Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2022.28536

261 (2022) 76–82
June

Innovative approach of sewage water restoration with vetiver grass (*Chrysopogon zizanioides*) in North India

Kunal Adhikary[a,b,*], Tapas Mandal[a], Jayoti Majumder[a], Rajkumar Jat[c]

[a]*Department of Floriculture and Landscape Architecture, Faculty of Horticulture, Bidhan Chandra Krishi Vishwavidyalaya, Mohanpur 741252, Nadia (WB), India, emails: kunalmanik102@gmail.com (K. Adhikary), tmbckv@gmail.com (T. Mandal), jayotisarkar1@gmail.com (J. Majumder)*
[b]*Department of Horticulture, School of Agriculture, ITM University, Gwalior Madhya Pradesh*
[c]*Department of Horticulture, College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar-263145 Uttarakhand, India, email: rajrulez95@gmail.com (R. Jat)*

Received 28 October 2022; Accepted 22 April 2022

ABSTRACT

Water pollution is a big concern in today's world, and it is particularly acute in a few Indian states. Water pollution causes serious health problems as well as a loss of output and crop/soil production. A study was conducted in the village of Kala Sanghian in Jalandhar, Punjab, where residents are exposed to numerous health risks as a result of contaminated water. To address the problem, an experiment based on the floating garden concept was set up to reduce wastewater pollution. The research is primarily focused on the phytoremediation efficacy of vetiver grass. Concentrations of various elements such as Al^{3+}, Cr^{6+}, Fe^{3+}, Zn^{2+}, and Pb^{2+} were measured in the control and experimental plots. The root of the vetiver grass has the following uptake ability: $Fe^{3+} > Al^{3+} > Cr^{6+} > Zn^{2+} > Pb^{2+}$. The bioconcentration factor value of the experimental plot for Pb^{2+} (2.2826) and Cr^{6+} (108.72) is significantly higher than the control (0.4651 and 40.711, respectively). Translocation factors (TF) greater than one indicate that the plant is effective at transporting that particular metal from root to shoot tissue. The range of TF in control plot is (1.5 to 0.19) and for experimental plot it is 0.09–0.7. The presented results could be compared to "rhizofiltration", which is the removal of aqueous pollutants by the plant root system.

Keywords: Vetiver grass; Translocation factor; Bioconcentration factor; Phytoremediation; Water treatment

1. Introduction

Rapid industrialization (e.g., dyes, paper, thermal power plants, pharmaceutical, paint, cement, sugar industries, etc.) has resulted in the generation of increasing amounts of wastewater over the last 40–50 y. Organic matter, inorganic matter, and heavy metals are abundant in discharged wastewater. Wastewater is any type of water that has had its physicochemical properties harmed by anthropogenic, or man-made, activities. Wastewater is defined as liquid waste discharged by residential homes, commercial properties, industry, and/or agriculture. Petroleum hydrocarbons, chlorinated hydrocarbons, heavy metals, acids, alkalis, dyes, detergents, and other chemicals all have a significant impact on the physicochemical properties of water [1].

Punjab, India's northwest state, covers 5.03 million ha and is located between 29° 33′–32° 31′ N latitude and 73° 53′–76° 55′ E longitude. The state's geographical area is cultivated to the tune of 84%, which is a national record. Irrigation covers 4.04 million ha, or about 95% of the net sown area. Tube wells irrigate 72% of the land, canals irrigate 23%, and rainwater irrigates the remaining 5%. The following is a breakdown of operational holdings: 19% of landowners have less than 1 ha, 46% have 1–4 ha, 28%

---

* Corresponding author.

have 4–10 ha, and 7% have more than 10 hectares. Despite accounting for only 1.53% of the country's total land area, Punjab produces 20% of the country's wheat, 11% of its rice, and 13% of its cotton. Punjab contributes approximately 65% of wheat and 42% of rice to India's food grain pool, earning it the moniker "food basket of the country" [2].

Anthropogenic activities such as mining, smelting, untreated sewage disposal, and the use of pesticides and fertilisers in agriculture have been increasing the concentrations of potentially toxic trace elements in the environment year after year [3]. Trace element pollution of soil, water, and air is one of the most serious environmental issues, with serious consequences for both environmental quality and human health [4]. Heavy metal pollution in the environment can be attributed to both natural and anthropogenic sources. Weathering of minerals, erosion, and volcanic eruptions are the main natural contributors, whereas mining, agricultural activities, smelting, electroplating, sludge dumping, industrial effluents, and so on are the main anthropogenic contributors. Even at very low concentrations, heavy metals have a negative impact on human and mammalian health [5].

Alternative approaches include plant-based technologies, commonly referred to as phytoremediation, which are considered environmentally friendly, non-invasive, energy-efficient (primarily solar-powered), and cost-effective for remediating sites with low-to-moderate trace element concentrations. However, if phytoremediation is chosen to clean up trace element pollution, the question is which type of plant is best suited for the job? There is no general answer to this question because there are different options for different cases [6]. Grasses used for biofuel or fibre production, as well as grasses used for animal feed (in this case, the forage produced cannot be used as animal feedstock), are potentially suitable candidates for phytostabilization and, in some cases, phytoextraction, because most species have extensive root systems (allowing for the exploration of large soil volumes), high biomass yields, fast growth rates, adaptations to soil infertility, and successive shoot regrowth [7]. The most important trace elements in the context of environmental pollution are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn) (He et al., 2015). These trace elements can be classified as essential (Cu, Ni, and Zn) or non-essential (As, Cd, Cr, Hg, and Pb) for plants, but both essential and non-essential trace elements can be toxic, even at low concentrations [8,9].

The various types of phytoremediation that plants use during their remediation processes include phytoextraction, phytostabilization, phytodegradation, rhizodegradation, rhizofiltration, and phytovolatalisation [10]. Phytoextraction and phytostabilization are two of the most well-known techniques used by plants for heavy metal remediation [11]. Phytoextraction refers to the uptake of heavy metals by plant roots and their translocation to aboveground biomass, whereas phytostabilization refers to the immobilisation or reduction of metal mobility. Metals could accumulate in the roots, be adsorbed on the root surface, or precipitate around the root zone during this process. Plants with a fast growth rate, a large biomass production, and a high tolerance to heavy metals are said to be ideal for the phytoextraction process [12], whereas plants with a well-developed root system, a high tolerance to heavy metals, and a low root to shoot translocation capacity are good candidates for phytostabilization [11].

Vetiver grass (*Chrysopogon zizanioides* L.) is a grass related to maize, sorghum, sugarcane, and lemon grass. It is native to tropical and subtropical India, and it is one of the most common Vetiver grass species in South and Southeast Asia. There were numerous accessions of vetiver ia *zizanioides* (L. Nash) and other vetiver species such as *Chrysopogon fulvus* (Spreng.), *C. gryllus*, *Sorghum bicolor* (L.), and *Sorghum halepense* in addition to *Chrysopogon zizanioides* L. Because the genera vetiver and *Chrysopogon* cannot be distinguished based on Random Amplified Polymorphic DNAs (RAPDs), they were merged. *Vetiver zizanioides* (L. Nash) has been renamed *Chrysopogon zizanioides* (L Roberty), with chromosome base numbers of $x = 5$ and 10, $2n = 20$, and $2n = 40$ [13].

The major source of concern in the proposed study site is that untreated drain water is used for irrigation by the majority of farmers, despite the fact that it has been reported that consumption of polluted groundwater has left a large number of people suffering from various diseases, including cancer. Despite the fact that ground water in Punjab is insufficient for drinking, its excessive use for irrigation is causing a serious water crisis. It has been discovered that more than 75% of the total geographical area in Punjab is overdeveloped in terms of ground water development [14]. Contamination of agricultural soils by wastewater application poses health risks due to the presence of PTEs, which has long-term environmental and health implications [15]. The consumption of polluted groundwater has resulted in a large number of cancer cases, with the villages of Gazipur, Allowal, Badshapur, Mehmuwal Mahla, Kohar Kalan, Athola, Mandala Chana, Gidderpindi, Bahmania, Madala, Isewal, and Namajepur in Jalandhar District bearing the brunt of the burden. Tumour and cancer cases, as well as stomach, eye, skin, and respiratory issues, are common among residents of Jalandhar villages near the Kala Sanghian Drain (Fig. 1).

To address the pollution issue, a phytoremediation system with semi-aquatic grasses for wastewater treatment was used, which was a novel and innovative approach. They are natural, green, practical, easy to use, and inexpensive. Recent studies have shown that vetiver has the ability to absorb and tolerate toxic levels of nutrients [16]. As a result, a study was carried out in a specific location, Kala Sanghian Drain – Jalandhar, with a floating garden made of vetiver grass. The primary goal of this approach was to comprehend the accumulation of heavy metal ions by the roots of vetiver in comparison to the cleansing of irrigation water.

2. Materials and methods

Kala Sanghian Drain in Jalandhar District, with latitude 31.32, longitude 75.51, and altitude 224 m, was chosen for the study. We have a water treatment plant at the chosen location, but it is not functioning properly, resulting in a reduction in pollution control efficiency. As a result, we employ and are increasingly concerned with integrated and interdisciplinary approaches to sustainability, such as

Fig. 1. Poor condition of irrigation water (A) treated sewage water again dump into the poor and old streamlets, (B) leather industries effluent wastes dump into the drain and (C) small drain streamlets within the farmer's fields.

physical, biological, social, and mechanical approaches. This is an example of a creative and long-term pollution control strategy (Figs. 2 and 3).

A study was carried out in the proposed area in the year 2019-20. Kala Sanghian village is in Punjab's Jalandhar District. Agriculture, such as the cultivation of vegetables and cereal crops, is thriving in this area. As illustrated in the paper, small-holding farmers continued use of untreated sewage water for irrigation results in soil and crop contamination.

The importance of proper GPS location monitoring prior to the application portion cannot be overstated. We are primarily concerned with the use of bio flora and natural bio filters (plants such as vetiver grass) to reduce pollution and then reuse it to produce revenue. The next stage is to create a work plan after obtaining the right Geo-location map (Fig. 4). Sewage water treatment can be accomplished in a variety of ways, including physical means such as correct aeration in a water body, mechanical methods such as manual cleaning of water streamlets, and biological approaches such as phytoremediation, in which we employed vetiver grass to recover wastewater. To limit the level of pollution at the experimental site, a small moving island model was created using vetiver grass (Fig. 5). In Fig. 6, a graphical abstract of the concept was also shown, which clarified the concept of sewage water treatment using a movable model of vetiver grass.

The biological oxygen demand (BOD), chemical oxygen demand (COD), bioconcentration factor (BCF), and translocation factor (TF) of the collected treated sewage water samples utilised for irrigation were investigated chemically. The ratio of concentration of metallic elements in plants tissue (roots and shoots) of those in contaminated sites was estimated, which is also known as the BCF. The TF was developed to determine the movement of metallic elements from the plant's root to its shoot.

$$\text{Bioconcentration factor (BCF)} = \frac{\text{Metal conc. in the plant parts (mg/kg)}}{\text{Metal concentration in sample (mg/kg)}}$$

$$\text{Translocation factor (TF)} = \frac{\text{Conc. aerial}}{\text{conc. root}}$$

We collected samples of water (media), leaves, and roots. Water samples were collected on days 0 and 28 to determine BOD and COD. Leaf samples were collected for metal content determination on days 0, 14, and 28 of both uptake and elimination conditions. Root samples were also collected on day 0 and day 28 in both uptake and elimination conditions to determine metal content. As additional supporting data, water acidity (pH), water temperature, humidity, and air temperature were collected.

Vetiver plants were harvested and split into roots and shoots in the experimental area. To eliminate any silt particles adhered to the plant surfaces, plant samples were thoroughly washed with running tap water and rinsed with deionized water. Plant tissue samples were oven dried to a consistent weight at 700°C, then ground into powder and stored in paper bags in desiccators for further examination. The samples were digested according to the "AOAC Official Method 985.01" as described by the AOAC (2002). Using argon and nitrogen gases, metal concentrations in wastewater and plant samples were evaluated using Inductively Coupled Plasma ICP-OES (Perkin Elmer, Optima 2000 DV).

The experiment's design is LSD. There is one experimental site (with vetiver grass) and one control (without vetiver grass) site with a total of five treatments and four replications. The primary elements that are estimated for the intended experiment are Al^{3+}, Cr^{6+}, Fe^{3+}, Zn^{2+}, and Pb^{2+}.

To determine the mean, SD, significance, and correlation coefficients, all analysis findings (averaged across four replicates) were statistically treated. Using the R-package doebioresearch v. 0.1.0, the LSD design analysis and the least significant difference test were carried out [17]. In Excel, BOD and COD were used for a t-test mean comparison test. The correlation study was carried out with the help of the R-package psych v 2.1.9 [18].

3. Results and discussion

We have two plots from the experiment: one is the control plot (without vetiver grass), and the other is the

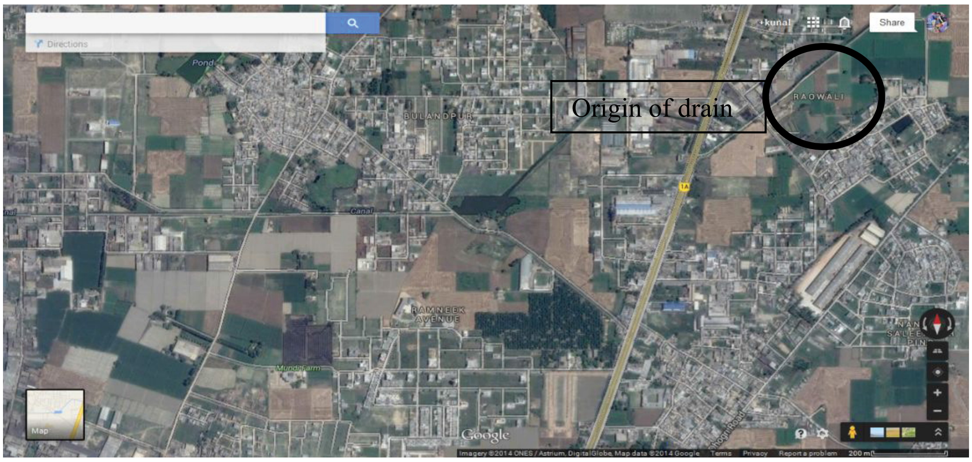

Fig. 2. ArcGIS map of the Kala Sanghian Drain in Jalandhar District. (https://www.arcgis.com/home/webmap/viewer.html?useExisting=1).

Fig. 3. ArcGIS map of the Kala Sanghian Drain in Jalandhar District. Untreated sewage water is used as an irrigation (https://www.arcgis.com/home/webmap/viewer.html?useExisting=1).

experimental plot (with vetiver grass) that contains the moving vetiver garden (Fig. 5) island for phytoremediation. Normally grown aquatic weed *Typha* (*Typha latifolia*) was taken for sample analysis in the control plot, and vetiver was specially forced for sample analysis and further comparison in the other phytoremediation plot.

Table 1, is the representation of the accumulation of Al^{3+}, Cr^{6+}, Fe^{3+}, Zn^{2+} and Pb^{2+} in the root and shoot parts of *Typha* grass in the control plot and vetiver in the treatment plot. It was also discovered that the concentrations of all the elements examined in the plant parts were significantly higher ($p < 0.05$) in the experimental plot than in the control plot, particularly in the root accumulation part. When untreated sewage water is used for irrigation, it has a direct impact on crop health. According to previous research, the toxic effects of Al^{3+} on plants include a decrease in chlorophyll pigment quantity, which is accompanied by a significant decrease in photosynthetic rate [19].

The results of the experiment show that metal accumulation is greater in the roots of the experimental plot plants than in the control plants. Root metal accumulation for Al^{3+}, Cr^{6+}, Fe^{3+}, Zn^{2+} and Pb^{2+} were 233.78, 110.64, 311.08, 29.24, and 4.33 mg/kg in the control plot, and 342.97, 296.18, 457.77, 133.73, and 21.54 mg/kg in the experimental plot. It has also been observed that metal accumulation is greater in the root than in the shoot, indicating rhizofiltration by the roots of the vetiver grass.

Metal accumulation in the shoot is lower in the control plot (46.29, 56.72, 77.05, 21.86, and 7 respectively), whereas it is higher in the experimental plot with vetiver grass (34.25, 23.80, 69.26, 10.06, and 0.44). The root of the vetiver grass has the following uptake ability: $Fe^{3+} > Al^{3+} > Cr^{6+} > Zn^{2+} > Pb^{2+}$. Previous research on the accumulation of various metal ions by aquatic and semi-aquatic plants revealed that the accumulation of most metals was higher in roots than in other parts of the plant [20,21].

The BCF is a common term, but it is an important factor to consider when assessing the phytoremediation potential of a given plant sample [22]. Table 1 in this report shows the BCF values of the elements. In general, if BCF is greater

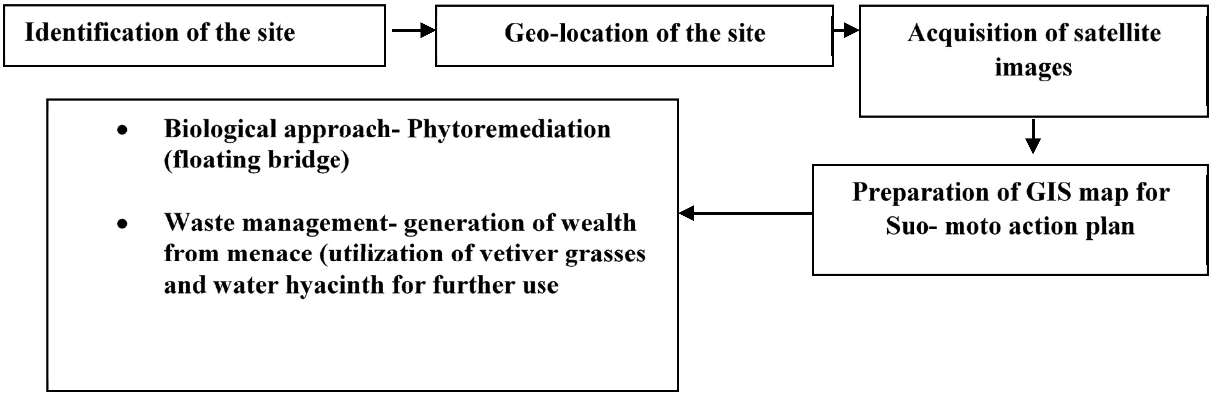

Fig. 4. Flow diagram of the work plan for treatment of sewage water.

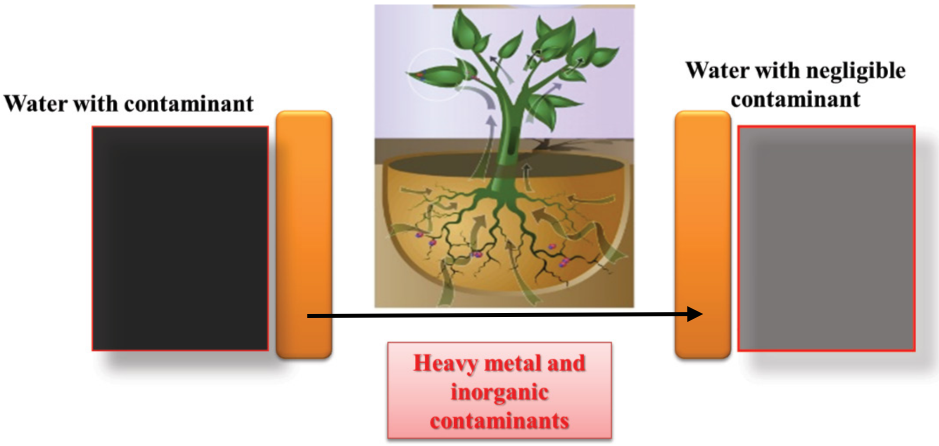

Fig. 5. Diagrammatic view of the concept.

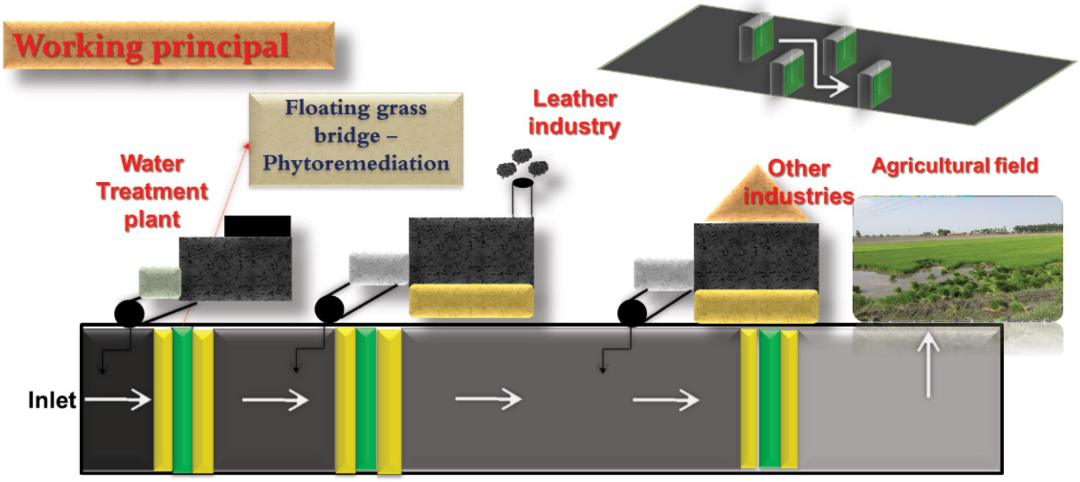

Fig. 6. Graphical abstract of the movable vetiver grass garden.

Table 1
Comparative study of plant and phytoremediation attributes

	Control (without vetiver grass)					Experimental plot (with vetiver grass)				
	Root, mg/kg	Shoot, mg/kg	BCF (CS/W)	BCF (CR/W)	TF (Control)	Root	Shoot	BCF (ES/W)	BCF (ER/W)	TF (EXP.)
Al^{3+}	233.78 ± 10.22^{b}	46.29 ± 1.57^{c}	6.61 ± 0.44^{b}	32.77 ± 1.95^{b}	0.29 ± 0.10^{c}	342.97 ± 1.75^{b}	34.25 ± 0.66^{b}	5.46 ± 0.69^{b}	48.86 ± 1.31^{b}	0.10 ± 0.01^{c}
C^{r6+}	110.64 ± 1.17^{c}	56.72 ± 1.43^{b}	21 ± 1.78^{a}	42.57 ± 1.68^{a}	0.7 ± 0.20^{b}	296.18 ± 3.38^{c}	23.80 ± 1.92^{c}	8.73 ± 0.38^{a}	110.24 ± 1.65^{a}	0.8 ± 0.07^{a}
Fe^{3+}	311.08 ± 4.47^{a}	77.05 ± 2.61^{a}	6.71 ± 0.33^{b}	26.49 ± 1.33^{c}	0.34 ± 0.08^{c}	457.77 ± 2.34^{a}	69.26 ± 0.64^{a}	5.94 ± 0.20^{b}	38.63 ± 1.18^{c}	0.17 ± 0.02^{b}
Zn^{2+}	29.24 ± 1.64^{d}	21.86 ± 1.86^{d}	5.3 ± 0.60^{b}	6.83 ± 0.20^{d}	0.84 ± 0.08^{b}	133.73 ± 2.40^{d}	10.06 ± 0.90^{d}	2.81 ± 0.55^{c}	32.04 ± 0.88^{d}	0.08 ± 0.01^{cd}
Pb^{2+}	4.33 ± 1.52^{e}	7.00 ± 1.00^{e}	0.59 ± 0.17^{c}	0.55 ± 0.12^{e}	1.73 ± 0.20^{a}	21.54 ± 2.23^{e}	0.44 ± 0.06^{e}	0.04 ± 0.01^{d}	2.72 ± 0.39^{e}	0.02 ± 0.01^{d}
SEm±	2.95	1.02	0.5	0.75	0.08	1.43	0.59	0.25	0.67	0.02
LSD ($p < 0.05$)	0.081	0.385	0.08	0.75	0.53	0.183	0.3	0.23	0.716	0.07

Table 2
Mean comparison of control and experimental plots for BOD and COD

	BOD		COD	
	Control (without vetiver grass)	Experimental plot (with vetiver grass)	Control (without vetiver grass)	Experimental plot (with vetiver grass)
	803.5 ± 50.67	437.38 ± 22.69	510.50 ± 41.40	269.63 ± 64.33
t-statistic value ($p < 0.05$)	8.9		18.65	

than one, it is assumed that the plant has good phytoremediation capacity and is a hyperaccumulator of that particular element. According to Table 1, the plants in the experimental plot (with vetiver grasses) have a high BCF factor in this study. The BCF (Control root/water) value of the experimental plot for Pb^{2+} (0.55) and Cr^{6+} (42.57) is significantly lower than the experimental value BCF (Experimental root/water) which is 2.72 and 110.24, respectively).

TF are used to assess a plant's ability to translocate metals from the root to the shoot [23]. TFs greater than one indicate that the plant is effective at transporting that particular metal from root to shoot tissue. The TF in the control plot ranges from 0.29 to 0.70, while the TF in the experimental plot with vetiver grass ranges from 0.29 to 0.70. (0.02 to 0.80). The highest TF value in the control plot was 1.73 for Pb^{2+}, while the highest value in the experimental plot was 0.8 for Cr^{6+} (Table 2).

BOD and COD samples were collected from both experimental and control plots in the current study. Following a t-test (mean comparison), it was discovered that the BOD of the control plot is 803.5 ppm, whereas the experimental plot has a value of 437.38 ppm. COD was measured at 510.50 ppm in the control plot and 269.63 ppm in the other plot. This study has been supported by various workers, in terms of rhizofiltration which involves the removal of aqueous pollutants by the plant root system [24,25].

4. Conclusion

Based on the results of the above experiment, it can be concluded that vetiver grass can be used as a phytoremediation agent for sewage water treatment. Various elements such as Al^{3+}, Cr^{6+}, Fe^{3+}, Zn^{2+}, and Pb^{2+} can be easily removed from wastewater, and because it is a moving garden concept, it can also improve the aesthetic value of the wastewater. The main aspects to judge and prove the hyper-accumulation of metals in plant roots are BCF and TF. The basic principle underlying the entire concept of the work is rhizofiltration. The experimental plots show promising results, indicating that in the proposed area, this approach is truly beneficial to the local community. In future more work can be done with the other heavy metals with their precise estimation of the concentration in the plant.

References

[1] R.S. Lokhande, P.U. Singare, D.S. Pimple, Study on physico-chemical parameters of wastewater effluents from Taloja Industrial Area of Mumbai, India, Int. J. Ecosyst., 1 (2011) 1–9, doi: 10.5923/j.ije.20110101.01.

[2] M.S. Aulakh, P.S.K. Mohinder, S. Dhanwinder, Water pollution related to agricultural, industrial, and urban activities, and its effects on the food chain: case studies from Punjab, J. New Seeds, 10 (2009) 112–137.

[3] M. Farai, O.A. Dorcas, S.M. Tichapondwa, M.N.C. Evans, Phytoremediation of Cr(VI) in wastewater using the vetiver grass (*Chrysopogon zizanioides*), Miner. Eng., 172 (2021) 107141, doi: 10.1016/j.mineng.2021.107141.

[4] A. Kabata-Pendias, Trace Elements in Soils and Plants, 4th ed., CRC Press, Boca Raton, FL, 2011.

[5] Food and Agriculture Organization of the United Nations and the United Nations Environment Programme, Global Assessment of Soil Pollution – Summary for Policy Makers, FAO, Rome, 2021.

[6] G.M. Tordoff, A.J.M. Baker, A.J. Willis, Current approaches to the revegetation and reclamation of metalliferous mine wastes, Chemosphere, 41 (2000) 219–228.

[7] F.H.S. Rabêlo, L. Borgo, J. Lavres Jr., The Use of Forage Grasses for the Phytoremediation of Heavy Metals: Plant Tolerance Mechanisms, Classifications, and New Prospects, V. Matichenkov, Ed., Phytoremediation: Methods, Management and Assessment, Nova Science Publishers, New York, NY, 2018a, pp. 59–103.

[8] S. Clemens, Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants, Biochimie, 88 (2006) 1707–1719.

[9] J. Vangronsveld, R. Herzig, N. Weyens, J. Boulet, K. Adriaensen, A. Ruttens, T. Thewys, A. Vassilev, E. Meers, E. Nehnevajova, D. van der Lelie, M. Mench, Phytoremediation of contaminated soils and groundwater: lessons from the field, Environ. Sci. Pollut. Res., 16 (2009) 765–794.

[10] T.V. Tangahu, S.R. Sheikh Abdullah, H. Basri, M. Idris, N. Anuar, M. Mukhlisin, A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation, Int. J. Chem. Eng., 2011 (2011) 939161, doi: 10.1155/2011/939161.

[11] M. Laghlimi, B. Baghdad, H. El Hadi, A. Bouabdli, Phytoremediation mechanisms of heavy metal contaminated soils: a review, Open J. Ecol., 5 (2015) 375–388.

[12] A.P.G.C. Marques, A.O.S.S. Rangel, P.M.L. Castro, Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology, Environ. Sci. Technol., 39 (2009) 622–654.

[13] R.P. Adams, M. Zhong, Y. Turuspekov, M.R. Dafforn, J.F. Veldkamp, DNA fingerprinting reveals clonal nature of *Vetiveria zizanioides* (L.) Nash, Gramineae and sources of potential new germplasm, Mol. Ecol., 7 (1998) 813–818.

[14] V.K. Tyagi, B.K. Sahoo, A. Khursheed, A.A. Kazmi, Z. Ahmad, A.K. Chopra, Fate of coliforms and pathogenic parasite in four full-scale sewage treatment systems in India, Environ. Monit. Assess., 181 (2011) 123–135.

[15] S. Khan, L. Aijun, S. Zhang, Q. Hu, Y.-G. Zhu, Accumulation of polycyclic aromatic hydrocarbons and heavy metals in lettuce grown in the soils contaminated with long-term wastewater irrigation, J. Hazard. Mater., 152 (2008) 506–515.

[16] S. Wagner, P. Truong, A. Vieritz, Response of Vetiver Grass to Extreme Nitrogen and Phosphorus Supply, Proceedings of the Third International Conference on Vetiver and Exhibition, Guangzhou, China, 2003, p. 176.

[17] R. Popat, K. Banakara, Doebioresearch: Analysis of Design of Experiments for Biological Research, R Package Version 0.1.0, 2020.

[18] W. Revelle, Psych: Procedures for Personality and Psychological Research, R Package Version 2.1.9, 2021.

[19] K.R. Ajoy, S. Archana, T. Geeta, Some aspects of aluminum toxicity in plants, Bot. Rev., 54 (1998) 145–178.

[20] M.F. Zaranyika, T. Ndapwadza, Uptake of Ni, Zn, Fe, Co, Cr, Pb, Cu and Cd by water hyacinth (*Eichhornia crassipes*) in Mukuvisi and Manyame rivers, Zimbabwe, J. Environ. Sci. Health, 30 (1995) 1157–1169.

[21] P. Chandra, K. Kulshreshtha, Chromium accumulation and toxicity in aquatic vascular plants, Bot. Rev., 70 (2004) 313–327.

[22] M.A. Sajad, M.S. Khan, S. Bahadur, A. Naeem, H. Ali, F. Batool, M. Shuaib, M.A.S. Khan, S. Batool, Evaluation of chromium phytoremediation potential of some plant species of Dir Lower, Khyber Pakhtunkhwa, Pakistan, Acta Ecol. Sin., 40 (2020) 158–165.

[23] C. Tu, L.Q. Ma, Effects of arsenic concentrations and forms on arsenic uptake by the hyperaccumulator ladder brake, J. Environ. Qual., 31 (2002) 641–647.

[24] S. Dushenkov, Y. Kapulnik, Phytofilitration of Metals, In: Phytoremediation of Toxic Metals – Using Plants to Clean-Up the Environment, John Wiley and Sons, Inc., New York, 2000, p. 330.

[25] S.F. Cardoso, L.M.X. Lopes, I.R. Nascimento, *Eichhornia crassipes*: an advantageous source of shikimic acid, Revista Brasileira de Farmacognosia, 24 (2014) 439–442.