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RESEARCH ARTICLE

Using phytoremediation by decaying leaves and roots of reed (*Phragmites austrates*) plant uptake to treat polluted shallow groundwater in Kuwait

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Abstract

Phytoremediation is the use of plants and their associated microorganisms, to remove or degrade biochemically the pollutants from the soil and groundwater environment. It is an emerging technology for water/soil/agricultural remediation, which offers a low-cost flexible technique suitable for use against a number of different types of contaminants in a variety of media. This research illustrates that this technology can be used to reduce the concentration of pollutants in Kuwait shallow groundwater to improve the efficiency of irrigation for greenery purposes. The investigation of this research was carried out through using reed plants in two experiments: First in decaying reed leaves and the second in reed roots. The change in the concentration of the inflow of the polluted groundwater and the outflow of the treated irrigation water was measured in the laboratory for chemical analysis. The two experiments indicated the ability of the reed plants to reduce the concentration of salt ions (Cl, Na, K, and SO_4) by about 66–78%. Roots reduced the total dissolved solid values by 66%, the plants were capable of reducing the concentration of nitrogen compounds significantly, and fluoride was reduced by ≈ 86% while the roots removed the lithium significantly. This research illustrates that the roots of the reed plants are capable to reduce the heavy metals of Cd, Co, Zn, and Fe significantly. The reduction of Al, Cu, and Cr by the roots of the reed plants was 53%, 39%, and 89% respectively. These results provide a preliminary indication that reed plants have the capability to remove pollutants at various levels and that salinity can be reduced considerably to improve irrigation efficiency in Kuwait.

Keywords Phytoremediation · Reed · Decaying leaves · Efficient irrigation · *Phragmites austrates*

Introduction

The rapid increase of the level of pollution in soil and shallow groundwater environment due to various industrial and agricultural activities has become a serious issue in Kuwait. This type of pollution has reduced the efficiency of native groundwater to irrigate crops in Kuwait and affected the health of residents (Aliewi and Al-Khatib 2015; Afzal et al. 2014). Phytoremediation has emerged since the 1980s as an important technology for plant-based soil and groundwater remediation. It is a sustainable and a promising treatment technology for soil and groundwater pollution problems (Dhanwal et al. 2017). Phytoremediation is a treatment technology, which utilizes the abilities of plants and their associated microorganisms to remove and degrade pollutants in soil and groundwater. Some of these pollutants include heavy metals (Mohan et al. 2015; Ahmadpour et al. 2015), organic and inorganic compounds, salts (Gerhardt et al. 2017), and hydrocarbon pollutants (Almansoory et al. 2015). Heavy metals above certain limits can be toxic and negatively affect the natural microbial distribution leading to disorder of important ecological processes (Kim and Owens 2010). Padmavathiamma and Li (2007) reviewed hyper-accumulation metals in plants as a means of phytoremediation treatment. They explained that

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plants absorb metals from soil, accumulate them in roots, and translocate them to harvestable leaves. Phytoremediation was used to decontaminate coalmine effluents from toxic metals using *Salvinia molesta* and *Pistia stratiotes* species from India (Lakra et al. 2017). Doni et al. (2015) also used the technology as a sustainable management strategy for the decontamination of polluted scoured marine sediments different plant species of Vaginatum plants and organic matter (compost). They showed that this treatment is capable of reducing significantly both heavy metals and total petroleum hydrocarbons. Using transgenic plants to enhance phytoremediation capabilities was investigated previously (Singh and Singh 2017) and illustrated to be successful. The Jatropha plant was used to treat organic and inorganic pollutants by phytoremediation (Kamusoko and Jingura 2017). They showed that this technology could enhance the management of water movement, leaching of contaminants, containment, and stabilization. They showed that the plant is able to survive on degraded land and has the ability to facilitate reclamation, uptake, translocation, and cleansing of pollutants. In petroleum industrial countries, the contamination of soil affects the growth of plants. Ma et al. (2018), Klimek et al. (2016), and Ogoko (2014) investigated the potential of two plants to petroleum-tolerant hydrocarbon (TPH) and polycyclic aromatic hydrocarbons (PAHs) in the soil contamination. They concluded that this type of pollution can affect the rate of soluble protein and height of plants.

In the industrial world, lithium pollution can affect the plant growth as reported by Antonkiewicz et al. (2017) who showed that plants from the Solanaceae are resistant to high lithium concentrations in salty soils. They can contain more than 1000 mg Li per kg. Wu et al. (2017) and Mahar et al. (2016) showed that bioremediation of plants and soil fertility to boost up plant growth can be enhanced. Plants are proved to use phytoremediation process for the removal of heavy metals and macro-elements from sewage sludge. Kołodziej et al. (2015) illustrate the use of sewage sludge in bioenergy production through studying the effects of sorghum biomass production. Moreover, phytoremediation is a cost-effective method of treatment as compared to conventional methods (Wan et al. 2016). In many cases, phytoremediation provides a feasible alternative to the traditional and more expensive methods such as “pump and treat.” In general, the cost of using this phytoremediation is one-third to one-fifth the costs of other conventional technologies (Carman and Crossman 2000; Black 1995). Phytoremediation is also known to be more acceptable by the public and the regulators since it is environmentally compatible and esthetically pleasing. Despite its important advantages, phytoremediation has some disadvantages and limitations, which make it undesirable for some environmental applications (Filippis 2015). Phytoremediation can only work at sites that are well suited for plant growth. The existence of contaminants in high concentration could be toxic to the plants and therefore may limit application on some sites or some parts of sites (Raskin and Burt 2000). The depth of contaminants is another obstacle that faces phytoremediation. If a pollutant is located in a deep aquifer, then plant roots cannot reach it. Contaminated aquifers must be within 20 ft of the surface in order for plant roots to be able to treat them. Some aquifers may be too deep or located under an urban area that makes it difficult to plant sufficient number of plants to do this job (Smith 1997). However, deep groundwater contaminants or leachate pond effluent may be treated by pumping and drip irrigation on plantations of trees (Schnoor et al. 1995). Phytoremediation is also limited by the suitability and growth rate of the plants. Choosing the suitable plant species is a key factor in phytoremediation. Some plants are able to degrade only certain contaminants. Also, each plant can tolerate specific types of environments (Filippis 2015). Table 1 illustrates the various kinds of contaminants and the plants used for each one.

Soil and groundwater quality deterioration in Kuwait is a result of urbanization and industrial activities. The aim of this research is to investigate the potential of reed plants as phytoremediation technology to enhance degradation and mineralization of the pollutants (e.g., heavy metals, N

Table 1 Examples of plants in phytoremediation (Smith 1997)

Plant	Contaminant	Use
Indian mustard greens	Heavy metals	Removes Pb, Cr, Cd, Zn, and Cu from soil.
Goosefoot	Salt pollution from petroleum production	These salt-resistant weeds have cleaned-up oil-patch areas ravaged by brine spills.
River reeds	Runoff from airplane deicing agents	In tests, the reeds rapidly broke down glycol antifreeze into water and CO_2.
Desert reeds	Salts and heavy metals	Remove heavy metals and reduce the concentration of salts ions.
Poplar trees	TCE, petroleum, atrazine, other groundwater contaminants	These deep-rooted trees have been used to halt the spread of contaminated groundwater.
Kochia and multiflora rose	Herbicide spills at agrichemical dealer lots	Used in combination, the tumble weed like Kochia plant and the woody multiflora rose halt the spread of herbicides.
Sunflowers	Radionuclides	Shown to remove uranium from water and have been successfully used at sites contaminated from the Chernobyl disaster.

compounds, and salts) in the native shallow groundwater in order to increase irrigation efficiency. This is an important issue for Kuwait, which suffers from shortages of suitable water resources for irrigation and agricultural lands. The reed plants were chosen because they are available and common in the desert of Kuwait.

Study area

The study area is Kuwait in the Middle East. Kuwait suffers from water scarcity, unfertile lands for agriculture, and industrial activities that pollute the existing water and land resources despite the fact that they are scarce.

Data used

The data used in this study are generated from two experiments on reed plants. One experiment is conducted in KISR laboratory and the second one is conducted in the agricultural fields of KISR in Kuwait city.

Methodology

Phytoremediation is a broad class of cleanup techniques which apply many treatment mechanisms. In the context, the treatment mechanism is well explained in Chappell (1998) and Van Deuren et al. (2002), which is summarized in terms of breaking down of organic containments in the soil or groundwater by microbial activity and then absorbed by roots or precipitation within the soil zone. Certain plants, called “hyper-accumulators,” absorb large amounts of heavy metals and concentrate them in the plant roots and leaves.

In this research, a groundwater well was identified within the premises of Kuwait Institute for Scientific Research (KISR) as a source of polluted shallow groundwater to be treated by reed plants for irrigation purposes. The native groundwater of this well was analyzed chemically at KISR laboratories. It was found that the TDS, concentration of salts, nitrates, and fluoride were elevated as presented in Table 2. It was an objective to illustrate that the reed plants are capable of reducing the concentration of heavy metals in KISR’s groundwater. In this methodology, the treatment by the reed plant will be tested through their roots and leaves. The significance of that is to test if the effective volumes around the roots and the leaves yield any difference in the efficiency of reed treatment. As will be seen later the effective contact volume of leaves is 3.5% of that volume of the effective contact volume of roots, so this paper investigates as well the relative efficiency of the roots in reducing the concentration of pollutants in the shallow groundwater of KISR premises.

Table 2 Chemical analysis of the original sample (native groundwater)

Parameter	Unit	Original sample
TDS	mg/l	11,675
Cl	mg/l	4148
SO_4	mg/l	2862
Na	mg/l	2720
K	mg/l	40.8
NH_4	mg/l	10.1
NO_3	mg/l	115
F	mg/l	2.3
Li	mg/l	0.23
Ca	mg/l	796
Mg	mg/l	354
Fe	μg/l	7.96
Zn	μg/l	15.1
Cr	μg/l	4.18
Co	μg/l	0.53
Cu	μg/l	3.1
Al	μg/l	71.32
Cd	μg/l	1.1

Reed plants were first implanted in the fields of KISR and irrigated with freshwater for about 6 months to allow them to grow up naturally, and then reed plants were irrigated with polluted groundwater from the beach well in two experiments: First, decaying reed leaves were tested in a controlled laboratory setting. Second, reed plant roots were irrigated with polluted groundwater to measure any change in the concentration of the inflow and outflow.

In the first experiment, samples of dry leaves were collected from the reed plants. The leaves were then cleaned with distilled water and left to be dried at room

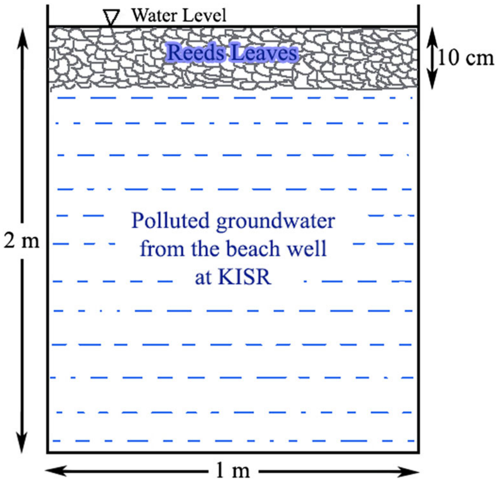


Fig. 1 Basic design of reed leaf experiment in the laboratory (Adobe Photoshop version 13.0.1)

temperature. Dry leaves were crushed roughly and used as such. Then, the reed leaves were forced to be fully sunk in the first 10 cm of the polluted groundwater in the experimental tank to maximize the contact between the reed leaves and the polluted groundwater as shown in Fig. 1. By this, the effective volume for the reed leaf experiment is 0.08 m^3. The leaf experiment was conducted at the Water Research Centre because of the controlled environment. The repeat time of the sampling was every 2 weeks in order to detect any changes in the concentration of pollutants.

The methodology of using the roots of the reed plant to treat the polluted irrigating water is illustrated in Fig. 2. In this methodology, a tank of 1 m diameter and 2 m height was used as the basin to conduct the experiment. This basin was filled with native soil for about 1.5 m to grow the reed plant. All these dimensions yield an effective volume of 2.31 m^3 as the portion of the field basin for the root experiment. The basin of the root experiment as shown in Fig. 2 was flooded with polluted groundwater from KISR's well to investigate the treatment efficiency of the roots of the reeds, to detect any change in the concentration of chemicals, metals, and salinity between the native water (Table 2) and the outflow taken from the sampling point shown in Fig. 2. Samples were taken every 2 weeks approximately as a repeat time for chemical analysis to detect gradual changes in pollutants concentration.

The materials and methods used for the determination of the concentration of pollutants were the standard methods (APHA 2015) in the laboratory as follows:

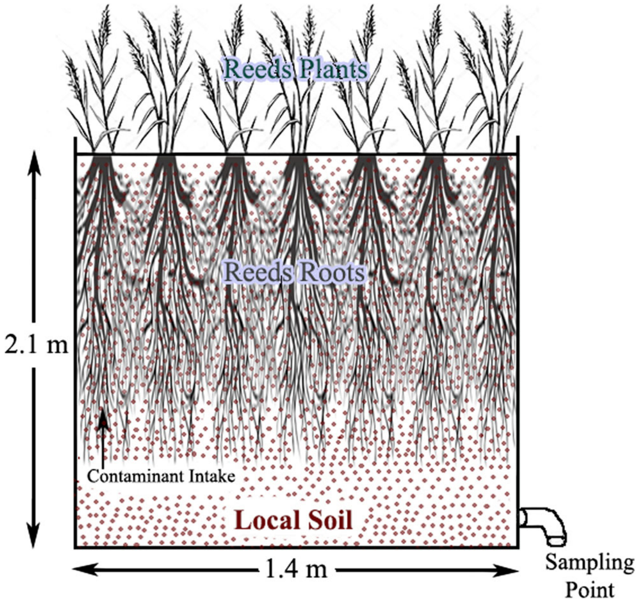


Fig. 2 Basic design of reed root experiemnt in the field

- Major cations and anions (Na, K, Ca, Mg, Cl, and SO_4): Ion chromatograph (ASTM D6919-09 and SMEWW Method No. 4110).
- Nutrients (NO_3, NH_4): Discrete analyzer (SMEWW Method No. 4500 G, E, F, and C).
- Trace metals (Fe, Zn, F, Li, Co, Cu, Al, Cd): ICP-OES (USEPA 200.7)

Results and discussion

Suitability of concentration of ions in irrigation water

Because this research addresses the use of plants to improve irrigation efficiency, the suitability of the concentration of ions in irrigation water for plant growth is first presented as follows:

- Lithium (Li) is toxic for plants. Lithium sources come mainly from Li industrial activities (Hull et al. 2014) and disposal of Li batteries (Al-Thyabat et al. 2013). Compared to other cations in soil, Li is mobile and may leach into receiving waters, be taken up by plants, or have other biological impacts. Li reduces the plant growth by altering metabolism of nutrients in plants (Shahzad et al. 2016). Therefore, reducing Li will help the growth of plants. It is understood that Li has metabolic functions in salt-tolerant plants (Antonkiewicz et al. 2017). Komorowicz, and Baralkiewicz (2016) and Esetlili et al. (2014) reported arsenic, lithium, and fluoride pollution in many industrial countries such as Poland, Turkey, the USA, and China. Anderson et al. (1988) report that the limits of Li in groundwater and soil should be within 0.5 mg/l and 0.98–1.48 mg/l respectively. However, Li is tolerated by most plants up to 5 mg/l in water. There is no official legal act about lithium concentration in the groundwater and soil of Kuwait but the country almost follows the limits provided by Anderson et al. (1988). In Kuwait, Li is a major concern at solid waste dumping sites, cement factories, sewage sludge from treated wastewater plants, agricultural farms where sewage sludge is used, and lithium batteries dumping sites.
- Fluoride (F) influences the metabolic effects of plant growth. A water fluoride level of 1.5 mg/l can be toxic to plants (Swarup and Dwivedi 2002). The anthropogenic sources were identified as fertilizers, combusted coal, and industrial waste, with phosphate fertilizer being the most significance source of F^- accumulated in the soil.
- Heavy metals can cause significant reduction in plant growth. The heavy metals that have the most toxic effect are Cd, Cu, Zn, and Cr (Athar and Ahmad 2002). The following limits (Rowe and abdel-Magid 1995) should

not be exceeded in irrigating water to reduce toxic effects and to improve irrigation efficiency: Al (5–20 mg/l); Cd (0.01–0.05 mg/l); Cr (0.1–1 mg/l); Co (0.05–5 mg/l); Cu (0.2–5 mg/l); Fe (5–20 mg/l); F (1–1.5 mg/l); Zn (2–10 mg/l); and Li (< 2.5 mg/l) (Ahmadpour et al. 2015).

- Freshwater can easily be absorbed through the roots without problems but brackish water faces difficulties to do that. Salinity can limit plant access to soil water by increasing the osmotic strength of the soil solution. In Kuwait, hotter weather requires more energy from plants to absorb water. The following limits (Rowe and abdel-Magid 1995) are favorable limits for good-quality water to irrigate with: TDS < 960 mg/l; Cl < 140 mg/l; K < 10 mg/l; Na < 50 mg/l; SO_4 < 400 mg/l.
- NH_4 should be in the range 15–30 mg/l and NO_3 around 50 to 100 mg/l (Rowe and Abdel-Magid 1995).

Domination of ions in the native groundwater (original sample)

The native groundwater was analyzed chemically using Piper methodology (Fig. 3). The results show that the type of this water is brackish with domination of Na-Cl-SO_4 salt ions. That means the salt is dominating this water, which makes it difficult to irrigate with especially the TDS value of 11,675 mg/l is substantially above the limit of 960 mg/l (Rowe and Abdel-Magid 1995).

The chemistry of the original water shows that Cl = 4148 mg/l which is > 140 mg/l, SO_4 = 2862 mg/l which is > 400 mg/l, Na = 2720 mg/l which is > 50 mg/l, and K = 40.8 mg/l which is > 10 mg/l. It should be noted that using the reed plant is not intended to bring down the concentration of these ions to the limit of their use but the aim is to illustrate that the reed plant can reduce considerably the concentration of these ions to improve irrigation efficiency and productivity. The concentration of NH_4 in the original sample is 10.1 mg/l which is less than the limit of 3.5–15 mg/l (Caicedo et al. 2000; Rowe and Abdel-Magid 1995) and for NO_3 is 115 mg/l which is less than the limit of 50–100 mg/l. The concentration of Li in the original sample is 0.23 mg/l < 5 mg/l and F is 2.3 mg/l which is greater than the limit of 1.5 mg/l.

Analysis of reducing salts in the polluted native groundwater

High concentration of salts affects plant growth by limiting the uptake of calcium and increasing the adsorption of sodium and potassium, resulting in a disturbance in the cationic balance within the plant. The decaying leaf method and root method were used to investigate the reduction of salts in the native polluted groundwater. Figure 3 shows on Piper diagram that the roots of the reed plants in the experiments used at KISR premises treat better the salts in the polluted shallow groundwater sample as follows:

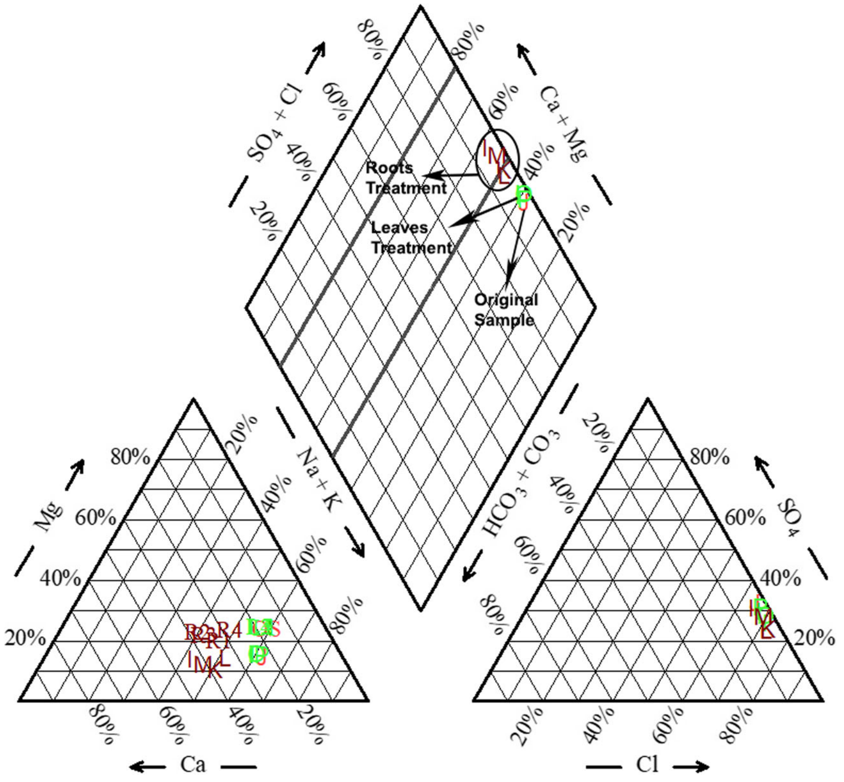


Fig. 3 Piper analysis before treatment and after treatment of the native polluted water using reed plants

Table 3 Concentration of salt ions (mg/l) after using reed plants

Elapsed time (weeks)	Na^+		Cl^-		SO_4^{2-}		K^+		TDS	
	R	L	R	L	R	L	R	L	R	L
Original	2720	2720	4148	4148	2862	2862	40.8		11,675	11,675
4		3069				3298				11,796
8	925		1740	–	793		18.04		11,632	
10	838	2648	1519	–		2519				11,632
12	805	2594	1430	–	644	2469	10.5		4024	11,291
Standard deviation*	1062		764		1140		5.6		3780	

L, leaves; *R*, roots

*For treatment values

- Original sample: alkaline water with SO_4/Cl salt domination
- Leaf treatment: alkaline water with less domination of SO_4/Cl salts
- Root treatment: earth alkaline water with less SO_4 salt domination. Not dominated by Cl ions and to be less dominated by SO_4 ions as salts, this means that on Piper diagram (Fig. 3) the roots managed to push the water type.

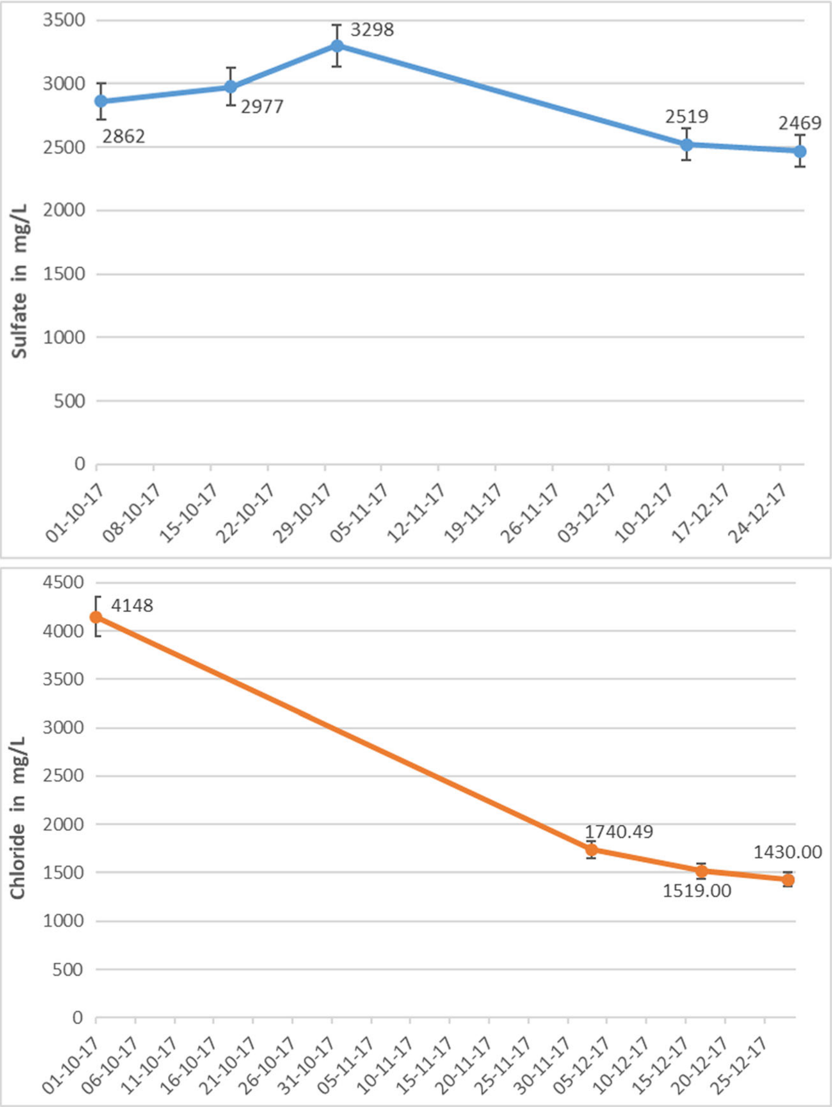


Fig. 4 Reduction of salt ions by reed plants (SO_4 by leaves and Cl by roots)

The results of reducing the concentration of salts are presented in Table 3 and some of them are shown in Fig. 4. It should be noticed that a 5% error bar is shown on this figure to illustrate the range of values with this error. Two remarks can be observed from Table 3. The first remark is that the concentration of salt ions (Na and SO_4) and TDS increased in the first month because of the effect of evaporation and then reduced because the efficiency of the decaying leaves to reduce the concentration of salts was greater than the effect of evaporation. The second remark is that leaves observed a slight reduction in the concentration of salt ions. However, the reductions in the TDS, SO_4, Cl, and K values for the same period in the root experiment were substantial as shown in Fig. 4 for Cl ion. It is believed that the roots have bigger surface area and stronger ability to absorb pollutants by the roots and to precipitate them from the irrigating water within the rhizosphere (phytostabilization process). In fact, the volume of 2.31 m^3 for the effective portion of the roots compared with 0.08 m^3 of the leaf effective portion supports that the roots are more efficient in reducing the concentration of salts in the shallow groundwater of KISR premises.

Analysis of reducing the concentration of N compounds

Irrigation water high in N can cause quality problems in crops. The existence of NH_4 as an example at higher concentrations than 30 mg/l is phytotoxic (Kiraly et al. 2013). When the level of NH_4 is lower than 3.5 mg/l, then the plant growth will be toxic to seedlings (Caicedo et al. 2000). The optimal level for NH_4 in soil for plant growth is around 25 mg/l. In Kuwaiti irrigation environment, the level of NH_4 is around 1 mg/l (Akber et al. 2006) which is less than 3.5 mg/l. But the native groundwater contains 10.1 mg/l of NH_4 (Table 2) which is greater than 3.5 and less than 25 mg/l. In Table 4, it is shown that the treatment with reed plant through leaves and roots reduced considerably the 10.1 mg/l of ammonium in 8 and 12 months respectively, illustrating the capabilities of the reed plant to almost remove the ammonium concentration from the irrigation water. It seems that the leaves are quicker than the roots in consuming the inorganic nitrogen (ammonium) as a nutrient (plant proteins). Any level of nitrates greater than 50 mg/l in groundwater (after leaching from agricultural soil) can cause pollution problems and low levels of nitrates in the soil will impact the growth of plants (Hachiya and Sakakibara 2017). In Kuwait, the level of nitrates in the soil of most farms was about investigated thoroughly by Akber et al. (2006) and Shahid and Omar (1999). They found the level of nitrates in the soil of these farms to vary between 5 and 298 mg/l. In general, the organic matter outside Kuwait farms is very low. The level of nitrates in the irrigating water as presented in Table 2 is 115 mg/l. It took the reed leaves and roots about 8 weeks (Table 4) to almost remove the 115 mg/l NO_3 ions from the polluted groundwater. This illustrates the capability of the reed plant to remove the nitrates almost completely.

It is clear that the reed plants have the capacity to almost remove N compounds completely in case of excessive nitrogen content. The reed plants transform the inorganic nitrogen from the irrigating groundwater into plant biomass, thereby removing the constituent from groundwater (Rowe and Abdel-Magid 1995). The plant biomass is normally managed to enrich soil fertility and site productivity. Some biomasses are used as a source of renewable energy. However, N is needed for plant growth; therefore, good fertilizers and irrigation management can help solve these problems (Rowe and Abdel-Magid 1995) especially their concentration in the soil of Kuwait away from the farms is not sufficient. Regardless of the crop, nitrates and ammonium should be credited toward the fertilizer rates in general.

Analysis of reducing the concentration of fluoride and lithium

The experiments carried out in this paper show that the reed plants reduced the concentration of F and Li ions

Table 4 Concentration of N compounds (mg/l) after using reed plants

Elapsed time (weeks)	NH_4^+		NO_3^-	
	R	L	R	L
Original	10.1	10.1	115	115
4		2.63		61.1
8	0.67	< 0.1	< 0.1	< 0.1
10	0.24	< 0.1	< 0.1	< 0.1
12	< 0.1	< 0.1	< 0.1	< 0.1
Standard deviation*	1.8		30.5	

L, leaves; *R*, roots

*For treatment values

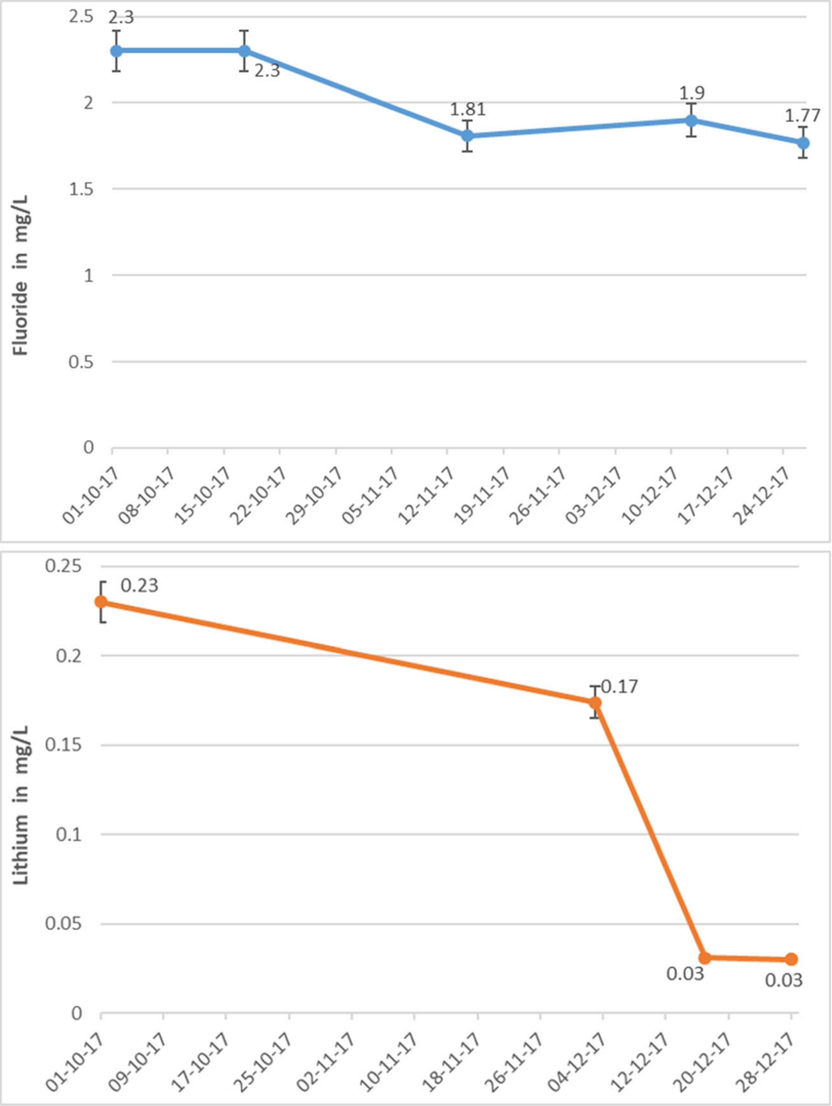
Table 5 Concentration of F and Li (mg/l) after using reed plant

Elapsed time (weeks)	F^-		Li^+	
	R	L	R	L
Original	2.3	2.3	0.23	0.23
4	0.32	2.06	0.20	0.14
8	0.28	1.85	0.17	0.13
10	0.17	1.9	0.03	0.12
12	0.17	1.77	0.03	0.12
Standard deviation*	0.9		0.06	

L, leaves; *R*, roots

*For treatment values

Fig. 5 Reduction of F and Li concentrations by reed plants (F by leaves and Li by roots)



through the absorption process as presented in Table 5 below. Table 5 and Fig. 5 show that the leaves of the reed plant reduced the concentration of F and Li ions by 23% and 48% respectively while the reed roots reduced 90 to 86% of the concentration of F and Li ions respectively**.** This result agrees with Antonkiewicz et al. (2017) who reported that after applying different Li concentrations within nutrient solution for the maize plant, the highest concentration of Li was found in the roots of maize while the lowest concentration of Li was found in the leaves**.** This illustrates the capability of the roots of reed plant to effectively absorb lithium as tested by Antonkiewicz et al. (2017). It should be noticed that a 5% error bar is shown on this figure to illustrate the range of values with this error. The bar is not shown on the figure when the concentration of Li is very small (i.e., 0.03 mg/l) producing an insignificant 5% error of this value.

Analysis of reducing the concentration of heavy metals

The reed leaves reduced Co, Cd, and Fe by almost 100% within a period of about 2.5 months (Table 6). They reduced the concentration of Zn, Al, Cr, and Cu by 76%, 73%, 72%, and 64% respectively. The reed roots reduced Co, Cd, Cr, Zn, and Fe by almost 100% within a period of about 3 months. They reduced the concentration of Al and Cu by 53% and 39% respectively.

For heavy metals, the reed roots act as “hyper-accumulators” to absorb large amounts of metals (such as Zn, Ni, and Cu) and concentrate them in the plant roots. This is why the reed roots are successful in removing heavy metals from polluted groundwater.

In summary, the results of reduction of the pollutants in Kuwaiti soil/groundwater environment are presented in Table 7.

Table 6 Concentration of some heavy metals (μg/l) after using reed Plants

Elapsed time (weeks)	Fe		Al		Zn		Cd	
	R	L	R	L	R	L	R	L
Original	7.96	7.96	71.32	71.32	15.1	15.1	1.1	1.1
4		1.8		39.7		7.1		0.3
8	< 0.01		35.94		15.1	3.7	< 0.1	< 0.1
10	< 0.01	0.29		22.47				
12	< 0.01	0.16	33.51	19.02	< 0.2		< 0.1	< 0.1
Standard deviation*	0.37		17		5.44		0.1	

L, leaves; *R*, roots

*For treatment values

Table 7 Summary of reduction of specific pollutants by reed plants

Parameter	Unit	Original sample	Leaves outflow	Reduction	Root outflow	Reduction
TDS	mg/l	11,675	11,291	3%	4024	66%
Cl	mg/l	4148	–	–	1430	66%
SO_4	mg/l	2862	2469	14%	644	78%
Na	mg/l	2720	2594	5%	805	70%
K	mg/l	40.8	–	–	10.5	74%
NH_4	mg/l	10.1	< 0.1	100%	< 0.1	100%
NO_3	mg/l	115	< 0.1	100%	< 0.1	100%
F	mg/l	2.3	1.77	23%	0.32	86%
Li	mg/l	0.23	0.12	48%	0.03	100%
Fe	μg/l	7.96	0.16	98%	< 0.01	100%
Zn	μg/l	15.1	3.7	76%	< 0.2	100%
Cr	μg/l	4.18	1.19	72%	0.47	89%
Co	μg/l	0.53	< 0.1	100%	< 0.1	100%
Cu	μg/l	3.1	1.13	64%	1.88	39%
Al	μg/l	71.32	19.02	73%	33.51	53%
Cd	μg/l	1.1	< 0.1	100%	< 0.1	100%

Analysis of statistical significance of the results

The purpose of this statistical analysis is to compare results from two experimental treatments by reed leaves and reed roots to decide if the difference between the two treatments is statistically significant. The parameter that will be used in the comparison of the results is the reduction of the concentration of pollutants. Collected data were from two groups: group A—treatment by reed leaves and group B—treatment by reed roots. The statistical tests will be used to determine whether a difference between means for the leaf and the root treatments is statistically significant. The following hypothesis will be used:

- Null hypothesis no. 1: there is no difference between the means for the leaf and the root treatments.
- Alternative hypothesis no. 1: A difference between the means for leaf and the root treatments due to reasons related to the mechanisms of treatment and surface area controls the direct contact between the leaves and roots with the pollutants.

The assessment of the hypotheses will be based on:

- If $P \leq 0.05$, then reject the null hypothesis and accept the alternative hypothesis.
- If $P > 0.05$, then accept the null hypothesis and reject the alternative hypothesis.

Step No. 1. Testing the significance of the reduction (in %) of the concentrations of salts.

Salt ion	Na	Cl	SO_4	K	TDS
Group A: L treatment	5%	5%	14%	4%	3%
Group B: R treatment	70%	66%	78%	74%	66%

Results of step no. 1

Treatment	N	Mean	Std. Deviation	Std. Error Mean
Reeds Leaves	5	.062	.04438	.01985
Reeds Roots	5	.708	.05215	.02332

The reduction of salt concentrations by reed leaves is 6.2 ± 4.4% (which is very low) and 70.8 ± 5.2% by reed roots (which is considerable). The independent samples test shows the following results:

	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Concentration of salt	-21.093	8	.000	-0.646	.03063	-.71663	-.57537

The above result is highly significant with confidence more than 99% level (*P* value = 0.000) to show that the root treatment has greater capability than leaf treatment in reducing the concentration of salts since the mean difference is 64.6%.

Step No. 2. Testing the significance to reduce the concentrations of fluoride and lithium (in %).

F and Li ions	F	Li
Group A: L treatment	23%	86%
Group B: R Treatment	48%	100%

Analysis of the reduction of the concentration of F and Li by leaves is on average 54.5% while it is 74% by roots, which indicates that the roots have a better capability than the leaves to reduce the concentration of these ions.

Step No. 3. Testing the significance to reduce the concentrations of heavy metals (in %).

Heavy metal ions	Fe	Zn	Cr	Co	Cu	Al	Cd
Group A: L treatment	98%	76%	72%	100%	64%	73%	100%
Group B: R Treatment	100%	100%	89%	100%	39%	53%	100%

Results of step 3

Group Statistics

Treatment	N	Mean	Std. Deviation	Std. Error Mean
Reeds Leaves	7	.8329	.15457	.05842
Reeds Roots	7	.8300	.25910	.09793

The reduction of heavy metal concentrations by reed leaves is 83.29 ± 15.46% while by reed roots 83.0 ± 25.91%. Both leaf and root treatments have the same mean. The independent samples test shows the following results:

	t-test for Equality of Means						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Concentrations of heavy metals	.025	12	.980	.00286	.11403	-.24560	.25131

From the *t* test with (*P* value = 0.98), the root and leaf treatments could not differ from each other. In other words, the treatment type does not affect on the concentrations of heavy metals.

Conclusions

This research has illustrated with evidence that reed plants are capable of effectively removing contaminants from the polluted shallow groundwater in Kuwait. The reduction percentage of contaminant concentration in Kuwait native and polluted groundwater is presented in Table 6.

In this study, the phytoremediation process was proved to be successful through decaying leaves and roots of the reed plants to reduce the concentrations of contaminants (salts ions, nitrogen compounds, and heavy metals). Table 6 shows that the roots of the reed plants can significantly reduce (Cl, Na, K, and SO_4) by about 66–78%. Also, the TDS value was reduced by the roots by 66%. The reed plants were capable of removing the nitrogen compounds (nitrates and ammonium ions) with high percentage of reduction. However, N is needed (within limits) for plant growth; therefore, good fertilizers and irrigation management can help solve these problems. Nitrates should be kept for irrigation purposes in Kuwait in the region of 50 to 90 mg/l. Fluoride ion concentration was reduced by about 86% while the roots removed the concentration of lithium significantly. The concentration of the heavy metals in the native polluted groundwater is below the international standards (Rowe and Abdel-Magid 1995) but this research illustrates that the roots of the reed plants are capable to remove completely Cd, Co, Zn, and Fe. The reduction of the concentrations of the heavy metals (of Al, Cu, and Cr) by the roots of the reed plants was 53%, 39%, and 89% respectively.

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