Pb was detected in the leaf, but present in the stems with a concentration of 4.9 mg/kg.

Heavy metals in *P. australis* (stem) showed an increase in order of Fe > Zn > Cu > Ni > Pb > Cr. The results shown in (Table 5) lists the highest value found in the roots for Fe 21,654 mg/kg and the lowest value for Pb 6.6 mg/kg.

The concentration of Zn, Cu, Cr and Ni in the roots were recorded as 127, 30.3, 24.4, and 22.4 mg/kg, respectively. Heavy metals in *P. australis* (roots) was found to increase in order of Fe > Zn > Cu > Cr > Ni > Pb. Recent review [35] on the importance of biological and ecological properties of *P. australis* found that metal uptake through phytoremediation can be affected by soil pH, cation capacity, clay substance, organic matter substance and the presence of other ions. *P. australis* are most impacted by metals in the sediment than by those ones in water, subsequently, bioaccumulation is more noteworthy when sediments are contaminated. The highest concentration of heavy metals (Fe, Zn) was found in the roots except for lead (Pb). Our results revealed that heavy metals (Fe, Zn, Cu, Cr) are accumulated more in the roots, thus are in agreement with published data on the accumulation of heavy metals in the roots of *P. australis* during the seasonal cycle [36–38]. All plant organ displayed strong abilities to accumulate heavy metals in their roots and stems whereas large accumulation was found in the roots. Previous studies [39,40] reported that roots showed higher affinity to towards heavy metals (Zn and Cu) accumulation than stem and leaves, thus roots could act as barrier against heavy metals transfer from the sediment. According to Sawidis et al. [41], roots of *P. australis* can accumulate awesome amount of overwhelming metals because of the cortex parenchyma with intercellular air spaces. Iron (Fe) in all plants organ was translocated from roots to stems, but the accumulation of roots remained higher. By contrast, results with high translocation of Fe in the shoot have also been previously reported but in different plant types [42]. Zn plays an important role in the environment and can revitalize the most prominent role in plant nutrition and enzymatic activities. The concentration value that detected in stems and leaves were in agreement with various authors [43]. Zn concentrations in all plant organs were significantly below the phytotoxic range of 500–1,500 mg/kg [44]. Search results showed zinc concentration was around 70.2 mg/kg compared to our research results 80.3 mg/kg that use *P. australis* for landfill leach at treatment [45]. Research results published by Windham et al. [43] revealed that the concentration of zinc in the leaf reached 79.03 mg/kg compared to the result obtained in this study (80.3 mg/kg). Cu plays a vital role in plant sustenance at low concentrations but becomes harmful at higher levels [46]. However, Cu concentrations in all plant were below the phytotoxic range of 25–40 mg/kg [44]. Using constructed wetlands for treating river contaminated by swine operations, Yeh et al. [47] reported that leaf uptake for copper element was 12 mg/kg, which is close to our recorded data for Cu (12.5 mg/kg). Other studies [48] reported that vegetation assimilated copper and zinc with the most noteworthy aggregation found within the roots. Pb is immobile in soil and tends to accumulate in roots [49]. Pb concentrations found in this study were higher than the values reported by others [50], especially in regards to stem. Pb leaf concentrations were below the detection limit of the analytical instrument used. A study in Romania, [51] investigated the spatial variability in trace metal concentrations in the tissues of *P. australis*, where leaves showed Pb concentration of 0.2 mg/kg. Compared to the results of our study that was below detection limit, the highest value was for the presence of lead in plant leaves 31–50 mg/kg with a purification and removal rate of 64–81% [52]. Ni has toxic effects on plants. The values of bioaccumulation in the plant organs agree with Laing et al., [53]. Nickle (Ni) concentrations in leaf of *P. australis* in the Scheldt estuary was 0.5–5.8 mg/kg and the differences between current study might be related to pollution levels and physico-chemical sediment, water or sediments characteristics at the sampling site. In Belgium, using CWs for domestic wastewater treatment, metal concentrations in the stems for nickel reached 0.52 mg/kg compared with our result was 6.4 mg/kg. Concerning chrome, our result revealed 1.6 mg/kg compared the 1.3 mg/kg published data [54]. The plant organs in this study showed toxic levels of chrome, Cr is a toxic for plants. According to Allen [55], concentrations of Cr greater than 0.5 mg/kg are toxic to plants. In this study, all plant organs showed Cr values above the phytotoxic threshold. Cr concentrations in roots were comparable with data found in other studies [56]. A pattern of accumulation in the vegetation parts

Table 5
Concentrations of heavy metals (mg/kg) in *P. australis* in three vegetation samples

Heavy metals	Plant leaf	Plant stem	Plant root
Zn	80.3	73.3	127
Fe	326.3	435.1	21,654
Cu	12.5	11.9	30.3
Pb	BDL	4.9	6.6
Ni	6.7	6.4	22.4
Cr	51	1.6	24.4

BDL: below the detection limit.

of *P. australis* for Zn was recorded, the accumulation of Zn in the stems showed the lowest value of 26.6 mg/kg and the highest value was 75.3 mg/kg dry weight (Table 2).

The obtained results support the work published by Dean et al., [59], who reported efficient removal of metals (>80% of Fe, Zn and Cu) due to high root metal accumulation by the natural wetland plant species and association of acidophilic bacteria in the wetland rhizosphere.

4. Conclusions

The primary objective of this study was to investigate the efficacy of phytoremediation using natural wetlands in Nablus West watershed to improve the water quality along Wadi Zomer flow course. According to the findings of this study, the industrial wastewater that is discharged to the wastewater treatment plant or illegally leaked into Wadi Zomer contains many organic and inorganic pollutants including heavy metals. The highest percentage of heavy metals was iron in all parts of the study. The occasional uncontrolled illicit industrial discharges along the Wadi course and the occasional sewer overflows under emergency events at NWSTP have impaired the water quality at Station S2 (0 + 0.5 km) and Station S4 (0 + 2.0 km). The shock pollution loads did not affect the efficacy of the self-purification capacity of the natural wetlands, the latter are non-motile and got adapted to pollution. Therefore, the natural wetlands proved an efficient role in phytoextraction of selective heavy metals, thus improved the water quality of Wadi Zomer. The results of this study support the urgent needs for long-term monitoring of industrial effluents before discharge into public sewers, where long-term impacts and fate of heavy metals in soil and vegetation along Wadi Zomer course warrant further studies. Understanding the impacts of vegetation varieties on pollution reduction and diversity of microbial assemblage in the sediment enhance could promote the widespread of natural wetlands for pollution phytoremediation. Effective water quality monitoring of industrial discharges and sewage works outlets along Wadi Zomer. Future research on water quality monitoring should include emergent chemicals and bio-indicators pertaining to water-borne disease including microbial pathogens and selective viruses. The ability of different natural wetland plants for nitrogen assimilation in Wadi Zomer considering nitrogen mass balance under variable oxic and anoxic conditions in water-sediment zone and study the effect of C/N ratio on nitrification and denitrification processes form future studies.

Funding

The Palestinian-Dutch Academic Cooperation (PADUCO2) Program on Water funded this research within the project "Promotion of Applied Integrated Practices and Technologies for Sustainable Industrial Wastewater Management in Palestine (INWA)". Special thanks are due to Tareq Aqhash of Birzeit University Testing Laboratory Center for providing fieldwork and partial lab analysis, especially during the lockdowns due to COVID-19 pandemic.

Conflicts of interest

The authors declare no conflict of interest.

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