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# POTENTIAL OF CONSTRUCTED WETLANDS FOR THE TREATMENT OF HEAVY METALS FROM WASTEWATER

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## ABSTRACT

Overpopulation, urbanization, and economic race increase the pressure on freshwater resources resulted in water scarcity challenges around the globe. Moreover, the generation of wastewater also enhancing the scarcity threats for freshwater resources. Water scarcity issues forced the policymaker, thinker, scientist, and researcher to think about non-conventional water resources to cope with the increasing demands. Because of this wastewater recycling and treatment play an evident role to fulfill the growing demand for freshwater in socioeconomic sectors especially, for agriculture due to its 70 % dependency on freshwater resources. Different wastewater treatment methods along with merits and demerits are in practice for the socio-economic system. Constructed wetlands are environment friendly and cost-effective technology to remove metal and non-metal pollutants from contaminated water. This paper aims to compile information about heavy metals' effects and their treatment through constructed wetlands. It also reviews intensely the potential of different types of constructed wetlands by using different aquatic plant species for the removal of contaminants from wastewater.

**Keywords:** Water Scarcity, phytoremediation, wetland plants, heavy metals, water pollution.

## INTODUCTION

The magnitude of stress on water resources is increasing because of climate change. The overall water demand is increasing due to the higher use of water consumption. The wastewater production and its pollution loads are growing as a result of an increase in demand. Currently, agriculture is using 70 % of freshwater for crop irrigation (Khaver, 2017), and competition for other sources is expected to increase in the future. Pakistan is the world's fourth-highest water user and ranks third among countries facing water shortages, as reported by the International Monetary Fund (IMF). The per capita water availability in Pakistan is reduced from 1100 – 908 $m^3$ from the year 2006 to 2017 (Imran, Bukhari, and Gul, 2018), While it was about 5000 $m^3$ per year in the 1950s (Aziz et al., 2018). Therefore, non-conventional source i.e., wastewater has become important for irrigation purpose. Wastewater used for irrigation can have several benefits if properly planned, managed, and implemented. It is an important plant nutrient source for low-fertility soils. Wastewater irrigation can decrease the necessity for fertilizers (Lima et al., 2021). This wastewater could be used for irrigation purposes after treatment if it does not contain heavy metals in excessive amounts.

It is important to remove heavy metals or pollutants from wastewater in order to reduce the threat to human health and the environment. The wastewater can be treated through various conventional and non-conventional methods such as reverse osmosis (Al-

Alawy and Salih, 2017), ion exchange (Levchuk et al., 2017), chemical precipitation (Huang et al., 2017), adsorption, solvent extraction (Burakov et al., 2018), and membrane filtration system (Johnson and Rogers, 2005). However, among these techniques, most are less efficient and need high capital investment and time taking for the removal of unwanted toxic materials (Bolisetty et al., 2019).

An environmental friendly and cost-effective indigenous wastewater treatment technology is required for the treatment of heavy metal and contaminant-polluted wastewater (Ashraf, Afzal, Naveed, et al., 2018). In under-developed nations like Pakistan, constructed wetlands (CW) are a cost-effective, environment friendly and energy-efficient solution for wastewater treatment. Several processes such as microbial activity, adsorption, sedimentation, filtration, phytoaccumulation, and volatilization are used in CW to remove contaminants (Liu and Tran, 2021). Different aquatic floating plants play an important role in the detoxification process in CW by absorbing pollutants directly into their tissues. The potential of different types of CW by using aquatic plants is the focus of this review.

### *Water Scenario at Global and National Level*

The availability of freshwater resources in the world is declining due to the changing climate, as stated in the IPCC Fourth Assessment Report (Pörtner et al., 2022). The water runoff and availability are affected by the change in the extent and pattern of precipitation and temperature (Coulson et al., 2014). The competition for the allocation of water resources is expected to increase in the future due to climate change, with a major cut in the share of the agriculture sector. There is a 3 fold increase in global water use since 1950 and annual water demand is increased from 1.22 to 4.0 trillion cubic meters between the years 1950 and 2014 (Connor, 2015). Out of the total, about 70 % of total global freshwater is used for crop irrigation, 20 % is for industry and the remaining 10 % fulfills domestic needs (Khaver, 2017). The Organization for Economic Co-operation and Development (OECD) projected that global water demand would increase by 55 % between the years 2000 and 2050, mainly because of increasing requirements in manufacturing (4 fold), thermal power generation (1.4 fold), and domestic sectors (1.3 fold) (Manders et al., 2012). Therefore, in the future, there will be lesser water available for agriculture due to increasing demand in other sectors.

Pakistan ranks third among countries facing water shortages, as reported by the IMF (Nabi et al., 2019). Approximately 192 MAF of water each year comes from the Indus River and its tributaries, of which 96 MAF is used for irrigation, 36 MAF flows to the sea, and the remaining 10 % is absorbed by system losses such as seepage and evaporation. The per capita water availability is also reduced from 1100 to 908 cubic meters between the year 2006 to 2017 (Imran, Bukhari, and Gul, 2018). With an increase in overall water use, wastewater production and pollution load are also continuously increased (Connor et al., 2017). Therefore, there is a need to explore the possibility of irrigation with wastewater after treatment. In Pakistan, excessive pumping of groundwater results in the lowering of the water table beyond its sustainable limits. Much of the water that is used in domestic and industrial sectors is returned to the system as wastewater, which is further polluted by the surface water bodies (Qureshi and Ashraf, 2019).

Pakistan produces 6.414 billion $m^3$ of wastewater per year, of which 4.953 billion $m^3$ comes from municipal sources and 0.395 $m^3$ comes from industry (Yamin et al., 2015). A total of 0.876 billion cubic meters of wastewater is used in agriculture out of total wastewater production (Murtaza et al., 2010) which irrigates about 32500 ha of land. It has been estimated that about 26 % of vegetables are produced by using wastewater irrigation (Norton-Brandão et al., 2013; Naz et al., 2016). The main reasons for the use of untreated wastewater for irrigation are the shortage of canal water, the increase in soil organic matter, its continuous availability throughout the year, low cost, and improved plant growth. The city of Multan has wastewater discharge of 66 × 106 $m^3$ per year (Kahlown et al., 2006). The livelihoods mainly depend upon agriculture and the area is irrigated by the canals which are already polluted with sewage wastewater.

### *Wastewater Sources*

Water, which is an essential need of all living beings, is currently polluted by several natural processes and human activities (Hussain and Asi, 2008). Water contamination is mostly caused by by-products of numerous industries, including metal, pesticides, textiles, cement, energy, and electricity, dying, leather, food production, and so on (Irfan, 2009; Awan et al., 2012; Mahmood et al., 2019). Agriculture also contributes significantly to water pollution due to agricultural practices such as fertilizer and pesticides, as farmers apply different nutrients like potassium, nitrogen, and phosphorous as chemical fertilizers or manure. When these nutrients exceed the plant's needs can wash out into the waterways. Different studies show that there is a presence of different pesticides in freshwater (Mahboob et al., 2014; Mahmood et al., 2014; Ali et al., 2016) surface water (Ahad et al., 2006), and shallow water sources (Muhammad et al., 2015). Wastewater from households is also polluting the water sources as it contains soap, grease from sinks, surfactants, and dirt, etc.

### *Wastewater Effects on the Ecosystem*

The disposal of untreated wastewater into surface water bodies is disturbing the entire ecosystem (surface and groundwater, soils, crops, livestock, aquaculture, and the human) (Imran, Bukhari, and Ashraf, 2018). About 245,000 $km^2$ of the marine ecosystem, and fisheries, livelihood in peri-urban zones, and food chain are affected by the disposal of wastewater into the water bodies (Corcoran, 2010). The consumption of food produced in peri-urban areas by using sewage wastewater is a serious threat to public health (Singh et al., 2010). Toxic levels of heavy metals in crops and vegetables deteriorate food quality and pose serious health is to consumers (Murtaza et al., 2015). The use of vegetables by humans, produced with wastewater can lead to the depletion of nutrients in the human body and cause disabilities with malnutrition, immunological disorders, intrauterine growth retardation, and upper gastrointestinal cancer. Wastewater irrigation without treatment to land for prolonged periods raises the accumulation of HMs at toxic level in the soil (Paul, 2017). Using untreated wastewater can also cause soil hardening and contamination of shallow groundwater tables (Li et al., 2018).

#### *i. Components of Wastewater*

The organic components of the wastewater may comprise fats, grease, pesticides, surfactants, phenols, proteins, oils, and carbohydrates. While, inorganic components involve chlorides, phosphorus, sulphur, nitrogen, and heavy metals like zinc (Zn), copper (Cu), lead (Pb), arsenic (As), cadmium (Cd), selenium (Se), nickel (Ni), chromium (Cr), and vanadium (V) (Liu and Lipták, 1999).

### *Deleterious Effects of Heavy Metals*

#### *i. Arsenic*

Arsenic is a unique element having distinct properties and toxicity that is well recognized for its role in public health (Hong et al., 2014). Arsenic has been identified as a carcinogenic agent due to its link to skin and lung cancers in humans (Martinez et al., 2011). In Pakistan, the provinces of Punjab and Sindh have the highest concentrations of arsenic in ground and surface water. In Punjab and Sindh, respectively, 3 and 16 % of water supplies are contaminated with As above a level of 50 mg/L, while arsenic levels above 10 mg/L are found in 20 and 36 % of Punjab and Sindh's water supplies, respectively (Saqib et al., 2013).

### *ii. Cadmium*

Cadmium (Cd) is a toxic metal that occurs naturally in the environment as well as a pollutant from agriculture and industry. It is the most toxic element to which a man can be exposed in the environment or at work. Once ingested, Cd is retained in the human body and accumulates over time (Bernard, 2008). Cadmium can affect bones either directly or indirectly through its effects on bone tissue (Järup and Åkesson, 2009). Cd concentration in Pakistan is high in drinking water due to effluent discharged from the steel, aluminum, and marble industries (Tariq et al., 2006). Cd levels of wastewater exceeded the NEQS acceptable range of 0.18 to 0.37 mg/L (Mahmood and Malik, 2014).

### *iii. Lead*

Lead toxicity is a serious environmental disease with serious health consequences. Lead exposure affects every function of the human body (Patrick, 2006). Increased oxidative stress has a variety of negative effects on the renal, reproductive, hematopoietic, and central nervous systems (Flora et al., 2012). Over half of the studies show that lead (Pb) concentrations in wastewater samples are higher than the permissible level, which is 0.50 mg/L set by Pakistan's National Environment Quality Standard (Waseem et al., 2014). The highest level of lead pollutant (2.34 mg/L) was found in a sample from textile industries in KPK (Manzoor et al., 2006).

### *iv. Nickle*

Nickel is abundant in the atmosphere (air, water, and soil), and it can come from both natural and anthropogenic sources (Genchi et al., 2020). Contact from Nickle can cause various effects on human health such as cardiovascular, lung fibrosis, kidney disease, allergy, and lung cancer (Oller et al., 1997). The highest value of Ni was found in a sample of wastewater taken from Lahore to check the effect on vegetables. The values between 0.91 and 5.94 mg/L were found to be higher than the acceptable limit of 1.0 mg/L set by Pakistan's National Environmental Quality Standards (Mahmood and Malik, 2014).

### *v. Copper*

Copper is important for human health and also toxic depending upon the ingested amount. It is associated with immune function, cardiovascular risk, and bone health, and cholesterol metabolism (Araya et al., 2007). A study from Lahore, Pakistan reported that Cu content in vegetables (Spinach) irrigated with wastewater contains 5.77 mg/kg on contaminated soil. Leafy vegetables, according to the study, have a greater ability to remove heavy metals from the soil (Mahmood and Malik, 2014).

### *vi. Chromium*

Chromium is a naturally abundant element that is found in plants, rocks, soil, animals, and volcanic dust (Wilbur et al., 2012). Chromium is carcinogenic and health hazards associated are nasal ulcers, skin allergies, bronchial asthma, and developmental problems. It may cause death if taken in an excess amount (Chatterjee, 2015). Cr levels in samples from different parts of Pakistan range from 0.001 to 9.8 mg/L. In Kasur, Punjab province, the maximum mean value was 2.12 mg/L from well water (Tariq et al., 2008). Whereas 0.16–0.29 mg/L was reported from surface water contamination from Nowshera, KPK province, both studies show industrial wastewater's impact on water quality.

### *vii. Iron*

Iron ranks 4th among all the elements present on the earth's surface and occurs in abundance (Dodd, 2020). Iron overload in the body can lead to an accumulation of iron in the liver and other organs, as well as the production of free radicals, which can damage cells and tissues (Yuen and Becker, 2021). This increases the chances of certain cancer. The permissible limit set by NEQS for Fe is 8 mg/L and analysis from different regions of Pakistan shows that most areas are under safe limits with few exceptions (Manzoor et al., 2006).

## *Constructed Wetlands*

A constructed wetland is a biogeochemical, efficient and reliable approach for removing contaminants from wastewater discharged from a variety of point and non-point sources (Uysal, 2013).

Different aquatic floating plants play an important role in the detoxification process in CW by absorbing pollutants directly in their tissues. These plants use physicochemical and biological methods to remove pollutants from wastewater (DalCorso et al., 2019), which helps in the remediation process (Khan and Faisal, 2018). Various studies are reported with many combinations of various types of CW, vegetation, and their pollutant removal efficiency from the wastewater (Table 1).

## *Potential of Some Wetland Plants*

The major wetland plant used to treat wastewater includes *Lemna gibba* (duckweed) (Demim et al., 2014), *Eichhornia crassipes* (Water hyacinth) (Rizwana et al., 2014), *Typha latifolia* (cattail), *Pistia stratiotes* (water cabbage) (Prajapati et al., 2012; Iqbal et al., 2019), *Bacopa monnieri* (Borker et al., 2012; Badejo et al., 2015) *Centella asiatica* (Pennywort) (Hanafiah et al., 2020) and *Alternanthera philoxeroides* (Alligator weed) (Rane et al., 2015).

### *i. Lemna gibba (Duckweed)*

*L. gibba* commonly known as duckweed is a floating aquatic macrophyte and is mainly found on the surface of water (Zimmo, 2003). It can be found in a variety of aquatic habitats, including lakes and rivers. The removal of heavy metals from duckweed was over 80 % for all HMs, and a maximum value of 99 % was observed for nickel (Bokhari et al., 2016). All the physicochemical parameters of the domestic wastewater were significantly decreased after the seven days of culture of duckweed (Patel and Kanungo, 2010). It is reported that it have higher pollutant removal efficiency for N, P, K, and other HMs. (El-Din and Abdel-Aziz, 2018).

### *ii. Pistia stratiotes (Water cabbage)*

It is a free-floating aquatic plant found in lakes, streams, and ponds. It has the potential to remove nutrients and heavy metals from sewage sludge and drainage ditches. It is highly suitable to treat wastewater in tropical areas (Fonkou et al., 2002). It has great potential for heavy metals uptake (Cu, Zn, Fe, Cr, and Cd) developing no reduction in growth due to HM's accumulation (Khan et al., 2014). Accumulation of Cr and Cu was observed by using *P. stratiotes* was 85 mg and Cu was 96 mg (Tabinda et al., 2018). Schwantes et al., 2019 evaluated the removal efficiency of *P. stratiotes* from the domestic sewage, and the bioaccumulation of Ca, K, Mg, Zn, Cu, Fe and Pb has been detected in the living tissues of *P. stratiotes.*

### *iii. Phragmites austrilus (Reed)*

The most extensively distributed emergent plant species in the world, used for phytoremediation of different wastewater, sediments, and soil (Rezania et al., 2019). Its worldwide occurrence, tolerance to the varied environment is an ideal choice for phytoremediation (Shakeel Ahmad et al., 2014). To measure the removal efficiency of different plants, a trial was done in which they found that 19.07 % (Pb), 10.67 % (Zn), and 23.27 % (Cu) were removed through *P. austrilus* (Hemamalini et al., 2019).

### *iv. Typha latifolia (Cattail)*

*T. latifolia* is the most common aquatic plant that plays an important role in filtering the runoff and can accumulate heavy metals in their tissues. To check the efficiency of *T. latifolia* in CW for the uptake of heavy metals, a study was performed, and the result shows that *T. latifolia* removed 83 % Cu and 92 % Zn (Yeh et al., 2009). The efficiency of *T. latifolia* through CW was observed for the removal of HMs from industrial wastewater. The removal efficiency of *T. latifolia* was 83.6 % for Cu, 96.2 % for Cd, and 95.9 % for Pb respectively (Ayaz et al., 2020).

### *v. Eichhornia crassipes (Water hyacinth)*

*E. crassipes* is used in the phytoremediation of wastewater on sites contaminated with copper and lead (Liao and Chang, 2004). It is the most productive plant that produces a good amount of biomass (Abd.Razak et al., 2014). A Study by Mishra and Tripathi, 2009**,** shows that it is efficient in the removal of zinc and chromium. To assess the efficacy of phytoremediation, *E. crassipes* were used to observe Cr and Cu accumulation. Cr uptake in the roots and leaves of *E. crassipes* was 90 mg, 53 mg, and Cu was 86 mg, and 50 mg, respectively (Tabinda et al., 2018).

## CONCLUSION

Since toxic heavy metal pollution of water is a serious environmental issue, successful remediation techniques are necessary. The use of physical and chemical methods to treat heavy metal-contaminated water has significant drawbacks. Constructed wetlands, which use a variety of species or combinations of species, have proven to be a flexible treatment option for a variety of wastewaters. The uptake of heavy metals by plants using phytoremediation technologies appears to be a promising way to treat heavy metals-contaminated water. It is a solar-driven system that is both environmental sustainable and ecologically responsible, and it has a high level of public acceptance. When compared to other widely used conventional technologies, it has several advantages. To achieve a high level of remediation efficiency, many factors must be considered. Most importantly, further research is required to better understand each species' potential, with the goal of determining which species or groups of species are best suited to each form of waste. Another highlight is the selection of new species across continents, as many species with significant potential for treating effluents are possibly unknown due to the variety of flora on the planet.

### *Data Availability Statement*

The authors confirm that the data supporting this study is available with this article as the supplementary material (S1).

## AUTHOR CONTRIBUTION

Hasnain Raza and Qurat ul Ain contributed equally to this review paper as primary authors. They conceptualized the study and designed the framework. Hasnain Raza conducted the literature review and drafted the manuscript. Qurat ul Ain reviewed and revised the manuscript for critical intellectual content. Tehmina Bibi contributed to the literature review of the manuscript. Haseena Bibi provided about the manuscript for accuracy and completeness. Huda Bilal formatted the manuscript and give the expert opinion. All authors have read and approved the final manuscript.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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