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Improving the irrigation quality of Kuwait native shallow groundwater using phytoremediation technology

Hana'a Burezq[a],*, Amjad Aliewi[b]

[a]*Desert Agriculture and Ecosystems Program (DAEP), Environment and Life Sciences Research Center (ELSRC), Kuwait Institute for Scientific Research (KISR), Shuwaikh, Kuwait, Tel. +96524989786; email: haborizq@kisr.edu.kw*
[b]*Water Resources Development and Management Program (WRDMP), Water Research Centre (WRC), Kuwait Institute for Scientific Research (KISR), Kuwait, Tel. +96524989901; email: aaliewi@kisr.edu.kw*

ABSTRACT

In Kuwait, shallow groundwater is used mainly for irrigation purposes. This groundwater is, however, brackish with TDS values ranging from 4,000 to 15,000 mg/L. Also, this groundwater is normally subjected to industrial and agricultural pollution increasing the concentration of heavy metals, nitrogen compounds and salt ions. The aim of this paper is to illustrate through field experiments that the roots of the Reeds plants (which are common in Kuwait) are capable to improve the efficiency of irrigation by reducing the concentration of some pollutants in the native groundwater in Kuwait. Two basins were constructed in the fields of KISR premises then Reeds plants were allowed to grow up under climatic conditions of Kuwait until they were 2.5 m tall. Then the Reeds plants were irrigated with native shallow groundwater from Kuwait aquifers. Samples of inflowing irrigating water and outflowing water from the bottom of the basins were taken over a period of 3 months. The water quality between the two waters was compared. The results show that the Reeds roots are capable of reducing the concentration of salt ions by about 70%, and removing completely heavy metals from the irrigating groundwater and hence improving the irrigation efficiency considerably.

Keywords: Phytoremediation; Reeds roots; Salts ions and heavy metals

1. Introduction

Pollution of groundwater resources and upper ground soil in Kuwait due to intensive industrial and agricultural activities has reduced the efficiency of native groundwater to irrigate crops (Aliewi and Al-Khatib 2015 and Afzal et al. 2014). A relatively new technology known as phytoremediation has emerged as a solution to remediate both soil and groundwater for better irrigation (Dhanwal et al. 2017). Phytoremediation is a suitable treatment technology for different pollutants that include heavy metals (Mohan et al. 2015 and Ahmadpour et al. 2015), organic, inorganic compounds, salts (Gerhardt et al. 2017) and hydrocarbons pollutants (Almansoory et al. 2015, Brynhildsen and Rosswall 1997, Kim and Owens 2010 and Lakra et al. 2017). The technology was also used (Doni et al. 2015, Singh 2017 and Kamusoko and Jingura 2017) to illustrate that it is capable of removing both heavy metals, organic and inorganic pollutants in addition to total petroleum hydrocarbons. Wu et al. 2017 and Mahar et al. 2016 showed that bioremediation of plants and soil fertility can be improved. Moreover, phytoremediation is a cost-effective method of treatment (Wan et al. 2016 and Vose et al. 2000). In many cases phytoremediation is a better solution than "pump and treat" solutions (Vose et al. 2000, Carman and Crossman 2000 and Black 1995).

Phytoremediation, however, has some limitations in some environmental applications (Filippis 2015) such that the technology is suitable only for locations that are well suited for plant growth. The high concentration of contaminants is toxic to the plants and in these locations the technology is not applicable (Raskin et al. 2000). In order for the technology to be successful, the depth to contaminants should not be great. It should be within 20 feet of the ground surface in order for plant roots to be able to treat them (Smith 1997 and Schnoor et al. 1995). Phytoremediation is also controlled by the suitability and growth rate of the plants. Table 1 presents the contaminants type and the plants used for each one.

* Corresponding author.

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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 de-icing 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 such as 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.

The aim of this paper is to use the indigenous Reeds Plants as phytoremediation technology to examine its capability to enhance degradation of the pollutants and hence increase irrigation efficiency. Kuwait is chosen as the study area because it suffers from water scarcity and infertility of agricultural lands.

2. Technical approach

Phytoremediation is the use of many treatment mechanisms using plants (Chappell 1998 and Van Deuren et al. 2002). In this paper, a polluted beach well at KISR's premises was planned to be treated by Reeds plants. The native groundwater of this well was analyzed chemically at KISR laboratories and the results are presented in Table 2. Reeds plants were first implanted (in the fields of KISR) and irrigated with freshwater for about 6 months to allow them to grow up naturally. After that the Reeds plants were irrigated with polluted groundwater from the beach well using a closed basin in the field. Then the basin in Fig. 1 was flooded with polluted groundwater from the beach well to investigate the treatment efficiency of the roots of the Reeds in a way to detect any change in the concentration of pollutants between the native water and the outflow taken from the sampling point shown in Fig. 1. The volume of the portion of the field basin that was effective for the roots experiment as 2.31 m^3 (the root zone in this experiment is 1.5 m).

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

Parameter	Unit	Original sample
TDS	mg/L	11,675
Cl	mg/L	4,148
SO_4	mg/L	2,862
Na	mg/L	2,720
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

3. Results and discussion

The suitability of the concentration of ions in irrigation water for plant growth is presented as follows:

- Lithium (Li) is toxic for plants. It affects the mobility of nutrients from soil to plants. Lithium sources come mainly from Li industrial activities (Hull et al. 2014) and disposal of Li batteries (Al-Thyabat et al. 2013). Li reduces the plant growth by altering metabolism in plants(Shahzad et al. 2016). Therefore, reducing Li will help the growth of plants.
- 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).
- 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).
- 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.

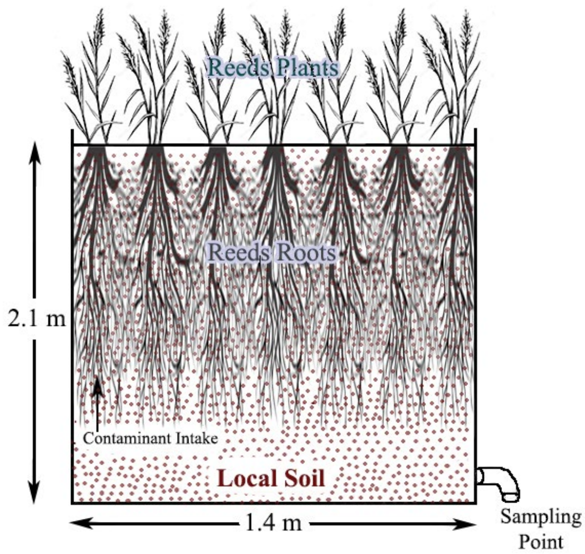

Fig. 1. Basic design of Reeds roots experiment in the field.

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).

The native groundwater was analyzed chemically and showed 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 TDS value of 11,675 mg/L which is substantially above the limit of 960 mg/L (Rowe and Abdel-Magid 1995). Also the chemistry of the original water shows that Cl = 4,148 mg/L which is >140 mg/L, SO_4 = 2,862 mg/L which is >400 mg/L, Na = 2,720 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 roots of Reeds 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 these roots 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 15 mg/L and for NO_3 is 115 mg/L which is greater than the limit of 50–100 mg/L. The concentration of Li in the original sample is 0.23 mg/L < 2.5 mg/L and F is 2.3 mg/L which is greater than the limit of 1.5 mg/L. 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 roots of the Reeds plants were used to investigate the reduction of salts in the native polluted groundwater which is an alkaline water with SO_4–Cl salts domination. By Reeds roots treatment, the type of water changed to earth alkaline water with less SO_4 salts domination. The results of reducing the concentration of salts are presented in Table 3 and some of them are shown in Fig. 2. The reductions in the TDS, SO_4, Cl and K values for

Table 3
Concentration of salt ions (mg/L) after using Reeds roots

Elapsed time (weeks)	Na^+	Cl^-	SO_4^{2-}	K^+	TDS
Original	2,720	4,148	2,862	40.8	11,675
4					
8	925	1,740	793	18.04	11,632
10	838	1,519			
12	805	1,430	644	10.5	4,024

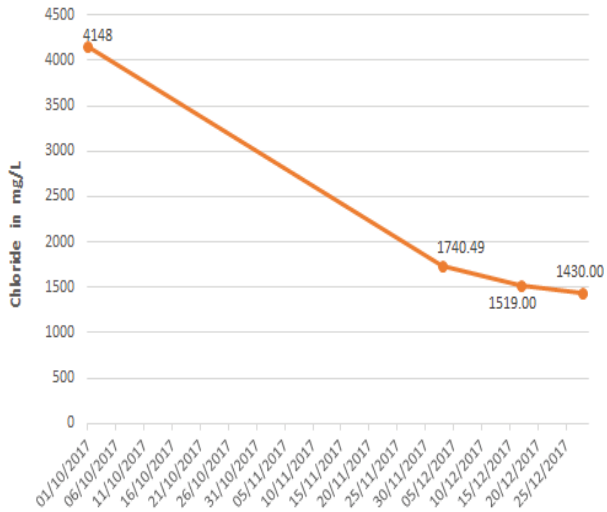

Fig. 2. Reduction of chloride by Reeds roots.

Table 4
Concentration of N compounds (mg/L) after using Reeds roots

Elapsed Time (weeks)	NH_4^+	NO_3^-
Original	10.1	115
4		
8	0.67	<0.1
10	0.24	<0.1
12	<0.1	<0.1

the same period of time in the experiment were substantial as shown in Fig. 2 for Cl ion. It is believed that the roots have big surface area and strong ability to absorb pollutants by the roots and to precipitate them from the irrigating water within the soil zone.

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 (Király et al. 2013). It took the Reeds roots 2 to 3 months to remove NH_4 and NO_3 ions from the polluted groundwater (Table 4). The Reeds roots transform the inorganic nitrogen from the irrigating groundwater into plant biomass, thereby removing the constituent from groundwater (Rowe and Abdel-Magid 1995). In this study, NH_4 and NO_3 were removed completely. However, N is needed for plant growth, therefore, good fertilizers and

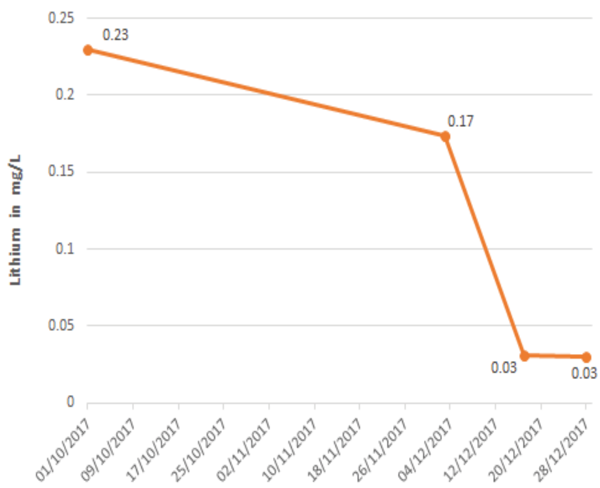

Fig. 3. Reduction of Li concentrations by Reeds roots.

irrigation management can help solve these problems (Rowe and Abdel-Magid 1995). Regardless of the crop, nitrates should be credited toward the fertilizer rates in general.

The experiments carried out in this paper shows that the Reeds roots almost removed (90% to 100% reduction) the concentration of F and Li ions (Fig. 3).

The Reeds 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 (Table 5).

For heavy metals, the Reeds roots act as "hyper-accumulators" to absorb large amounts of metals (such as Zn, Ni and Cu) and concentrate them in the plant roots. Therefore, the Reeds roots are successful in removing heavy metals from polluted groundwater.

4. Conclusions

This paper has illustrated with evidence that Reed plants are capable of effectively removing contaminants from the polluted shallow groundwater in Kuwait. The reduction percentage of contaminants concentration in Kuwait native and polluted groundwater is presented in Table 6. In this study, the phytoremediation process was proved to be successful through roots of the Reeds plants to reduce the concentrations of contaminants (salts ions, nitrogen compounds and heavy metals). Table 6 shows that the roots of the Reeds 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 Reeds plants were capable of removing the nitrogen compounds (nitrates and ammonium ions) with 100% complete 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 completely. The concentration of the heavy metals in the native polluted groundwater (Table 6) is below the international standards (Rowe and Abdel-Magid 1995) but this research illustrates that the roots of the Reeds 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 Reeds plants was 53%, 39% and 89%, respectively.

Table 5
Concentration of some heavy metals (μg/L) after using Reeds roots

Elapsed time (weeks)	Fe	Al	Zn	Cd
Original	7.96	71.32	15.1	1.1
4				
8	<0.01	35.94	15.1	<0.1
10	<0.01			
12	<0.01	33.51	<0.2	<0.1

Table 6
Summary of reduction of specific pollutants by Reeds roots

Parameter	Unit	Original sample	Roots outflow	Reduction
TDS	mg/L	11,675	4,024	66%
Cl	mg/L	4,148	1,430	66%
SO_4	mg/L	2,862	644	78%
Na	mg/L	2,720	805	70%
K	mg/L	40.8	10.5	74%
NH_4	mg/L	10.1	<0.1	100%
NO_3	mg/L	115	<0.1	100%
F	mg/L	2.3	0.32	86%
Li	mg/L	0.23	0.03	100%
Fe	μg/L	7.96	<0.01	100%
Zn	μg/L	15.1	<0.2	100%
Cr	μg/L	4.18	0.47	89%
Co	μg/L	0.53	<0.1	100%
Cu	μg/L	3.1	1.88	39%
Al	μg/L	71.32	33.51	53%
Cd	μg/L	1.1	<0.1	100%

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