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Application of a *vetiver* system for unconventional water treatment

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ABSTRACT

In this research, a pilot phytoremediation experiment was conducted to evaluate the effectiveness of vetiver grass (*Vetiveria zizanioides* L. Nash) in the uptake of contaminants from two unconventional water samples. The vetiver was hydroponically planted in two unconventional water samples taken from a mine (W_1) and saline groundwater taken from wells located around the mine area (W_2). Although waters from the Golgohar mining site are not permitted to escape into public waters and the aim of the current research was to examine the efficiency of the vetiver system in the reusage of water for ore processing plant, this study just focused on salinity and thus the total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), anions (SO4, Cl) and cations (Na, K, Mg, Ca) were considered and analysed. The results indicated that all five elements were distributed more in the shoots than in the roots of the vetiver, particularly Na, K and Ca, as seen from the average concentration ratios of 74.7, 42, 55.9 43 and 60.2% for Na, Cl, Ca, Mg and K, respectively. The weed grown in W_2 with the upper plant growth had the highest SO_4, Na, K, Ca, Cl and Mg removal efficiencies of 70.9, 59.1, 58.4, 51.5, 48.7 and 23.8%, respectively, whereas the weed grown in W_1 showed efficiency of up to 43.6% Mg removal from the water samples. The results showed that treatment efficiencies of total hardness, TDS and EC of water samples were equal to 46, 31.5 and 28.3% for mine wastewater and 45.1, 33 and 28% for groundwater in the fourth week, respectively.

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Keywords: Vetiver; Unconventional water; Treatment; Salinity; Phytoremediation

1. Introduction

A progressively growing population and an industrialized global economy developing over the last century have led to dramatically elevated releases of anthropogenic chemicals into the environment [1–3]. Thus, as a consequence of both increasing population and industrial technology, humanity has created a condition where many aspects of life, including human life, are progressively becoming at risk. Until relatively recently, it was commonly believed that the Earth's atmospheric, terrestrial and aquatic systems were suitable for absorbing and breaking down waste from various sources, such as population centres, industry and agriculture [4].

Many areas of the world including Iran are already facing extreme water shortages. Iran, with mostly arid and semi-arid climatic conditions, is experiencing a severe water shortage [5]. One of the most important commodities for industry is water, and it is hard to imagine any type of industry without water. Water is needed as a direct raw material, and as an ingredient of the product itself. In other cases, water is an indirect commodity, used in washing, heating, cooling or as a part of the manufacturing process [6].

In most mineral processing plants, reusing water remarkably decreases the need for fresh water in the plant, and it reduces catchment costs. In particular cases of fresh water scarcity, highly saline water and even seawater are used such as the copper mine in Batu Hijau, Indonesia. The needs for water quality parameters are related to the physical and chemical characteristics that are consistent with the desired use. Thus, just like the water used for domestic purposes is different from the water supplied for industrial purposes, agriculture, etc. The same holds true for the mining sector [7,8].

Effective wastewater treatment may be achieved by different mechanisms, physical, chemical and biological, or by the uptake of vegetation [9–11]. Among the different techniques used for remediation, phytoremediation or the application of green plants is a cost-effective and environmentally friendly green technology, and an aesthetically acceptable method that applies the capacity of hyperaccumulator plants for the removal of contaminants from the polluted environment [12–24]. In the past decade, several researchers have succeeded in determining many plants, including edible crops and leafy vegetation, suitable for phytoremediation aims [6,25–28].

Appropriate plant species for phytoremediation applications must have a high uptake of both organic and inorganic contaminants, grow well in contaminated water and be easily controlled in quantitatively propagated dispersion [11]. One of the first vegetations applied for soil and water conservation aims was vetiver grass (*Vetiveria zizanioides*, recently reclassified as *Chrysopogon zizanioides*), which belongs to the gramineae family [29,30].

The vetiver, as a unique tropical plant, has been used in about 100 countries for the purposes of soil and water conservation, land reclamation, water refinement, pollution control and many other environmental applications, especially in relation to the looming food crisis in the developing countries [11]. Due to its special morphological and physiological attributes, and its tolerance to high levels of heavy metal and adverse situations, vetiver has also been successfully applied in the field of environmental conservation [30,31]. It is excellent for the removal of heavy metals from polluted soil and water. While vetiver is not an aquatic plant, it may be established and survive under hydroponic conditions [32]. Thus, vetiver has strong capabilities for application in industrial wastewater and unconventional water treatment [33–36]. The vetiver system is easy to apply and cost-effective [30,31].

Due to the fact that waters from the Golgohar mining site are not permitted to escape into public waters, thus the purpose of this study was to evaluate the potential effectiveness of vetiver system phytoremediation for unconventional water treatment and decreasing salinity.

2. Materials and methods

2.1. Experimental site and plots

The experimental site was a 10 × 14 m field located in the agricultural zone of the Central Water Research Laboratory of the University of Tehran. The experimental samples included Golgohar mine wastewater (W_1) and groundwater (W_2) which came from around the mine.

This experiment was carried out as a factorial experiment with two factors (the used water with two levels, including Golgohar mine wastewater and groundwater, and the time of sampling with five levels, week 0 to week 4) in a completely randomized design with three replications per each treatment. Experimental plots were distributed throughout the site as 24 water pits, which were manually excavated using a spade with 80 cm × 20 cm × 20 cm dimensions. The unconventional waters were then passed through the pits and the water samples were collected from plastic tubes. All pits were isolated from the ground using high-density polyethylene membrane of 0.35 mm and filled with gravel.

Vetiver grass (*Vetiveria zizanioides* L. Nash) was selected having been cultured previously under hydroponic conditions in order to find out its interaction with contaminants. The plants used were similar in size and aspect, and the weeds were trimmed to 20 cm high before planting, which lasted for four weeks. One seedling was planted in a plastic cup full of sand. To allow water to soak the sand, the bottom of each cup was cut across in streaks. The three cups were settled in each water pit. During cultivation, weeds were thoroughly removed and the solution volume in the water pits was kept at 20 l by weekly addition of distilled water.

2.2. Water and plant sampling and analysis

Water samples were collected at the end of each week to analyse the total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), anions and cations. Water hardness, sulphate (SO_4), chloride (Cl), magnesium (Mg) and calcium (Ca) were identified by titration method with ethylenediaminetetraacetic acid (EDTA). The water samples were evaporated at 103–105˚C for one hour to measure the TDS mg L^{-1}. The estimation of the Na and K was done using a flame photometer (Model 405, Corning, UK).

Plants were harvested to examine the aforementioned parameters for shoot and root separately. To prepare the plants in the laboratory, first the plants were cleaned by hand, removing all the adhering material such as soil particles. Then, all roots and shoots were rinsed using tap water for 5 min, which was shaken off by hand. At the end, all roots and shoots were submerged in distilled water for 2 min, dried at 60˚C for 72 h and milled to a fine powder in a grinder. In order to carry out a complete analysis of the plants, titration method with EDTA was applied for determining Mg and Ca. Na and K were estimated by a flame photometer (Model 405, Corning, UK) and also, Mohr method was applied to determine chloride by titration with silver nitrate.

Laboratory and instrumental blanks analysed throughout the method showed that there was no sign of contamination or interference on the samples during laboratory handling. Recoveries, computed using spiked matrixes, were greater than 90%.

2.3. Data analysis

All experimental data were statistically processed using Excel and SAS/STAT software packages. The data were analysed using general linear models through Proc GLM in SAS [37]. The treatments, sampling times and their interactions were compared at significant level of 0.05 using least squares means procedure, and the multiple testing corrections were carried out using Tukey method through Proc GLM of SAS [37].

3. Results and discussion

3.1. Salinity and TH of samples at the end of the experiment

The results showed that treatment efficiencies of total hardness, TDS and EC of water samples were equal to 46, 31.5 and 28.3% for mine wastewater and 45.1, 33 and 28% for groundwater on the fourth week, respectively (Fig. 1). The concentration of these three factors during the four-week period after beginning the experiment and also means comparisons between treatments during sampling times showed in Tables 1–3. Although all three water quality parameters in two water samples decreased during the experimental period, but there was not significant difference at the end of third and fourth weeks. Other research includes that of Jayashree et al. [38], which used the vetiver system for two months for the treatment of textile water, and reported that pH reduced from 8.6 to 7.8 and EC from 1.34 to 0.22 dS/m. Ebrahim et al. [39] have shown that vetiver root helps the reduction of TDS by 55.9% in hard water by using adsorption technique. The results of other researchers showed that the EC values of contaminated water are directly proportional to its dissolved mineral matter content, and after culturing vetiver, EC reduced to a very low value [40–42]. Truong and Hart [40] and Lakshmana

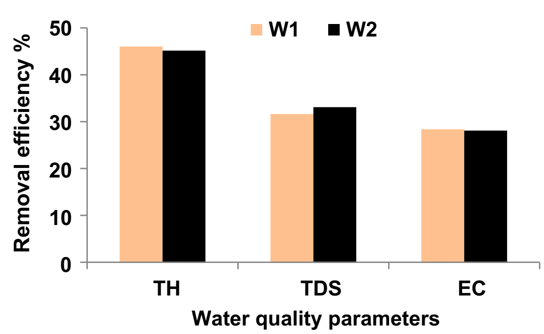

Fig. 1. Average TH, TDS and EC removal efficiencies percent of vetiver grown in two water samples.

Table 1
Least squares means (SE) of salinity and total hardness parameters in water samples

Water sample	EC (mmhos/cm)	TDS (mg/l)	TH (mg/l)
W_1	46.30 (0.40)^a	20.6 (0.40)^a	9,884 (208)^a
W_2	27.27 (0.40)^b	11.2 (0.40)^b	6,243 (208)^b

^{ab}The means with different letter, differ significantly at $p < 0.05$.

Table 2
Least squares means (SE) of salinity and total hardness parameters during four consequent weeks

Week	EC (mmhos/cm)	TDS (mg/l)	TH (mg/l)
0	42.82 (0.62)^a	22.3 (0.6)^a	11,506.4 (328.9)^a
1	39.15 (0.62)^b	20 (0.6)^a	10,020.4 (328.9)^a
2	36.01 (0.62)^c	15.6 (0.6)^b	7,050.3 (328.9)^b
3	33.87 (0.62)^{cd}	11 (0.6)^c	6,019 (328.9)^c
4	32.08 (0.62)^d	10.6 (0.6)^c	5,723.7 (328.9)^c

$^{a,b,\ldots,d}$The means with different letter differ significantly at $p < 0.05$.

et al. [41] have reported that for hardness ranging from 106 to 206 mg/L, after culturing vetiver, removal was about 60% over two months. Furthermore, Maffei [43] and Troung and Stone [44] have reported that the vetiver system has a high level of tolerance to salinity. Ibezute et al. [45] have showed that vetiver grass significantly reduced TDS and EC by 98.96 and 98.11%, respectively. Also, Akpah et al. [46] have indicated that TDS was reduced by the vetiver system from 845 to 673 mg/l by a percentage of 20.36. Mudhiriza et al. [47] have reported that vetiver grass is able to decrease the amount of TDS in effluent about 95% at Day 21 of retention. Jayashree et al. [38] applied this system up to 60 d for the treatment of textile water and reported that pH decreased from 8.6 to 7.8, while EC decreased from 1.34 to 0. 22 dS/m.

3.2. Anions and cations' uptake and removal efficiency of vetiver

The concentration of anions and cations in the plant and total dry weight are the two factors involved in the level of elements' uptake. Since plant growth and element absorption by the vetiver grown in two unconventional water sources were different, the total uptake of investigated anions and cations were also completely different. The best plant growth was found in weed plants grown in W_2 and they showed upper uptake of elements (Table 4). Means comparisons between treatments during sampling times for anions and cations showed in Tables 5–7. The results indicated that anions and cations in two water samples decreased during four weeks. There were no significant differences for K and Mg in the first two weeks and also during third and fourth weeks.

The removal efficiency (%) is defined as the ratio of elements' uptake to the amount of original elements in water samples (Eq. (1)).

$$\%\ \text{Removal efficiency} = \left(\frac{C_{\text{inf}} - C_{\text{eff}}}{C_{\text{inf}}}\right) \times 100 \quad (1)$$

where C_{inf} is initial parameter concentration and C_{eff} is final parameter concentration in water samples. Removal efficiencies of the weed grown in W_2 were

Table 3
Least squares means (SE) of salinity and total hardness parameters in water samples during four consequent weeks

Water sample	Week	EC (mmhos/cm)	TDS (mg/l)	TH (mg/l)
W_1	0	53.27 (0.88)^a	28.2 (0.9)^a	14,129.6 (465.1)^a
	1	49.03 (0.88)^{ab}	26.1 (0.9)^a	11,868.6 (465.1)^a
	2	45.33 (0.88)^{bc}	21.3 (0.9)^b	8,597.1 (465.1)^b
	3	43.00 (0.88)^{dc}	14.1 (0.9)^c	7,612.1 (465.1)^b
	4	40.87 (0.88)^d	13.5 (0.9)^{cd}	7,217.5 (465.1)^b
W_2	0	32.37 (0.88)^e	16.4 (0.9)^{cd}	8,883.1 (465.1)^{bc}
	1	29.27 (0.88)^{ef}	13.9 (0.9)^{cd}	8,172.3 (465.1)^{bc}
	2	26.70 (0.88)^{fg}	9.9 (0.9)^{de}	5,503.4 (465.1)^{cd}
	3	24.73 (0.88)^g	7.9 (0.9)^e	4,427.8 (465.1)^d
	4	23.30 (0.88)^g	7.8 (0.9)^e	4,229.9 (465.1)^d

$^{a,b,\ldots,g}$The means with different letter differ significantly at $p < 0.05$.

Table 4
Element concentrations in water samples

	W_1		W_2	
Parameter (me L^{-1})	Before expriment	4th week	Before expriment	4th week
SO_4	94.9	34.3	98.5	28.7
Cl	586	307	326	167
Na	397	189	247	101
K	1.12	0.9	0.514	0.214
Mg	36.7	20.7	42	32
Ca	247	132	136	66

Table 5
Least squares means (SE) of anions and cations in water samples

Water sample	SO_4 (me L^{-1})	Cl (me L^{-1})	Na (me L^{-1})	K (me L^{-1})	Mg (me L^{-1})	Ca (me L^{-1})
W_1	58.6 (1.7)^a	381.7 (5.4)^a	267.3 (2.8)^a	0.99 (0.02)^a	24.1 (0.9)^a	161.9 (2.2)^a
W_2	48.9 (1.7)^b	214.7 (5.4)^b	152.5 (2.8)^b	0.39 (0.02)^b	29.8 (0.9)^b	90.8 (2.2)^b

^{ab}The means with different letter differ significantly at $p < 0.05$.

Table 6
Least squares means (SE) of anions and cations during four consequent weeks

Week	SO_4 (me L^{-1})	Cl (me L^{-1})	Na (me L^{-1})	K (me L^{-1})	Mg (me L^{-1})	Ca (me L^{-1})
0	96.7 (2.7)^a	456.2 (8.6)^a	322.1 (4.4)^a	0.9 (0.03)^a	39.2 (1.4)^a	191.7 (3.4)^a
1	60.2 (2.7)^b	386.4 (8.6)^b	304.8 (4.4)^a	0.8 (0.03)^a	33.9 (1.4)^a	169 (3.4)^b
2	44.1 (2.7)^c	256.4 (8.6)^c	159 (4.4)^b	0.7 (0.03)^a	26.5 (1.4)^b	102.8 (3.4)^c
3	37.8 (2.7)^{cd}	227.5 (8.6)^c	144.9 (4.4)^b	0.6 (0.03)^b	20 (1.4)^c	99 (3.4)^c
4	30.2 (2.7)^d	164.6 (8.6)^d	118.8 (4.4)^c	0.5 (0.03)^b	15.3 (1.4)^c	69.4 (3.4)^d

$^{a,b,\ldots,d}$The means with different letter differ significantly at $p < 0.05$.

Table 7
Least squares means (SE) of anions and cations in water samples during four consequent weeks

Water sample	Week	SO_4 (me L^{-1})	Cl (me L^{-1})	Na (me L^{-1})	K (me L^{-1})	Mg (me L^{-1})	Ca (me L^{-1})
W_1	0	94.9 (3.9)^a	586 (12.1)^a	397.2 (6.2)^a	1.12 (0.04)^a	36.7 (2.03)^a	246.7 (4.8)^a
	1	67.3 (3.9)^a	508.6 (12.1)^b	391.4 (6.2)^a	1.09 (0.04)^{ab}	31.4 (2.03)^{ab}	206.7 (4.8)^b
	2	49.6 (3.9)^b	306.2 (12.1)^c	202.4 (6.2)^b	0.98 (0.04)^{ab}	20.7 (2.03)^{ab}	133.9 (4.8)^c
	3	46.9 (3.9)^{bc}	296.2 (12.1)^{cd}	188.8 (6.2)^{bc}	0.9 (0.04)^{ab}	18.4 (2.03)^{ab}	132 (4.8)^c
	4	34.3 (3.9)^{bc}	211.7 (12.1)^{cd}	157 (6.2)^c	0.88 (0.04)^b	13.7 (2.03)^{bc}	90.4 (4.8)^d
W_2	0	98.5 (3.9)^{cd}	326.3 (12.1)^{de}	247.1 (6.2)^c	0.6 (0.04)^c	41.7 (2.03)^{cd}	136.7 (4.8)^c
	1	53.1 (3.9)^{cde}	264.1 (12.1)^{ef}	218.2 (6.2)^d	0.56 (0.04)^c	36.3 (2.03)^d	131.3 (4.8)^c
	2	38.6 (3.9)^{cde}	206.7 (12.1)^{ef}	115.6 (6.2)^e	0.51 (0.04)^c	32.3 (2.03)^d	71.7 (4.8)^{de}
	3	28.6 (3.9)^{de}	159 (12.1)^{fg}	101 (6.2)^{ef}	0.21 (0.04)^d	21.7 (2.03)^d	66 (4.8)^e
	4	26.1 (3.9)^e	117.7 (12.1)^g	80.6 (6.2)^f	0.08 (0.04)^d	17 (2.03)^d	48.3 (4.8)^e

$^{a,b,\ldots,g}$The means with different letter differ significantly at $p < 0.05$.

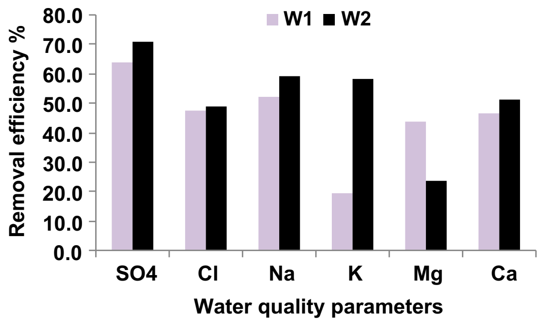

Fig. 2. Average SO_4, Cl, Na, K, Mg and Ca removal efficiencies of vetiver grown in water samples.

equal to 70.9, 59.1, 58.4, 51.5, 48.8 and 23.8% for SO_4, Na, K, Ca, Cl and Mg, respectively, whereas the weed grown in W_1 showed removal efficiency of up to 43.6% in Mg from the water samples (Fig. 2). Ibezute et al. [45] have reported that chloride alongside sodium, magnesium and sulphate were decreased by 98.71, 96.94, 97.17 and 98.89%, respectively, after treatment period. Anon [48] and Zheng et al. [33] have reported 98% reduction for total P during 4 weeks and 74% for total N after 5 weeks in polluted river water. Wagner et al. [49] applied vetiver in hydroponic system using sewage effluent and observed that both N and P recorded a reduction of over 90% from the effluent; it also decreased algae growth and faecal coliforms.

3.3. Concentration of anions and cations in shoots and roots of vetiver

Means comparisons of concentration of water quality parameters in shoots and roots of planted vetiver grass indicated in Tables 8–14. Among both investigated unconventional water samples, the vetiver grown in W_2 showed the lowest concentration of elements in shoots and roots. The weeds absorbed more elements from the mine wastewater (W_1). The highest Na concentration in shoots and roots was found in vetiver grown in W_1, while the shoots and roots of vetiver grown in W_2 had the highest K concentration. For Cl, the concentration was highest in vetiver shoots grown in W_1 and in the vetiver roots grown in W_1.

All five elements were more distributed in vetiver shoots than in roots, particularly Na, K and Ca, as seen from the average concentration ratios of 74.7, 42, 55.9, 43, and 60.2%, for Na, Cl, Ca, Mg and K, respectively. Mane et al. [50] reported that increase in root and root length of vetiver grass was observed at about 18.6–24.8%, and at 200 and 50 mM NaCl, respectively. Additionally, the mean leaf area extended with saline condition. They also found increased levels of polyphenols at higher salinity due to the accumulation of secondary metabolites. The EC and TDS of the soil show a linear increase at increasing salinity, and the vetiver is resistant to up to 100 mM of salinity because of rising growth and photosynthetic parameter. Roongtanakiat et al. [6] utilized vetiver grass for removal of heavy metals from industrial wastewaters,

Table 8
Least squares means (SE) of concentrations of water quality parameters in vetiver grass planted in water samples

Water sample	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
W_1	0.43 (0.01)^a	1.49 (0.03)^a	4.05 (0.09)^a	1.22 (0.02)^a	0.52 (0.02)^b
W_2	0.32 (0.01)^b	0.6 (0.03)^b	1.93 (0.09)^b	0.77 (0.02)^b	0.74 (0.02)^a

^{ab}The means with different letter differ significantly at $p < 0.05$.

Table 9
Least squares means (SE) of concentrations in vetiver grass planted during four consequent weeks

Week	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
0	0.21 (0.01)^a	0.15 (0.05)^e	0.32 (0.14)^e	0.02 (0.04)^e	0.44 (0.03)^d
1	0.33 (0.01)^b	0.80 (0.05)^d	2.63 (0.14)^d	0.61 (0.04)^d	0.49 (0.03)^{cd}
2	0.39 (0.01)^{bc}	1.16 (0.05)^c	3.40 (0.14)^c	0.88 (0.04)^c	0.60 (0.03)^{bc}
3	0.43 (0.01)^c	1.43 (0.05)^b	4.01 (0.14)^b	1.58 (0.04)^b	0.72 (0.03)^b
4	0.54 (0.01)^d	1.70 (0.05)^a	4.60 (0.14)^a	1.86 (0.04)^a	0.87 (0.03)^a

$^{a,b,\ldots,e}$The means with different letter differ significantly at $p < 0.05$.

Table 10
Least squares means (SE) of concentrations of water quality parameters in shoot and root of planted vetiver grass

Organ of plant	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
Shoot	0.44 (0.01)^a	1.63 (0.03)^a	4.73 (0.09)^a	1.20 (0.02)^a	0.68 (0.02)^a
Root	0.32 (0.01)^b	0.46 (0.03)^b	1.25 (0.09)^b	0.77 (0.02)^b	0.57 (0.02)^b

^{ab}The means with different letter differ significantly at $p < 0.05$.

Table 11
Least squares means (SE) of concentrations of water quality parameters in vetiver grass planted in water samples during four consequent weeks

Water	Week	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
W_1	0	0.21 (0.02)^d	0.15 (0.07)^d	0.32 (0.2)^e	0.02 (0.06)^f	0.34 (0.04)^e
	1	0.41 (0.02)^{abcd}	1.17 (0.07)^{bcd}	3.62 (0.2)^{abcd}	0.71 (0.06)^{de}	0.38 (0.04)^e
	2	0.45 (0.02)^{abc}	1.65 (0.07)^{abc}	4.64 (0.2)^{abc}	1.07 (0.06)^{cde}	0.48 (0.04)^{de}
	3	0.48 (0.02)^{ab}	2.02 (0.07)^{ab}	5.56 (0.2)^{ab}	1.91 (0.06)^{ab}	0.59 (0.04)^{bcde}
	4	0.62 (0.02)^a	2.44 (0.07)^a	6.10 (0.2)^a	2.35 (0.06)^a	0.79 (0.04)^{abc}
W_2	0	0.21 (0.02)^d	0.15 (0.07)^d	0.32 (0.2)^e	0.02 (0.06)^f	0.53 (0.04)^{cde}
	1	0.25 (0.02)^{cd}	0.43 (0.07)^d	1.64 (0.2)^{de}	0.51 (0.06)^{ef}	0.60 (0.04)^{bcde}
	2	0.33 (0.02)^{cd}	0.67 (0.07)^{cd}	2.16 (0.2)^{cde}	0.68 (0.06)^{de}	0.72 (0.04)^{abcd}
	3	0.38 (0.02)^{bcd}	0.83 (0.07)^{cd}	2.47 (0.2)^{cde}	1.25 (0.06)^{cd}	0.86 (0.04)^{ab}
	4	0.47 (0.02)^{abc}	0.95 (0.07)^{cd}	3.07 (0.2)^{bcde}	1.38 (0.06)^{bc}	0.95 (0.04)^a

$^{a,b,\ldots,f}$The means with different letter differ significantly at $p < 0.05$.

Table 12
Least squares means (SE) of concentrations of water quality parameters in shoot and root of vetiver grass planted in water samples

Water	Organ of plant	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
W_1	Shoot	0.53 (0.01)^a	2.32 (0.05)^a	6.48 (0.13)^a	1.54 (0.04)^a	0.65 (0.02)^a
	Root	0.34 (0.01)^b	0.66 (0.05)^{bc}	1.61 (0.13)^c	0.89 (0.04)^b	0.39 (0.02)^b
W_2	Shoot	0.34 (0.01)^b	0.95 (0.05)^b	2.98 (0.13)^b	0.87 (0.04)^b	0.72 (0.02)^a
	Root	0.30 (0.01)^b	0.26 (0.05)^c	0.89 (0.13)^c	0.67 (0.04)^b	0.75 (0.02)^a

^{a,b,c}The means with different letter differ significantly at $p < 0.05$.

Table 13
Least squares means (SE) of concentrations of water quality parameters in shoot and root of planted vetiver grass during four consequent weeks

Week	Organ of plant	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
0	Shoot	0.14 (0.02)^e	0.20 (0.07)^e	0.33 (0.2)^d	0.02 (0.06)^d	0.46 (0.04)^{cd}
	Root	0.29 (0.02)^d	0.10 (0.07)^e	0.31 (0.2)^d	0.02 (0.06)^d	0.42 (0.04)^d
1	Shoot	0.35 (0.02)^{cd}	1.16 (0.07)^{cd}	4.03 (0.2)^{bc}	0.64 (0.06)^c	0.53 (0.04)^{bcd}
	Root	0.31 (0.02)^{cd}	0.43 (0.07)^{de}	1.23 (0.2)^d	0.57 (0.06)^c	0.45 (0.04)^{cd}
2	Shoot	0.45 (0.02)^{bc}	1.77 (0.07)^{bc}	5.45 (0.2)^{ab}	1.06 (0.06)^{bc}	0.61 (0.04)^{bcd}
	Root	0.32 (0.02)^{cd}	0.55 (0.07)^{de}	1.35 (0.2)^d	0.69 (0.06)^c	0.59 (0.04)^{bcd}
3	Shoot	0.53 (0.02)^b	2.30 (0.07)^{ab}	6.52 (0.2)^a	1.89 (0.06)^a	0.78 (0.04)^b
	Root	0.33 (0.02)^{cd}	0.57 (0.07)^{de}	1.49 (0.2)^d	1.26 (0.06)^b	0.67 (0.04)^{bcd}
4	Shoot	0.76 (0.02)^a	2.75 (0.07)^a	7.31 (0.2)^a	2.39 (0.06)^a	1.03 (0.04)^a
	Root	0.36 (0.02)^{cd}	0.65 (0.07)^{de}	1.87 (0.2)^{cd}	1.33 (0.06)^b	0.71 (0.04)^{bc}

$^{a,b,\ldots,e}$The means with different letter differ significantly at $p < 0.05$.

Table 14
Least squares means (SE) of concentrations of water quality parameters in shoot and root of vetiver grass planted in water samples during four consequent weeks

Water	Week	Organ of plant	Mg (gr/100 gr)	Ca (gr/100 gr)	Cl (gr/100 gr)	Na (gr/100 gr)	K (gr/100 gr)
W_1	0	Shoot	0.14 (0.03)^{f}	0.20 (0.1)^{i}	0.33 (0.29)^{h}	0.02 (0.09)^{h}	0.41 (0.06)^{gh}
		Root	0.29 (0.03)^{def}	0.10 (0.1)^{i}	0.31 (0.29)^{h}	0.02 (0.09)^{h}	0.27 (0.06)^{h}
	1	Shoot	0.49 (0.03)^{bc}	1.73 (0.1)^{d}	5.62 (0.29)^{c}	0.79 (0.09)^{fg}	0.43 (0.06)^{fgh}
		Root	0.33 (0.03)^{cde}	0.60 (0.1)^{ghi}	1.62 (0.29)^{fgh}	0.62 (0.09)^{fg}	0.33 (0.06)^{gh}
	2	Shoot	0.54 (0.03)^{b}	2.50 (0.1)^{c}	7.49 (0.29)^{b}	1.39 (0.09)^{cde}	0.56 (0.06)^{defgh}
		Root	0.35 (0.03)^{cde}	0.80 (0.1)^{fgh}	1.79 (0.29)^{fgh}	0.75 (0.09)^{fg}	0.41 (0.06)^{gh}
	3	Shoot	0.60 (0.03)^{b}	3.24 (0.1)^{b}	9.27 (0.29)^{a}	2.36 (0.09)^{b}	0.75 (0.06)^{abcdef}
		Root	0.36 (0.03)^{cde}	0.81 (0.1)^{fgh}	1.83 (0.29)^{fgh}	1.46 (0.09)^{cde}	0.43 (0.06)^{fgh}
	4	Shoot	0.87 (0.03)^{a}	3.92 (0.1)^{a}	9.70 (0.29)^{a}	3.12 (0.09)^{a}	1.08 (0.06)^{a}
		Root	0.37 (0.03)^{cde}	0.96 (0.1)^{fg}	2.49 (0.29)^{ef}	1.56 (0.09)^{cd}	0.51 (0.06)^{efgh}
W_2	0	Shoot	0.14 (0.03)^{f}	0.20 (0.1)^{i}	0.33 (0.29)^{h}	0.02 (0.09)^{h}	0.50 (0.06) ^{efgh}
		Root	0.29 (0.03)^{def}	0.10 (0.1)^{i}	0.31 (0.29)^{h}	0.02 (0.09)^{h}	0.56 (0.06)^{defgh}
	1	Shoot	0.20 (0.03)^{ef}	0.60 (0.1)^{ghi}	2.45 (0.29)^{efg}	0.49 (0.09)^{gh}	0.63 (0.06)^{cdefg}
		Root	0.29 (0.03)^{def}	0.27 (0.1)^{ih}	0.83 (0.29)^{h}	0.53 (0.09)^{g}	0.58 (0.06)^{cdefgh}
	2	Shoot	0.35 (0.03)^{cde}	1.04 (0.1)^{efg}	3.41 (0.29)^{de}	0.73 (0.09)^{fg}	0.66 (0.06)^{bcdefg}
		Root	0.30 (0.03)^{def}	0.29 (0.1)^{hi}	0.92 (0.29)^{gh}	0.63 (0.09)^{fg}	0.78 (0.06)^{abcdef}
	3	Shoot	0.44 (0.03)^{bcd}	1.33 (0.1)^{def}	3.77 (0.29)^{de}	1.43 (0.09)^{cde}	0.81 (0.06)^{abcdef}
		Root	0.30 (0.03)^{def}	0.32 (0.1)^{hi}	1.16 (0.29)^{fgh}	1.06 (0.09)^{ef}	0.90 (0.06)^{abcd}
	4	Shoot	0.58 (0.03)^{b}	1.57 (0.1)^{de}	4.91 (0.29)^{cd}	1.66 (0.09)^{c}	0.98 (0.06)^{ab}
		Root	0.36 (0.03)^{cde}	0.33 (0.1)^{hi}	1.24 (0.29)^{fgh}	1.09 (0.09)^{def}	0.91 (0.06)^{abc}

$^{a,b,\ldots,i}$The means with different letter differ significantly at $p < 0.05$.

and reported that metals were observed less in shoots than in roots. Ebrahim et al. [39] indicated decrease in TDS by 55.93% in hard water with the help of vetiver root using adsorption method. Wagner et al. [49] reported that both N and P supplies increased vetiver growth significantly (<1% level). Andra et al. [51] studied on Pb–PC_n (phytochelatins) complexes in root and shoot compartments of vetiver grass and found that Pb concentrations were significantly lower than those observed in root.

4. Conclusion

Phytoremediation for industrial waste water polluted with various elements such as heavy metals could be carried out using vetiver technology. The results of many studies [e.g. 6,52] indicated that quality of wastewater has a significant effect on vetiver growth and the uptake of different elements. Field experiments provide practical information for achieving the evolution of phytoremediation strategies that cannot be provided by laboratory tests. It has been observed that application of a floating plant system for phytoremediation of wastewater as a predominant method is economical to build, needs little conservation and improves biodiversity [9].

The main purpose of this research was to examine the efficiency of the vetiver system for the treatment of two unconventional water samples during four weeks. The results of this study's field research showed that vetiver has a potential application for phytoremediation of anions and cations from unconventional water. Although, treatment efficiencies were low compare to similar studies which had water as media, vetiver system showed a suitable potential to be applied *in situ* to treat unconventional water. In addition, the results of this study indicated that the treatment efficiencies of unconventional water sample taken from the mine could be very different depending on the water salinity variability during a year.

The quality of the unconventional water, and particularly the concentration of anions and cations, showed a significant effect on vetiver growth and the uptake of contaminants. The hydroponic system is a good environment to grow vetiver and to achieve absorption of pollutants by the shoot and root. In such a system, the shoots and roots could be easily harvested. High concentrations of anions and cations could also influence plant growth and cause low absorption efficiency; thus, this system would be effective after pre-treatment or in unconventional waters with low to medium contamination of anions and cations. The number of weeds applied for the removal of pollutions should be adequate to decrease the rates of contaminants to meet the standards required; otherwise, re-cultivation may be needed to obtain suitable results. Compared to previous phytoremediation, the results suggest a system with more potential for becoming cost-efficient, and also suitable methods for absorption of contaminants from the environment. Future studies may also focus on more detailed analysis of not only elements' removal by plant but also on elements that are bound/adhered to the polyethylene membrane and which are unavailable for plant uptake.

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