Research Article

Phytoremediation of Heavy Metals from Irrigation Water – Case Study of Hayatabad Peshawar

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Abstract | This research study was focused on investigating the heavy metals (HM) concentration in the effluents generated from the Hayatabad Industrial Estate and the phytoremediation capabilities of two locally available plant species *Arundo donax* (*A.d*) and *Typha latifolia* (*T.l*) for removing HM from the untreated wastewater of Hayatabad Peshawar used for irrigation downstream. The wastewater analysis showed that HM concentration exceeds the limits of thresholds values. For phytoremediation the *T.l* was tested in both on-site (in-situ) and laboratory conditions (ex-situ) while *A.d* was applied only in an ex-situ setup. For *T.l*, the average uptake of copper (Cu) was 5.40 and 6.46 mg kg^{-1}, similarly for the lead (Pb) average uptake was 4.55 and 4.55mg kg^{-1}, while for nickel (Ni) the average uptake was, 2.80 and 2.76 mg kg^{-1} in ex-situ and in-situ plantation respectively. Whereas for *A.d.* the HM uptake was 3.22, 2.27, and 1.49 mg $kg^{-1}$for Cu, Pb, and Ni, respectively in ex-situ plantation. The uptake of Chromium (Cr) and Cadmium (Cd) was insignificant due to their low concentration in wastewater. The *T.l* had the average removal efficiency for Pb, Ni, and Cu in the order of 36.9%, 27.3%, and 22.9%, while for *A.d* it was 33.3%, 33.1%, and 24.5%, respectively. The *T.l* showed better results when compared with the *A.d* for HM recovery from wastewater. Both the species has aided advantage for translocation of HM off the treatment site as the biomass has usage in the local market.

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Introduction

To sustain a clean environment, freshwater resources for sustainable development are considered among the critical factors. The increase in global population, growth in per capita income, and rise in urbanization trend are the strong drivers for diversified food demand and have intensified the water demand within agriculture and across the agricultural, industrial, and domestic needs (Rosegrant *et al*., 2020). The global population is likely to reach 9.8 billion by the year 2050, with the largest anticipated growth in South Asia and Africa where water and food security issues already exist (Zhang, 2008). There are concerns over clean water access for human consumption by the year 2030 (Drechsel, 2015).

To meet the need of increasing population, the rapid industrial growth has resulted in the increase of effluent to the ecosystem. Wastewater contains a variety of pollutants including heavy metals and can generate serious environmental threats if not treated appropriately. Heavy metals have environmental concern because these contaminants are not naturally degradable as compared to organic contaminants. The typical widely reported heavy metals contaminates are lead (Pb), cadmium (Cd), copper (Cu), and chromium (Cr) (Tauqeer *et al*., 2016) Many of the heavy metals are important micronutrients for all living organisms in certain low concentrations. Some of these heavy metals are cofactors of enzymes and are useful in important biochemical processes like photosynthesis, flowering, and fruit production in plants (Sheoran *et al*., 2016). However, excess concentration of heavy metals may have a toxic effect on crop growth. The conventional techniques of leaching, electro-kinetical treatment, vitrification, and excavation treatment for heavy metals toxins are expensive and applicable to small areas restoration. The Phytoremediation is an emerging technology using plants for environmental restoration (Mukhopadhyay and Maiti, 2010). This process is regulated by environmental conditions and the bioavailability of heavy metals contaminants. The Phytoremediation reclamation technique concept was emerged in 1990s to remove, immobilize or degrade the heavy metals toxins resulted from anthropogenic activities. This process is not only cost effective, but also environmentally acceptable and suitable for large fields over long term treatment application. There are certain plants referred to as metallophytes that can grow in the metalliferous soils and, some of these even accumulate a significant amount of heavy metals and are referred as accumulators.

In Pakistan no detailed hazard assessment information repository is available about the intake of heavy metals due to the intake of food grown on contaminated wastewater. This heavy metal accumulation in vegetables and other crops poses serious public health risks on large scale. A nationwide assessment on wastewater use finds the direct use of wastewater effluent particularly in suburbs of the cities. The rationale behind this practice is the nutrient value of the wastewater, the absence of freshwater for irrigation, and the proximity to urban markets (Ensinka *et al*., 2004). It was found that vegetables irrigated with wastewater effluent had higher heavy metal than the threshold values (Iqbal *et al*., 2020). Another report indicates that vegetables cultivated in district Mardan, KP, Pakistan with wastewater effluent had a significantly higher concentration of toxic heavy metals when compared to the WHO/FAO permissible limits (Amin *et al*., 2013). Similarly, in the suburbs of Peshawar, wastewater containing heavy metals is used for vegetable production (Ali *et al*., 2017; Khan, 2017). In the majority of cases, the heavy metal contamination of soil and water is from industrial wastewaters discharged from manufacturing and raw material processing units (McIntyre, 2003). If the effluent is not treated properly, the concentration of heavy metals could exceed the permissible thresholds and may cause undesired changes in the physicochemical and biological composition of receiving water body, and eventually may have adverse effects on the ecosystem and human health.

The wastewater generated from the industries and the residential areas of Hayatabad, Peshawar is not getting any treatment and is directly used for irrigation downstream by farmers. This is posing a high risk to human health through the accumulation of toxic metals in the food chain. This necessitates an effective and affordable remedy to reduce contaminants in the wastewater stream until a functional wastewater treatment plant is provided and environmental regulatory measures are enforced by the concerned regulatory authorities.

Bioremediation of heavy metals through phytoremediation technique is recently gaining global attention for reclaiming heavy metals from mixed domestic and industrial effluent and/or agricultural contaminated lands rich in plant essential nutrients. In this approach usually, the locally available plants are recommended to be used for contaminant uptake and translocation when the biomass is harvested and transported off-site for beneficial use. This objective of this research study is to:

- Investigate the heavy metals concentration in the effluents generated from the Hayatabad Industrial estate
- Assess the phytoremediation remediation capability of two locally available plant species *Arundo donax* (*A.d*) and *Typha latifolia* (*T.l*) for removing heavy metals from the untreated wastewater.

Materials and Methods

Wastewater samples were analyzed in the laboratory and results were compared with irrigation water guidelines of the Food and Agriculture Organization (FAO) of the United Nations. The biomass samples of both plant species from in-situ and ex-situ setups were also analyzed for metal uptake by selected species. The Heavy Metals (HM) concentration in wastewater and plants sample were used for determining the bioaccumulation factor (BAF) and the removal efficiency (RE) for each metal by both plant species in an ex-situ setup were determined. Based on the average biomass production of both plants per m^2 area, the expected uptake from 1 kanal ($\approx$ 500 m^2) area was approximated. Finally, the local uses of both plants' biomass were highlighted. Four potential sites for phytoremediation were also identified within the wastewater stream's right of way for future planning by the concerned authorities.

Study area

Hayatabad (Figure 1) is situated to the south-western side of Peshawar city, the capital of the Khyber Pakhtunkhwa, Pakistan. This public sector housing project was initiated during the late 1970s as an upscale suburb. Later, an industrial zone "Hayatabad Industrial Estate" was also annexed, comprising of different types of industries ranging from pharmaceutical, marble, matches, steel, and, paper industries. The Peshawar Development Authority (PDA) had laid a sewerage network including a sewage treatment plant located in Phase-III initially intended for the treatment of 4,542 m^3/day of sewage, and later the capacity was extended to 15,140 m^3/day. Currently, the plant is nonfunctional due to inadequate operation and maintenance. At present, the wastewater from both the municipal and industrial zones is discharged without any treatment to the mainstream causing environmental pollution in the adjoining areas.

Wastewater sampling

The wastewater was collected from the stream's outlet where both municipal and industrial effluent was mixed. During sample collection, larger particles were filtered. Necessary protective measures were taken for protection from possible direct contact of effluent as described by (USEPA, 2017). Samples were collected at 6 hours intervals and were stored in 200 liters plastic (high-density polyethylene) barrels for offsite irrigation and laboratory analyses. The analyses for Cu, Pb, Ni, Cd, and Cr detection were performed in the Centralized Resources Laboratory University of Peshawar using the Spectrophotometric Technique.

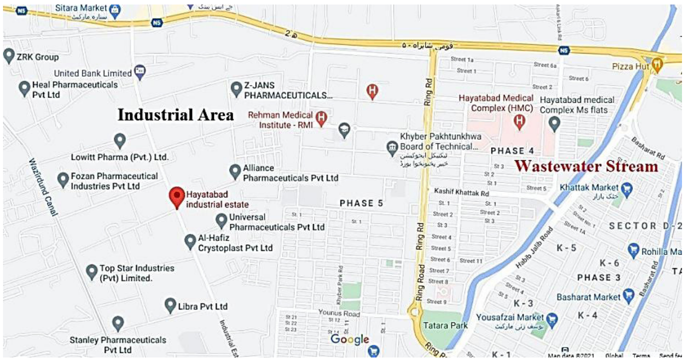

Figure 1: *Study area map.*

Plant material

Two local plant species *Arundo donax* (*A.d*) and *Typha latifolia* (*T.l*) were used for the reclamations of the HM from the untreated wastewater effluent. These plant species have previously been described globally with the ability to remove HMs, however, has not been tested in the prevalent condition for treatment of effluent generated from Hayatabad Peshawar.

The *A.d* is locally known as "Nacha, Durma or Null plant" is a water-loving species, grows near the water streams or in swamps/waterlogged areas. It is a perennial plant that grows from roots when harvested and is usually transplanted in the late winter and sprouts in the early spring season (Angelini *et al.*, 2005). It can grow 3m in height and has a bamboo-like structure with a hollow stem of 2 to 3cm diameter. It bears a narrow leaf structure with dark green color (El-Bassam, 2010).

The *T.l* plant locally known as "Lokha" is always found nearby rivers and streams. It is also a water-loving species and grows well in waterlogged conditions in fine soils. The best growing condition is 0.6 to 0.9 m depth of water. Normal height is 1.5 to 2 m with 2 to 5 cm broadleaf with dark green color. It is identified among other species of the same class by its large cylindrical spike of the female flower (Tsyusko *et al.*, 2005). It is also classified as accumulator for its natural ability of up taking HMs especially from wastewater (Anning *et al.*, 2018).

Plantation

The *T.l* was cultivated within the right of way of the stream (In-situ), and in the Laboratory of National

Institute of Urban Infrastructure Planning (NIUIP), University of Engineering and Technology (UET) Peshawar (ex-situ) as shown in Figure 2 and 3, respectively. While the *A.d* was plantation was carried out at NIUIP, UET Peshawar. Since the stream also served as a flood waterway and floods may wash away the new plantation therefore ex-situ (laboratory scale) study was also conducted in control conditions. Crops growth at their mid growth stages is shown in Figure 4, the growth of both species was initiated in early March which reached close to maturity by the end of May.

Figure 2: *Planation at the research site.*

Figure 3: *Lab plantation, construction of planter and soil bed preparation. Preventing seepage losses using plastic sheet. Masonry work around the perimeter to isolate the site and maintain a constant water depth during plants growth.*

Irrigation with wastewater

The plants were irrigated with industrial effluent. In in-situ wastewater was diverted to the plantation site to maintain the plants in full submerged condition. While for ex-situ plantations, the irrigation water was supplied through an elevated water tank. The irrigation was scheduled on daily basis to maintain saturated conditions. The volume of wastewater applied for irrigation ex-situ setup is calculated by measuring the difference of the pre-irrigation and post irrigation depth of the irrigation tank multiplied by the area of the tank. Total 38 numbers of irrigation were applied with a total volume of 2251 liters. On average, 62 liters were applied to both plants per irrigation.

Figure 4: *Plants at their full growth stage.*

Plants harvesting

After two months the plants were fully matured as shown in Figure 4. the plants were harvested from both locations and biomass samples of plant parts (Stem, Leaves, Roots) were prepared as shown in Figure 5 and carried to the laboratory for biomass analysis.

Figure 5: *Samples of leaves, stem, and roots samples for biomass analysis.*

Biomass analysis

Biomass samples were analyzed for HMs concentration through Atomic Absorption Spectrometric Method. The biomass was chopped and then dissolved in an acidic solution. The prepared solution was tested for HMs detection in an Atomic Absorption spectrometer.

Bioaccumulation factor (BAF)

Bioaccumulation factor may be defined as the concentration present in a tissue of a living organism divided the concentration of the medium to which the organism is exposed. For BAF we analyzed the plants' tissue from leaves, roots, and stem. The following formula was used to calculate the BAF (Alaboudi *et al.*, 2018).

$$BAF = HM_P / HM_W$$

Where; HMP is Heavy Metal accumulation in plant species and HMW is Heavy Metal concentration in wastewater. BAF is a useful indicator for classifying the plant species for HMs recovery from wastewater. If BAF > 1 means can accumulate and If BAF < 1 plant species is unable to recover the contaminant from wastewater (Branković *et al.*, 2019).

Removal efficiency (RE)

Removal efficiency means how efficient the plant is in the overall removal of the selected element. The RE for HMs by each species was calculated using the following formula adopted from a study (Ahmed *et al.*, 2020) that investigated the heavy metal recovery from the aqueous solution.

$$Removal\ efficiency = \frac{HM_{In} - HM_{Out}}{HM_{In}} \times 100$$

Where; HM_{in} and HM_{out} are Heavy Metal Concentration at the inlet and outlet of the wetland, respectively.

Results and Discussion

Wastewater analysis

The average values of heavy metals found in the wastewater samples were 1.13, 0.71, 0.41, 0.27, and 0.02 mg l^{-1} for Cu, Pb, Ni, Cr, and Cd, respectively, and were found above the allowable limit of FAO irrigation water guidelines of 0.2, 0.1, 0.2, 0.01, and 0.01 mg l^{-1} respectively, as compared in Figure 6. The sewage water used for irrigation in the same area was examined in 2012, which showed 0.25, 0.61, 0.03, and 0.75 mg l^{-1} concentrations for Pb, Ni, Cr, and Cd, respectively (Perveen *et al.*, 2012). The total amount of wastewater applied is provided in Figure 7. is The comparison of data shows an increase of 64% for Pb and 88% for Cr while a decrease of 32% for Ni and 97% for Cr. This difference may be due to their selection of 40 different points throughout the district instead of focusing on a single stream of wastewater or due to the increase in industrial production over time. In 2017, the analysis of wastewater from the same stream carried out by (Khan, 2017) reported the concentrations for Cu, Ni, Pb, and Cr at 0.48, 0.36, 0.57, and 0.51 mg l^{-1}, respectively. The comparison showed an increase of 57%, 12%, 19% for Cu, Ni, and Pb, respectively while a decrease of 47% for Cr. Application of this contaminated wastewater directly for irrigation, usually practiced downstream of the industrial area, potentially affect the soil, crops and human health through the food chain (Khan, 2017). A similar study (Ayaz *et al.*, 2020) analyzed the industrial wastewater of the same study area for 9 weeks, with one-week interval, the concentration of Cu, Pb, and Cd ranged from 11.0-17.9, 5.24-9.92, and 3.9-8.5 mg l^{-1} respectively. Their reported concentrations are higher than this study, as they were focusing on pure industrial wastewater.

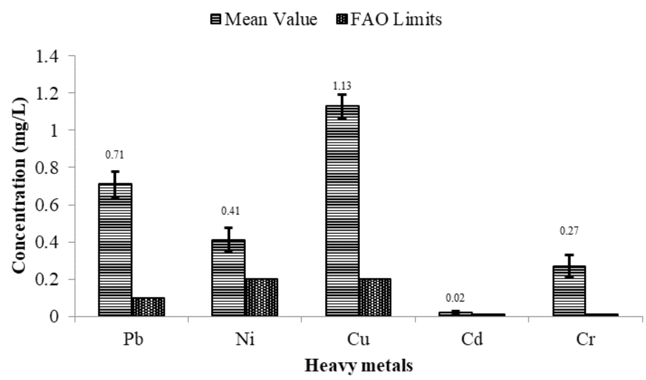

Figure 6: *Heavy metals concentration in wastewater.*

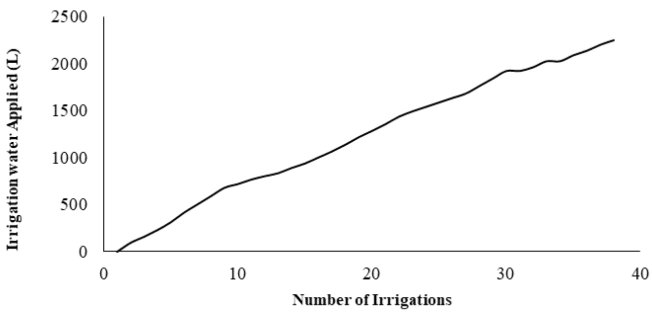

Figure 7: *Applied irrigation water for plantation period.*

Metal uptake

The Cu uptake by both species was significant. The maximum uptake was observed in *T.l* roots with 9.76 mg kg^{-1} in in-situ and the minimum occurred in *A.d* stem of 2.18 mg kg^{-1} in ex-situ. Comparing plant uptake, the *T.l* showed more uptake than *A.d*. The *T.l* roots showed 2.11 mg kg^{-1} more uptake in ex-situ samples. Similarly comparing leaves uptake for both plants, *T.l* leads by 1.22 mg kg^{-1} than *A.d* (Table 1).

The same pattern of better performance by the *T.l* for Cu uptake was also reported by (Anning *et* *al*., 2013) with 49.98±15.11 and 31.45±1.23 mg kg^{-1} for shoots and roots respectively. Bonanno *et al*. (2013) Suggested that the *A.d* may be used for phytoremediation of Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn for contaminated water bodies. Elhawat *et al*. (2014) examined the potential of *A.d* for Cu uptake from synthetic contaminated water and reported 96% removal, and concluded that it may be used for cleaning of wastewater having Cu concentration of up to 26.8 mg l^{-1}.

In the case of Pb, both plants showed the best performance in uptake, but less as compared to Cu. The maximum uptake was observed in *T.l* roots in-situ and the minimum occurred in leaves of *A.d* in ex-situ setups. The average uptake of *A.d* and *T.l* were 2.27 and 4.55 mg kg^{-1} in ex-situ, respectively, while 6.55 mg kg^{-1} in in-situ for *T.l*. The *T.l* showed 2.00 mg kg^{-1} more uptake in in-situ. Comparing part to the part performance of plants in the same conditions, *T.l* showed 1.71 mg kg^{-1} more in roots and 2.8 mg kg^{-1} in leaves in an ex-situ plantation.

Del Rio *et al*. (2002) tested many plant species including *A.d* for phytoremediation of Pb, Cu, Zn, etc from a contaminated sludge and reported 0-23 mg kg^{-1} of Pb uptake, which is much higher compared to the present study. Klink (2017), used *T.l* with one other plant species for phytoremediation in 19 sites selected from seven lakes in western Poland. The Pb concentration was 0.81 ± 0.10 µg L^{-1} in water and uptake concentrations were 1.07 ± 4.16, 3.90 ± 1.47 for roots and leaves, respectively. His study showed better performance for leaves while in the present study roots have more uptakes. A research study Bonanno *et al*. (2013) used three species of Typha including *T.l* on a natural wetland receiving municipal wastewater with metal contamination for two seasons and recorded the experiment results in spring as well as in autumn. The Pb concertation in water was 2.56 ± 0.45 and 3.68 ± 0.64 µg L^{-1} in spring and autumn season respectively and the corresponding uptake was 13.7 ± 2.35 and 10.9 ± 1.94 mg kg^{-1} for roots and 0.71 ± 0.11 and 0.65 ± 0.10 for leaves. In their study more uptakes were observed in roots as compared to the other parts, the present study also followed the same pattern.

The Ni uptake was also detected in each sample, but it is less than the uptakes of Cu and Pb. The maximum uptake of 4.34 mg kg^{-1} was observed in *T.l* roots in in-situ and a minimum of 0.97 mg kg^{-1} was shown by the *A.d* stem under ex-situ. Comparing plant performance under ex-situ conditions *T.l* roots showed 1.21 mg kg^{-1} more uptake than *A.d* roots and similarly, in leaves uptake, *T.l* leads by 0.91 mg kg^{-1}.

Another study (Kumari *et al*., 2015) observed the approach of *T.l* in removing heavy metals including Ni from secondary treated wastewater in a 15-day experiment with Ni concentration of 0.078 (80% lower than the present study) mg L^{-1} in wastewater. They recorded Ni removal of 50.4 ± 15.9 % by *T.l*. The Cd uptake was not detected in any of the in-situ samples and 0.5 mg kg^{-1} was found in roots *T.l*. This might be due to the very minute concentration of Cd in wastewater, as the *T.l* has a good ability to uptake Cd as demonstrated by Fediuc *et al*. (2002).

In all ex-situ samples, no Cr uptake was found except in the roots of *T.l* with a very minute uptake of 0.03 mg kg^{-1}. In in-situ samples, *T.l* roots show 0.37 mg kg^{-1} uptake, and no uptake was detected in leaves of the same plant. Overall, for Cr uptake, the values were not significant.

Table 1: *Heavy metal detected (mg/kg) in plant biomass.*

Heavy metal	*Typha latifolia*				*Arundo donax*		
	In-Situ		Ex-Situ		In-situ		
	Roots	Leaves	Roots	Leaves	Roots	Stem	Leaves
Cu	6.44	4.37	9.76	3.16	4.33	2.18	3.15
Pb	4.98	4.12	7.44	5.66	3.82	1.67	1.32
Ni	3.65	1.96	4.34	1.17	2.44	0.97	1.05
Cd	ND	ND	0.5	ND	ND	ND	ND
Cr	0.03	ND	0.37	ND	ND	ND	ND

**ND (not detected), minimum detection range was 0.01 mg/kg*

Bioaccumulation factor (BAF)

The plant samples were analyzed for their ability of removing HM from wastewater. The test results showed that the BAF value was greater than one for Cu, Pb, and Ni, indicating that both *A.d* and *T.l* can remove these metals (Table 2). For Cu, the maximum value is 8.64 for *T.l* in in-situ setup while the minimum value is 1.93 for *A.d* stem in ex-situ setup. Considering the average uptake of each plant, the BAF values become 2.84 and 4.78 in the ex-situ setup for *A.d* and *T.l* respectively, while 5.72 in in-situ condition for *T. l*. A phytoremediation study (Boularbah *et al*., 2006) used *A.d* along with other plant species for restoration of a mining contaminated site and reported 7.1 mg kg^{-1} Cu uptake. Based on average values of harvestable part of biomass (i.e. leaves and stem) *T.l* has better BAF than the *A.d*, the same pattern in favor of *T.l* for Cu uptake in term biomass was also reported by (Hejna *et al*., 2020).

Table 2: *Bioaccumulation factor for Typha latifolia and Arunda donax.*

Heavy metal	*Typha latifolia*				*Arundo donax*		
	In-situ		Ex-situ		In-situ		
	Roots	Leaves	Roots	Leaves	Roots	Stem	Leaves
Cu	5.70	3.87	8.64	2.80	3.83	1.93	2.79
Pb	7.01	5.80	10.48	7.97	5.38	2.35	1.86
Ni	8.90	4.78	10.59	2.85	5.95	2.37	2.56
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.11	0.00	1.37	0.00	0.00	0.00	0.00

In case Pb, the maximum value of 10.48 was observed for *T.l* roots in in-situ and a minimum value of 1.86 was for *A.d* leaves in ex-situ setup. The greater value of BAF for *T.l* roots than other parts of the species for Pb uptake was also reported by (Anning *et al*., 2018). Taking average uptake of each plant, the BAF values were 3.2 and 6.4 in the ex-situ setup for *A.d* and *T.l* respectively and 7.9 in in-situ conditions for *T.l*. It indicates that *T.l* shows high values of BAF than *A.d*.

For Ni, the maximum value was 10.59 for *T.l* in in-situ conditions and the minimum value of 2.37 is for *A.d* stem in an ex-situ setup. Considering the average uptake of each plant, the BAF becomes 3.63 and 6.84 in ex-situ setup for *A.d* and *T.l*, respectively, and 6.72 in in-situ conditions for *T.l*. Recently, Azizi *et al*. (2020) applied *T.l* and *A.d* for Cd, Ni, Zn, and Cu removal from sediments and reported that the *T.l* have better accumulation capacity as compared to *A.d*. As there is no Cd uptake in 6 out of 7 samples, therefore BAF for these 6 samples was zero. The BAF for the roots in field conditions goes higher due to the small concentration of Cd in wastewater. For Cr the BAF of three samples shows a little uptake, having values of 0.11 and 1.37 for *T.l* roots in ex-situ and in-situ conditions, respectively.

In-situ vs ex-situ heavy metals plants uptake

Overall, the samples from the in-situ setup showed more uptake than ex-situ samples for *T.l* (Figure 8). This might be due to the continuous supply of wastewater and presence of already accumulated metals in soil that was imported from the wastewater right of way. These results show an agreement with (Husnain *et al*., 2013) who carried out phytoremediation of heavy metals on sugar industry effluents and reported better accumulation of heavy metals (20-55%) in in-situ conditions. In ex-situ plantation setup, for Cu, 1.05 mg kg^{-1} and Pb 2.0 mg kg^{-1} more uptake was recorded for *T.l*. On part to the part basis of the same plant, *T.l* roots showed 2.46 and leave 1.54 mg kg^{-1} increase in in-situ for Pb, *T.l* showed approximately equal uptake of nickel in both conditions.

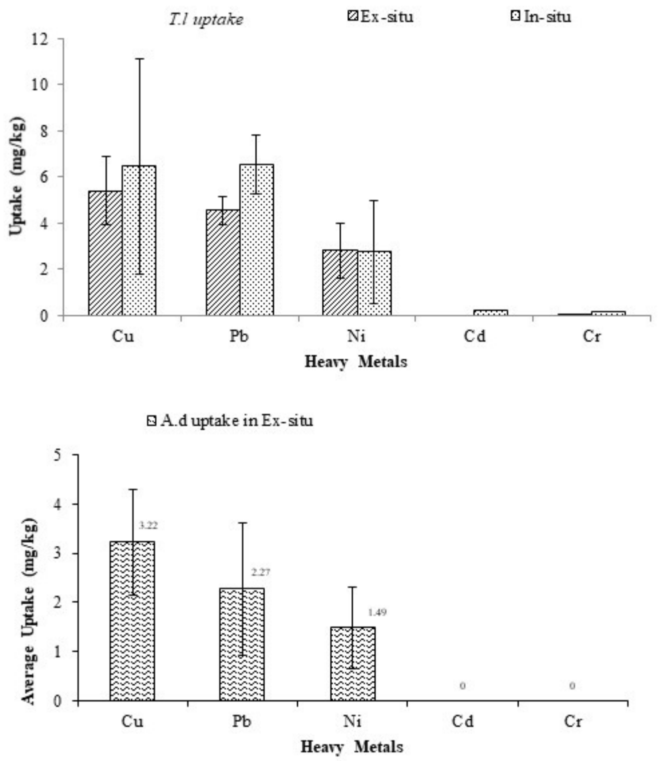

Figure 8: *Comparison of plants performance in ex-situ and in-situ conditions.*

Removal efficiency (RE)

The total amount of wastewater applied for irrigation in ex-situ setup was 2252 liters, out of this total volume 20 % (450 liters) were accounted for losses and 1801 liters were used by plants. As both, the seedbeds were on the same level and an equal amount of water was applied to each plant, on this basis water used by each plant became 901 liters. As the seedbeds were level and there were 19 plants of *A.d* and 24 plants of T. Latifolia, so, water used per plant of *A.d* became 47.4 liters and that of *T.l* became 37.5 liters. As we know the heavy metal concentration is one liter so the total heavy metals applied to each plant can be calculated by just multiplication of applied water per plant. Considering the average uptake of each plant for each metal the RE is calculated and shown in Figure 9.

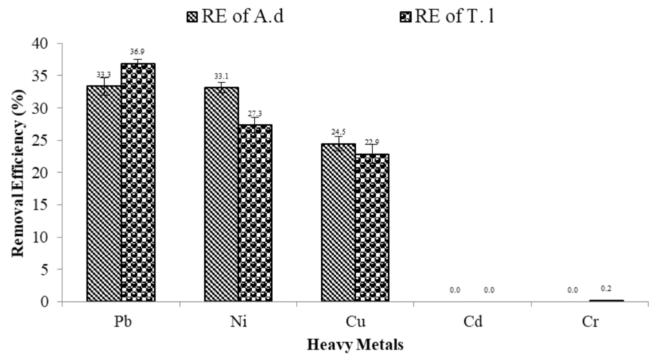

Figure 9: *Comparison of removal efficiency for Arundo donax and Typha latifolia.*

T.l showed higher efficiency of 36.9 % for Pb removal, while for Cu and Ni *A.d* showed better efficiency of 33 and 24.5%, respectively. For Cd and Cr no efficiency was calculated. Comparing RE of the same plant for each metal, *A.d* showed 33.3%, 33.1%, and 24.5% for Pb, Cu, and Ni removal respectively, while *T.l* showed 36.9%, 27.3%, and 22.9% for Pb, Cu, and Nickel respectively. Overall, the efficiency falls in the satisfactory category for Pb, Cu, and Ni. In a research study (Sun *et al*., 2013) *T.l* with other two species were used for phytoremediation of wastewater generated from an electrolyte industry and reported removal efficiency of 70-80% for Cu, Cr, Zn ad Mn. Another study (Morari *et al*., 2015) planted *T.l* with one other species on two wetlands receiving urban wastewater. Their experiment lasted for two years, and the results showed RE 91% for Cu and 88% for Pb. Ayaz *et al.* (2020) conducted a constructed wetland experiment for phytoremediation of industrial wastewater using four types of plant species including *T. Latifolia*. The removal efficiency for the Pb, Cu, and Cd was 81.0 %, 80.3 %, and 39.5%, respectively. The comparison shows that they recorded almost double efficiencies with the same pattern as found in this study Pb>Cu>Cd. Elhawat *et al.* (2014) reported 96.6 to 98.8 % RE of *A.d* for Cu from a synthetically contaminated aqueous solution.

Expected uptake 1 kanal plantation

According to a study (Angelini *et al*., 2005), 1 m^2 area planted with *A.d* can produce 3 kg of biomass, and therefore 1 Kanal (505 m^2) can produce 1515 kg of biomass. Based on the average uptake of *A.d* for each metal, the total uptake is shown in Table 3.

The maximum expected uptake will be for Cu of 4.88 kg $Kanal^{-1}$, and the minimum will be for Cr and Cd of 0 kg $Kanal^{-1}$. These show a clear direction in favor of phytoremediation use for the removal of the mentioned metals. It is one of the most profitable energy crops requiring little or no inputs for production and can produce 40 Mg ha^{-1} dry biomass annually. Its fresh biomass production may reach 59 Mg ha^{-1} having a high irrigation rate (700 mm $year^{-1}$) (EI-Bassam, 2010).

Similarly, according to Maddison *et al.* (2009), the average biomass production of *T.l* is about 20 tons ha^{-1} (1.83 kg m^{-2}) and 916 kg $Kanal^{-1}$. Considering average uptake at field condition the uptake of each metal is shown in Table 4.

Table 3: *Expected uptake of HMs from 1 kanal area by A. Donax.*

Metals	Average uptake in mg /kg	Area (m^2)	Biomass Produced (kg/kanal)	Total uptake in (kg/kanal)
Cu	3.22	505	1515	4.88
Pb	2.27			3.44
Ni	1.49			2.25
Cd	0			0.00
Cr	0			0.00

Table 4: *Expected uptake of heavy metals from 1 Kanal area by T. Latifolia plant.*

Metals	Average uptake (mg /kg)	Area (1kanal)	Biomass produced (kg/kanal)	Total uptake in (kg/Kanal)
Cu	6.46	505	916	5.92
Pb	6.55			6.00
Ni	2.76			2.52
Cd	0.25			0.23
Cr	0.19			0.17

Here the maximum uptake is for Lead of 6.0 kg $Kanal^{-1}$ and minimum for Cr of 0.17 kg $Kanal^{-1}$. This is just a glance of phytoremediation on a mega scale that can remove a significant amount of HMs when applied on a larger scale. Geurts *et al.* (2020) reported peak dry biomass production of 10-30 ton yr^{-1} ha^{-1} and can grow on a wide range of soils.

Local uses of T.l and A.d biomass

T.l biomass is used for various purposes on the commercial and domestic scale in the southern districts of Khyber Pakhtunkhwa, especially in Lakki Marwat. According to the locals, *T.l* plants are sold at PKR 0.5 million per acre. The main use is in brick kilns as a fuel, other domestic use includes making of shelters, fruit baskets, ropes, mats, and as combustion fuel in homes. There is a well-established business of ropes made from *T.l* leaves and are sold at PKR 500 per bundle in the market.

The *A.d* can sustain for 20 to 25 years once it is planted, it increases its density from year to year. The biomass produce has many local uses like, for construction purposes, making of musical instruments, as soil conservation agent, for domestic fuel, etc. Being a perennial crop *A.d* provides many ecological benefits such as better vegetation cover, soil conservation through its deep roots system, and no need for pesticides (Fernando *et al*., 2010). *A.d* has much potential as an energy crop and may be used for fuel and paper production (Fiorentino *et al*., 2013).

Suitable sites for phytoremediation downstream project area

There are many suitable sites within its right of way of wastewater stream to be used for phytoremediation, the following sites are visited and found feasible for this purpose. The details are shown in Table 5. The Google Earth© images of the above-given sites are also shown in Figure 10, indicating the perimeter by a boundary line.

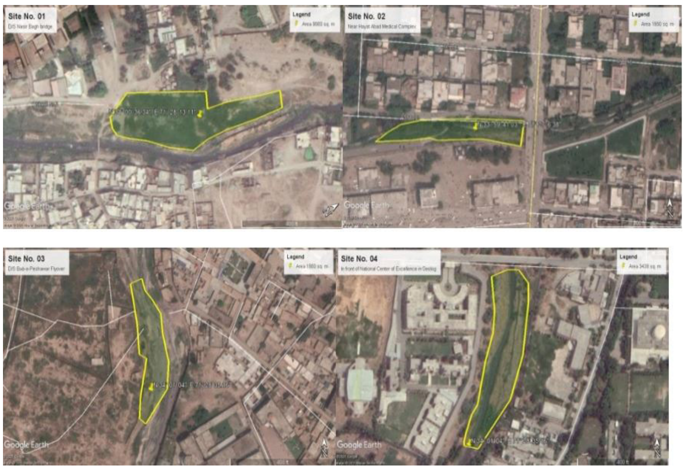

Figure 10: *Potential phytoremediation sites in the right of way of drain.*

The total area of the above sites becomes 33 kanal and based on previous calculations for the uptake of heavy metals from 1 Kanal, the total expected uptake is shown in Figure 11. The calculations show that a significant amount of heavy metals can be removed from the industrial wastewater by just utilizing these four sites and thousands of acres of agricultural land can be saved from heavy metals contamination.

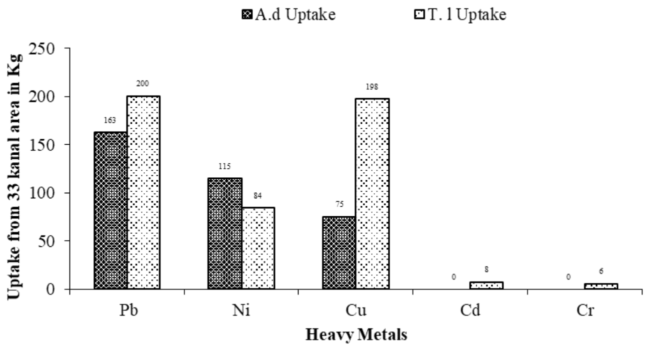

Figure 11: *Estimated heavy metals uptake by plantation.*

Conclusions and Recommendations

The laboratory analysis of industrial wastewater indicated that it contains heavy metals and exceeds the limits set forth by the FAO. The wastewater had concentration of 1.22, 0.41, 1.13, 0.19, and 0.27 mg L^{-1} for Pb, Ni, Cu, Cd, and Cr, respectively. Phytoremediation was applied in two sets of conditions, in laboratory conditions and in the right of way of stream. In order to estimate the phytoremediation capabilities of *T.l* and *A.d*, water collected from stream was applied for irrigation in the laboratory plantation, while for onsite a suitable inlet was installed to divert water to the plantation.

In an ex-situ setup, a total of 38 numbers of irrigations was applied with average water of 62 liters per irrigation and the total volume becomes 2251 liters. The results showed that both plants are suitable to remove heavy metals from the wastewater. In the ex-situ setup, the average uptake of Cu was 5.40 and 3.22 mg kg^{-1} for *T.l* and *A.d* respectively, while in the in-situ conditions the uptake was 6.46 mg kg^{-1} for *T.l*. Similarly, for the Pb average uptake was, 4.55 and

Table 5: *Coordinates and address of the potential phytoremediation sites.*

S. No	Address	Latitude	Longitude	Area (m^2)	Area Kanal
1	D/S Nasir Bagh bridge	34° 00' 36.34"	71° 28' 13.11"	9680	19
2	Near Hayat Abad Medical Complex	33° 59' 41.03"	71° 27' 6.38"	1950	4
3	D/S Bab-e-Peshawar Flyover	33° 59' 55.42"	71° 27' 36.27"	1800	4
4	Along the National Center of Excellence in Geology	34° 01' 04"	71° 28' 35.16"	3438	7

2.27 mg kg^{-1} in ex-situ for *T.l* and *A.d*, respectively, while in in-situ for *T.l* the uptake was 6.55 mg kg^{-1}. For Nickel, the average uptake was 2.80 and 1.49 mg kg^{-1} for *T.l* and *A.d* respectively in ex-situ setup, while in the in-situ condition for *T.l* the uptake was 2.75 mg kg^{-1}. No uptake was detected for Cd in the ex-situ setup while in-situ 0.25 mg kg^{-1} concentration was recorded for *T.l*. The Cr uptake was not detected in *A.d* while for *T.l* 0.02 and 0.19 mg kg^{-1} was detected in ex-situ and in-situ conditions, respectively.

In general, the metal uptake was higher in the in-situ setup for Cu and Pb as compared to ex-situ conditions. Among the plant parts, roots showed higher concentration for each metal uptake in both conditions. Overall *T.l* showed higher uptake for each metal than *A.d*. The BAF for Pb, Cu, and Ni was greater than 1, and for Cr and Cd, the BAF value was less than 1. *T.l* showed the highest removal efficiency of 36.9% for Pb, 27.3 for Ni, 22.9 for Cu, and 0 for Cr and Cd. The *A.d* RE was 33.3, 33.1, 24.5, 0, 0 % for Pb, Ni, Cu, Cd, and Cr, respectively.

Phytoremediation application on large scale was approximated based on, *A.d* and *T.l* average biomass production of 3 and 1.83 kg m^{-2} respectively, from 1 Kanal area. The expected total uptake of *A.d* was 4.8, 3.44, 2.25, 0, and 0 kg Kanal^{-1} and that of *T.l* was 5.92, 6.00, 5.52, 0.23, and 0.17 kg Kanal^{-1} for Cu, Pb, Ni, Cd, and Cr, respectively. Four potential phytoremediation sites were identified within the wastewater stream right of way, their coordinates and addresses are mentioned. The local biomass uses of *A.d* and *T.l* were also highlighted.

The KPEPA and PDA should take serious notice of the industries that are disposing their untreated wastewater to natural streams; the violators should be penalized under the (https://na.gov.pk/uploads/documents/Pakistan=Environmental-Protection-Act-1997.pdf). Industries producing heavy metals in their waste shall install the heavy metals recovery plant to prevent soil and water contamination. The wastewater stream right of way, wetland shall be constructed to reclaim the heavy metals from the soil and water.

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Novelty Statement

The research is focused on recovery of heavy metals from untreated mix wastewater generated from Hayatabad, Peshawar, Pakistan. Two locally available plant species *Arundo donax* and *Typha latifolia* were used for recovering hazardous heavy metals from the untreated wastewater. Both plant species showed encouraging results. The study has positive impact on human health and environment.

Author's Contribution

Noor Muhammad: Did field work, collected data, wrote original draft.
Tariq Mahmood Khalil: Conceptualization, methodology, supervision
Rashid Rehan: Supervision, funding, project administration.
Iftikhar Zeb: Wrote, reviewed and edited.

Data availability

The data that support this study will be shared upon reasonable request to the corresponding author.

Conflict of interest

The authors have declared no conflict of interest.

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