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Changes in Physico-Chemical Composition of Wastewater by Growing *Phragmites ausrtalis* and *Typha* in an Arid Environment in Saudi Arabia

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Abstract

Kingdom of Saudi Arabia is facing an acute shortage of good quality of water which is further aggravated due to inadequate and non-renewable groundwater resources. Hence, it is very important to explore other alternatives such as natural wastewater treatment (phytoremediation) for water supplies that can both lower the dependent on groundwater resources and overcome the challenges and limitations associated with conventional wastewater treatment technologies. Therefore, the main objective of this research was to study the performance and efficiency of green plants such as *Typha* and *Phragmites australis* for wastewater treatment in eastern Saudi Arabia. The experiment was carried out in fiberglass tanks (each with a capacity of 4.0 x 7.0 x 0.5 m^3) in the field. There was a total of 4 fiberglass tanks with 2-replications. A percent decrease of 72.86 and 49.74%, 39.30 and 18.07%, 39.84 and 52.87%, 38.73 and 40.86%, 74.49 and 57.82%, and 66.82 and 63.14% was observed for turbidity, TSS, nitrate, ammonia, BOD, and COD by growing *Phragmites australis* and *Typha*, respectively. The heavy metals such as aluminum, zinc, and arsenic showed considerable reduction of pollutants in treated water compared to raw wastewater under both plants. Overall, it seems that the improvement in wastewater quality was better by growing *phragmites australis* than *Typha*, however, there were no statistically significant differences between the two plants means in their performance of raw wastewater treatment. The study results indicate that green plants could be used in a phytoremediation system to treat wastewater in rural and small communities.

Introduction

Currently, the world is facing an acute shortage of water especially in arid and semiarid regions including the Middle East (Gatica and Cytryn 2013). World Health Organization (WHO) reported that more than two billion of people in the developing countries lack adequate sanitation and wastewater treatment systems (WHO 2016). Many countries around the world such as Kingdom of Saudi Arabia, depend on nonrenewable groundwater for water supply. Therefore, treatment of domestic wastewater is a viable non-conventional water sources for nonrenewable groundwater and could help overcomes water shortage by providing alternative water supply which ultimately can be utilized for good usages like in agricultural irrigation which accounts for more than 80% of groundwater withdrawal. As such, it is very important to explore other alternative means of augmenting the existing inadequate irrigation supplies to lower the burden on the precious nonrenewable groundwater and to save it for future better usages. Treatment of domestic wastewater is considered very viable alternative to groundwater and could help overcomes water shortage in arid areas. Wastewater production has been increasing in Saudi Arabia as a result of rural and urban development and expansion. In Saudi Arabia, wastewater disposal was limited only to cesspits in small towns and rural areas, with treated, partially treated, or untreated wastewater often discharged into Wadis or sea in city areas when reuse is not achievable (Abu-Rizaiza 1999). According to Ministry of Environment, Water, and Agriculture (MEWA), Saudi Arabia, more than 1,801 billion m^3 of wastewater was treated from 99 wastewater treatment plants in Saudi Arabia during 2019 (MEWA statistical report 2019). Average amount of treated wastewater was more than 4936 million m^3 per day, out of this amount, less than 17.3% per day was being reused for irrigation and other purposes. Recently, Alkhudhiri et al. (2019) indicated that the total municipal wastewater production in Saudi Arabia increased from 2125 million m^3 in 2007 to 2884 million m^3 in 2018 and expected to increase annually about 4% between 2025 and 2050 to reach 5090 million m^3.

Currently, several conventional wastewater treatment technologies namely reverse osmosis (RO), membrane bioreactor (MBR), and simple aeration coupled with polymer are in place for wastewater treatment but are expensive, lack efficiency in removing all pollutants, and difficult to practice at small community places (Rai 2018; Kumari and Tripathi 2015; Jeevanantham et al. 2019; Shah et al. 2020). An alternative to these conventional wastewater treatment technologies is natural wastewater treatment which includes phytoremediation technology [treatment of wastewater by growing green plants] due to its low cost and easy application at rural and small communities without involving large capital investment (Ciria et al. 2005; Kumari and Tripathi 2015). Phytoremediation is considered as an effective method for removing harmful pollutants from the contaminated environment (Jeevanantham et al. 2019; Kalipci 2011; Windham et al. 2004). Treatment of wastewater is deemed as a potential and sustainable water supply source and is a promising solution to water scarcity. Wastewater recycling for irrigation has several benefits which include being a constant and sustainable water supply (Toze 2006), and a source of organic and inorganic nutrients and trace minerals supply to plants, and subsequent leading to higher yields and decrease in the demand for fertilizers (Almuktar et al. 2017; Toze 2006; Woltersdorf et al. 2018). Aburizaiza and Mahar (2016) proposed that the degrees of conventional wastewater treatment depend on several factors such as the types of reuses/discharges, local environmental conditions, methods of irrigation, irrigation of restricted or unrestricted agriculture and the types of intended irrigated crops. Wastewater contains wide variety of pollutants such as pathogens, substances and chemicals that pose risk to human and environmental health (Qureshi and Hanjra 2010; Hanjra et al. 2012; Hophmayer-Tokich and Krozer 2008). Pakdel and Peighambardoust (2018) reported that the presence of toxic substances such as pesticides, phenol, cyanides, toxic organics, phosphorous, suspended solids, and heavy metals in industrial and domestic untreated wastewater. Therefore, wastewater should not be reused or discharged into the environment before proper treatments. One of the wastewater treatment methods which might be appropriate for small and rural communities is the natural wastewater treatment called as phytoremediation. Natural wastewater treatment can overcome the challenges and limitations associated with conventional wastewater treatment technologies especially in rural areas.

Many studies have reported positive and encouraging results of natural treatment systems on removal of pollutants, nutrients, and heavy metals such as biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate, phosphorous, Cd, Cu, and other metals, from wastewater (Kalipci 2011; Kumari and Triphati 2015; Mangio et al. 2017; Tunçsiper 2019; . Kumari and Triphati (2015) indicated that *Phragmites australis* showed higher accumulative capacities for heavy metals (Cu, Cd, Cr, Ni, Fe, and Pb) than that of *T. latifolia*. However, higher removal of Cr, Fe, and Zn (66.2, 70.6, and 71.6%) was observed using combination of *Phragmites australis* and *T. Latifolia* than their individual culture suggesting interaction effect of both plants for the removal of these metals. They concluded that planting *Phragmites australis* and *T. latifolia* together might be more efficient in heavy metals removal. The mean reduction in water quality parameters of domestic wastewater by growing reed plant (*Phragmites australis*) was 64.5%, 68%, 79.7%, 21.0% and 20.7% for BOD, COD, suspended solids (SS), total Phosphorus (TP), and total nitrogen (TN), respectively (Kalipci 2011). He concluded that natural treatment systems for treatment of domestic wastewater are more economical than other treatment systems and will provide benefits in prevention of environmental pollution in rural areas. The mean reduction of COD was 48 and 58% while the mean reduction of BOD was 67 and 65% under *Typha* and *Phragmites australis*, respectively. Konnerup et al.

(2009) compared two ornamental plants (*Canna* and *Heliconia)* in constructed wetland units in Bangkok, Thailand. They observed that both plants grew well especially *Canna* which had higher growth rates relative to *Heliconia*. They reported that the removal rates of total suspended solid (TSS) were very high with efficiencies above 88%, while COD removal rates varied between 42 and 83% depending on the loading rates. They concluded that ornamental species like *Canna* and *Heliconia* could be used for wastewater treatment systems. Leto et al. (2013) compared two plant species (*Cyperus alternifolius L.* and *Typha latifolia L.*) for the treatment of domestic wastewater and found that these two species significantly impacted the treatment of wastewater with regard to all chemical, and physical parameters. Removal of BOD were lower in the *T. latifolia* (72.4%) than in the *C. alternifolius* (64.8%) planted area, while the nitrogen content was found on average to be higher in *T. latifolia* treatments. Mangio et al. (2017) reported that average removal from grey water passing reed grass species such as *Phragmites karka*, *Typha elephantina* and *Cyperus iria* was 43.65, 31.74 and 29.52% for TDS; 42.41, 34.15 and 29.50% for SO_4^-; 80.88, 71.28 and 46.18% for PO_4^-; and 54.53, 42.91 and 24.54 for NO_3-, respectively. The removal of TDS, SO_4, PO_4 and NO_3 was the highest when grey water was treated with *Phragmites karka*, followed by *Typha elephantine*. However, the lowest removal of all these parameters in most cases was found in grey water passing through *Cyperus iria*. They attributed the promising results of *Phragmites karka* to treat the greywater more effectively than the other reed grass species due to its dense tillering and morphological traits. In a recent study, Ashraf et al. (2020) investigated the potential of phytoremediation using different macrophytic species for the treatment of industrial effluents and found that the macrophytes under study significantly reduced the pollution load of tannery effluent. Furthermore, they found that the higher nutrient content of the effluent stimulated the growth of these macrophytes without any adverse effect on plants. *Leptochloa fusca* and *Typha domingensis* proved efficient for the removal of pollutants and showed higher growth rates and biomass than other tested macrophytes. Overall, natural wastewater treatment systems using macrophytes species could be considered a successful low-cost wastewater treatment solution method to improve water quality of polluted aquatic systems (Tunçsiper 2019; Ashraf et al. 2020).

An extensive review of literature revealed very little accomplishment on using phytoremediation for wastewater treatment in Saudi Arabia, and that small and rural communities in Saudi Arabia lack proper methods of wastewater treatment systems. Therefore, the main objective of this study was to explore if natural wastewater treatment (phytoremediation) is applicable in small and rural communities in Saudi Arabia, and assess and evaluate the performance and efficiency of the green plants namely *Typha* (cattail) and *Phragmites austrailes* (reed) for wastewater treatment to supplement the existing inadequate irrigation supplies for landscape development as well as for cooling purposes in different industries.

Materials And Methods

Site location and description

The experiment was conducted in Hofuf, Al-Ahsa, Eastern Province, Kingdom of Saudi Arabia, between 2015-2017 cropping seasons. Al-Hasa is a large populated oasis located in the eastern province of Saudi Arabia. An experimental site [20.0 x 30.0 m^2] was selected inside the Wastewater Treatment Plant of Hofuf. The experimental site was selected that it is easily accessible, wastewater source is nearby, and the source of electricity is available close to experimental site. The source of wastewater was from a nearby drainage canal as well as from cesspools located in the surrounding residential areas. The ground was leveled to zero level before placing the experimental tanks.

Preparation of fiberglass tanks

Four experimental fiberglass tanks each with a capacity of 4.0 x 7.0 x 0.5 m^3 were prepared locally. Two more tanks with a capacity of 4.0 x 9.0 x 2.0 m^3 were also prepared. One tank of the larger tanks was used for irrigation using raw wastewater and the other was used for collecting the treated water from all the experimental tanks. There was a total of 4 fiberglass tanks with 2-replications. Detailed design of one experimental fiberglass tank (as an example) is given in Fig. 1.

Two types of gravels namely big size (2.5 – 3.8 cm diameter) and small size (1.3 – 2.0 cm diameter) were bought from a contracting company in Riyadh and transferred to experimental site in Al-Ahsa. The total quantity of big size gravel was 20.0 cubic meters and that of small size was 40.0 cubic meters. These gravels were used to fill the experimental fiberglass tanks. The big size gravels were place at the bottom of each tank, and the small size gravels were place at the top of the big size gravels. The gravels were distributed equally in all the tanks. The gravels were prewashed prior to filling the tanks to remove the dust to avoid blockage of the tank's drainage outlets.

Two green plants namely *Typha* (cattail) and *Phragmites australis* (reed) were selected for the experiment. The *Typha* was collected from the bank of a drainage canal in the outskirts of Riyadh, Saudi Arabia and immediately transferred to the experimental site. The *Phragmites australis* was collected from the field near the experimental site in Al-Ahsa.

The experimental plants (*Typha* and *Phragmites australis)* were transplanted in the fiberglass experimental tanks manually. The good quality irrigation water was applied after plant transplantation for establishing the plants. After 2 weeks of transplantation, irrigation with raw wastewater was initiated to the experimental plants. The irrigation was applied with a constant flow of one cubic meter of water per tank per day. The setup of constructed wetland experiment fiberglass tanks after planting and initial irrigation are shown in Fig. 2.

Experimental treatments of testing plants

The experiment consisted of only two replications along with one replication as control treatment (raw wastewater) as given below.

Samples No	Description
RW	(raw wastewater)

T-1	*Phragmites australis* (reed plant)
T-2	*Typha* (cattail plant)
T-3	*Phragmites australis* (reed plant)
T-4	*Typha* (cattail plant)
OST	Outlet storage tank

Collection of water samples

Raw wastewater samples were collected in duplicate before starting the experiment to determine the physical and chemical composition as given in Table 1. Water samples were collected and evaluate for the effectiveness and efficiency of the system on pollutants removal, and therefore the improvement of treated water quality.

First sampling of wastewater and the treated water samples was collected from the experimental treatment tanks which was followed by subsequent water sampling during the experimental duration. Overall, a total of five water samplings were done during the experiment.

Analysis of water samples

Wastewater samples were analyzed in the King Abdulaziz City for Science and Technology (KACST) analytical laboratories by following the standard analytical methods as described in APHA (2005). Water samples (raw wastewater and treated water) were analyzed for turbidity, BOD, COD, total suspended solids (TSS), nitrate, SiO_2, and ammonia (NH_3–N). Also, the concentration of some heavy metals such as Al, Cu, Zn, As and Ag were determined. Some parameters such as total suspended solids, and pH were measured at site with portable conductivity bridge immediately after sample collection. After measuring these parameters, the water samples were stored in an ice box and shifted to analytical laboratory for further analysis.

The BOD analysis was carried in accordance with Standard Methods for the Examination of Water and Wastewater Methods (APHA 2005). The COD analysis was carried utilizing Hach Laboratory Method 8000 (Spectrophotometer Model DR/2010). The heavy metal ions concentrations were determined by ion chromatography using Dionex (ICS-500) ion chromatographic system.

Statistical analysis

Data were statistically analyzed using one-way analysis of variance (ANOVA) and regression techniques for treatment evaluation. The statistical analysis was used to evaluate the performance of the two aquatic plants in wastewater treatment at p-values 5% level of statistical significance for each parameter differences among treatments, and whether or not their performance in water treatment is significant different from each other. The statistical program used to perform this analysis was SPSS Statistics for Windows, PASW Statistics for Windows, version 18.0 (2009).

Results And Discussion

Initial wastewater analysis

The data is Table 1 shows the physical and chemical composition of the original wastewater samples that was later used for irrigating the experimental plants. This was done to select the wastewater from different drainage systems working the area for the disposal of wastewater from Hofuf city, Al-Ahsa Oasis.

Table 1 Physical and Chemical Analysis of Initial Wastewater Samples During 2015

Sample No.	Parameters	Units	Sample no. 1	Sample no. 2	Mean
1	pH		7.22	7.37	7.30
2	E.C.	ms/cm	1.915	1.932	1.924
3	T.D.S	mg/L	1226	1236	1231
4	TSS	mg/L	449.8	779.6	614.70
5	NH_3 – N	mg/L	24.7	23.2	23.95
6	Phosphorus (Soluble)	mg/L	13.96	18.76	16.36
7	Sodium	mg/L	88.78	96.28	92.53
8	Potassium	mg/L	25.2	23.55	24.38
9	Sulphate	mg/L	235.5	252	243.75
10	Nitrate	mg/L	2	N.D	2
11	Nitrite	mg/L	0.018	0.007	0.013
12	Chloride	mg/L	387	425	406
13	Calcium	mg/L	126.3	103.6	114.95
14	Magnesium	mg/L	36.34	33.54	34.94
15	SiO_2	mg/L	25.5	23	24.25
16	BOD	mg/L	196	293	244.5
17	COD	mg/L	370	695	532.50

ND non-detectable concentration

***Phragmites australis* (reed plant)**

A study of data in Table 2 indicate changes in physical and chemical parameters of wastewater by growing *Phragmites australis*. The percent decrease in different water quality parameters was calculated on relative basis by considering the raw wastewater as a reference to evaluate the performance of growing *phragmites australis* for wastewater treatment. The percent decrease in different physical parameters was 72.86%, 39.30%, 74.49% and 66.82% for turbidity, total suspended solids (TSS), BOD and COD respectively. Ammonia and nitrate contents decreased up to 38.73% and 39.84%, respectively in the treated water. This shows that the decomposition of the nitrogen containing organic compounds in the wastewater. While the mineralization of organic nitrogen into nitrate form, a source of easily available nitrogen for plant growth, decreased might be due to nitrogen uptake by the growing plants for nutrition. Also, it was observed that heavy metals, aluminum, copper, zinc, arsenic and silver were all decreased in treated wastewater by reed plants when compared to the raw wastewater. The percentage reduction of aluminum, copper, zinc, arsenic and silver was 22.89%, 50.0%, 85.71%, 27.27% and 80.0%, respectively. The study results agree with the findings of other researchers (Kalipci 2011; Dinka et al. 2016; Davison et al. 2001). By using reed (*Phragmites australis*), Kalipci (2011) reported that the mean reduction rate of domestic wastewater by using *Phragmites austratis* was 64.5%, 68%, 79.7%, 21.0% and 20.7% for BOD, COD, suspended solids (SS), total Phosphorus (TP), and total nitrogen (TN), respectively. Davison et al. (2001) found that the mean removal efficiencies ranged from 56% to 90% for SS, 70% to 93% for BOD, 38% to 66% for TN, and 42% to 70% for TP on four subsurface flow wetlands planted with *Phragmites australis* in New South Wales, Australia. The study of Dinka et al. (2016) provided further evidence that high nutrient retention capacity of *Phragmites australis* can be employed in the treatment of wastewater and provide protection and preservation to the aquatic systems.

Table 2 Physical and Chemical Composition of Water Samples by Growing *Phragmites australis* (reed plant) and *Typha* (cattail plant) with statistical analysis

Sample No.	Parameter	Units	Raw water		*Phragmites australis* (reed)			*Typha* (cattail)			*P*-value	
			Mean	Standard deviation	Mean	Decrease (%)	Standard Deviation	Mean	Decrease (%)	Standard deviation	ANOVA	*t-test*
1	**Turbidity**	NTU	106.35	45.50	28.86	72.86	12.48	53.45	49.74	35.84	0.243	0.204
2	**TSS**	mg/L	43.10	39.50	26.16	39.30	28.51	35.31	18.07	42.97	0.735	0.559
3	**$NH_3 - N$**	mg/L	10.45	3.62	6.4	38.73	7.58	6.18	40.86	6.45	0.966	0.774
4	**Nitrate**	mg/L	1.52	2.99	0.91	39.84	1.73	0.71	52.87	1.36	0.863	0.633
5	**SiO_2**	mg/L	35.06	28.68	17.38	50.45	5.42	25.44	27.45	5.53	0.082	0.846
6	**BOD**	mg/L	97.50	30.26	24.88	74.49	7.88	41.13	57.82	34.67	0.396	0.085
7	**COD**	mg/L	189.25	51.59	62.79	66.82	28.35	69.76	63.14	32.11	0.756	0.739
8	**Al**	mg/L	0.553	0.302	0.43	22.89	0.332	0.38	30.72	0.370	0.887	0.725
9	**Cu**	mg/L	0.033	0.023	0.017	50.00	0.006	0.033	0.00	0.024	0.301	0.07
10	**Zn**	mg/L	0.117	0.159	0.017	85.71	0.015	0.018	84.29	0.018	0.907	0.875
11	**As**	mg/L	0.037	0.064	0.027	27.27	0.046	0.032	13.64	0.055	0.91	0.654
12	**Ag**	mg/L	0.017	0.021	0.003	80.00	0.006	0.013	-20.00	0.012	0.251	0.148

Growth of experimental plants

Progressive growth of both the experimental plants (*Typha* and *Phragmites australis*) during the experimental period is shown in Fig. 3.

***Typha* (cattail plant)**

The data in Table 2 show changes in physical and chemical parameters of wastewater samples by growing *Typha* (cattail). The percent decrease in different water quality parameters was calculated on relative basis by considering the parameters of raw wastewater as a reference to evaluate the performance of growing *Typha* (cattail) for wastewater treatment. The level of reduction in different physical parameters was 49.74%, 18.07%, 57.82% and 63.14% for turbidity, total suspended solids (TSS), BOD and COD, respectively. The reduction in heavy metals was 30.72%, 0.0%, 84.29% and 13.64% and 20.0% for aluminum, copper, zinc, arsenic, and silver, respectively when compared to raw wastewater. The decrement in NH_3-N and nitrate was 40.86% and 52.87%, respectively in the treated water compared to the raw wastewater. This indicates the decomposition of nitrogen containing organic compounds by the microbial activity around the plant's roots during growth. The mineralization of organic nitrogen into nitrate form, a source of easily available nitrogen for plant growth, decreased which might be due to nitrogen uptake of nitrates by the growing plants for nutrition. Similar results were reported by others (Schierano et al. 2020; Ashraf et al. 2020; Ciria et al. 2005). Schierano et al. (2020) in a study to evaluate contaminants removal efficiency of subsurface flow constructed wetland for tertiary treatment of dairy wastewater using *Typha domingensis* reported that mean removal efficiencies of BOD and COD were 57.9% and 68.7%, respectively. However, they observed that the contaminants removal for nitrates (47.8%) and TP (29.9%) were lower than that of other parameters. Ashraf et al. (2020) in a study to evaluate the performance of macrophytes to remove pollutants from tannery effluent found that the mean removal percentage of *Typha domingensis* were 59% for BOD_5; 47% for COD; 43% for TDS; 69% for TSS; 49% for SO_4^{-2}; and 48% for Cr. The presence of *Typha latifolia* elevated constructed wetland performance in the removal of BOD, ammonia-N, and pathogen bacteria (Ciria et al. 2005).

Comparison between *Phragmites australis* and *Typha* plants

The results in Table 3 show a comparison of water quality parameters of treated wastewater between the two green plants during growth in raw wastewater. The percent reduction in some physical and chemical parameters such as turbidity, TSS, ammonia, nitrate, SiO_2, BOD, COD, and heavy metals was generally higher in treated water by growing *phragmites australis* than *Typha* green plant. This differential behavior of both the plants on water quality parameters may be due the difference in the physiological characteristics of each plant. However, it was noticed from table 2 that improvement in wastewater quality is better by growing *phragmites australis* than *Typha*. Table 2 presents the main chemical parameters and statistical analysis (ANOVA and t-test) which was performed to test if there were any significant differences between the two vegetative plants on wastewater treatment performance. For this reason, only mean values for the two green plants are shown. As can be seen in Table 3, both aquatic plants perform very well in removing the chemical substances form the treated water and as a result improving the quality of the wastewater. However, the statistical analysis did not show any significant differences between the two plants means in their performance of wastewater treatment. This indicates that these two green plants perform very effectively in reducing chemical substances from wastewater, and as a result could be used to treat wastewater in rural and small communities in a phytoremediation system.

The research findings were comparable to the findings obtained and reported by others. For example, Mangio et al. (2017) reported that the mean removal of different water quality parameters from greywater using grass species such as *Phragmites karka*, *Typha elephantina* and *Cyperus iria* was for 43.65, 31.74 and 29.52% for TDS; 42.41, 34.15 and 29.50% for SO_4^-; 80.88, 71.28 and 46.18% for PO_4^-; and 54.53, 42.91 and 24.54% for NO_3^-, respectively. The removal of TDS, SO_4, PO_4 and NO_3 was higher when the greywater was treated with *Phragmites karka* followed by *Typha elephantine* and was lowest in most cases in grey water passing through *Cyperus iria*. Calheiros el al. (2009) showed that *Phragmites australis* performed better than *Typha latifolia* when used to treat tannery wastewater on constructed wetlands. These two species provided high removal up to 88% of biochemical oxygen demand and 92% of chemical oxygen demand from tannery wastewater. Significant reduction of COD and BOD in treated wastewater than in raw wastewater were reported by Hussain et al. (2014). The mean reduction of COD was 48 and 58% while the reduction of BOD was 67 and 65% under *Typha* and *phragmites australis*, respectively. Also, Leto et al. (2013) found that the removal of BOD were lower in the *T. latifolia* (72.4%) than in the *C. alternifolius* (64.8%) when compared the tow species, while the nitrogen content was found on average to be higher in *T. latifolia* treatments.

Table 3 Comparative Study of Water Quality Parameters affected by Growing Green Plants

S. No.	Parameter	Units	Raw water	*Phragmites australis* (reed)	*Typha* (cattail)	% Relative increase/decrease between the Green Plants [+/-]
			Mean	Mean	Mean	
1	**Turbidity**	NTU	106.35	28.86	53.45	-85.20
2	**TSS**	mg/L	43.1	26.16	35.31	-34.98
3	**NH_3_N**	mg/L	10.45	6.4	6.18	+3.44
4	**Nitrate**	mg/L	1.52	0.91	0.71	+21.98
5	**SiO_2**	mg/L	35.06	17.38	25.44	-46.38
6	**BOD**	mg/L	97.5	24.88	41.13	-65.31
7	**COD**	mg/L	189.25	62.79	69.76	-11.10
8	**Al**	mg/L	0.553	0.43	0.38	+11.63
9	**Cu**	mg/L	0.033	0.017	0.033	-94.12
10	**Zn**	mg/L	0.117	0.017	0.018	-5.88
11	**As**	mg/L	0.037	0.027	0.032	-18.52
12	**Ag**	mg/L	0.017	0.003	0.013	-333.33

Conclusions

In this study, local aquatic plant species namely *phragmites australis* (reed plant) and *Typha* (cattail plant) were used to treat raw wastewater in constructed wetland tanks. The main objective was to evaluate the performance and efficiency of these green plants on wastewater treatment and explore if natural wastewater treatment is applicable in small and rural communities in Saudi Arabia.

The removal efficiency of the system showed considerable reduction of pollutants in treated water compared to raw wastewater under both plants. In general, these green plant species worked well on treating wastewater, with *phragmites australis* (reed plant) being slightly better. The percent decrease in turbidity, total suspended solids (TSS), ammonia, nitrate, BOD, COD, and heavy metals of treated wastewater was highly significant by growing *Typha* and *Phragmites australis* relative to raw wastewater for all tested parameters. However, the difference between the two plants in water treatment is not statistically significant indication that both plants work efficiently on removing these substances from raw wastewater.

The results illustrated the ability of the two aquatic plants to grow, survive and thrive in this wastewater with different concentrations of different heavy metals and other pollutants indicating that aquatic plants could be used in a phytoremediation strategy to treat wastewater in rural and small communities. It is recommended however that more experiments at a larger scale and in different areas in the country should be done to provide better understanding of the system and obtain more knowledge and larger data sets to allow for sensitivity and uncertainty analyses.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

GH and AIA planned, designed, and conducted the experiments. ASA, GH, and AIA conducted the sampling and analysis for different physicochemical parameters, and statistical analysis. ASA and GH drafted the manuscript. All authors contributed to the final manuscript.

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Figures

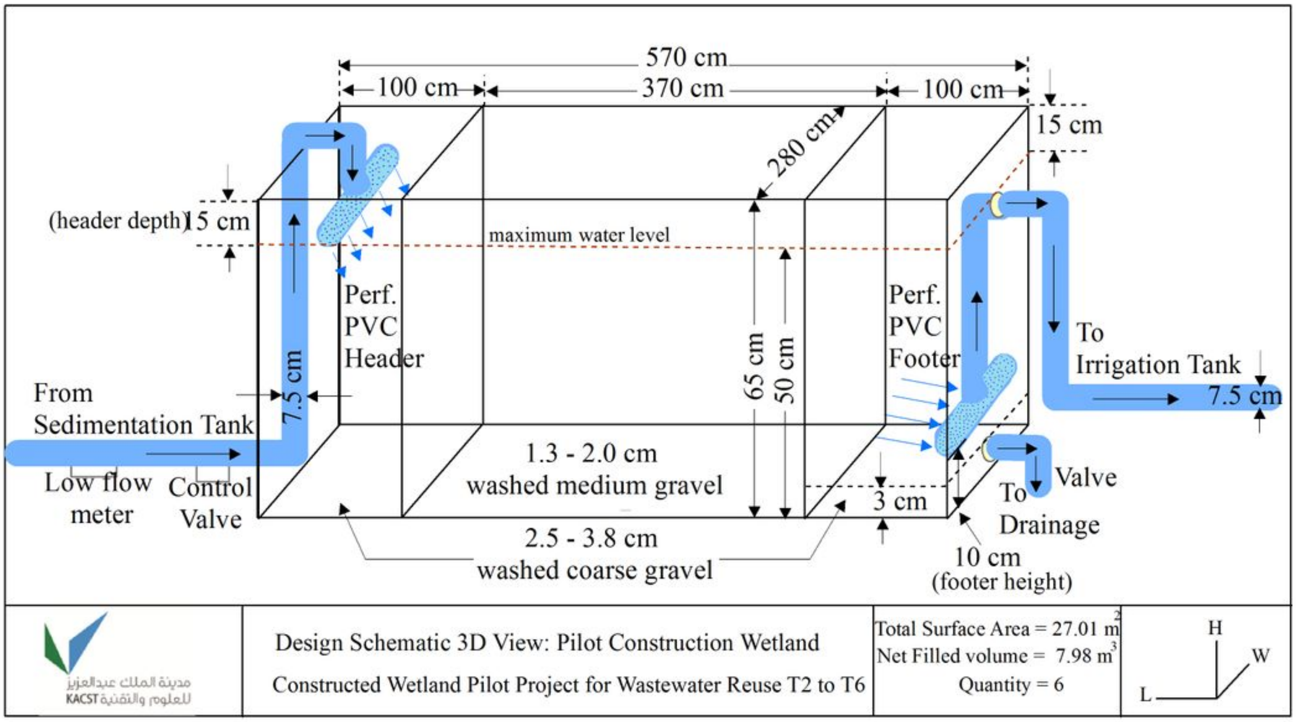

Figure 1

Detailed Design of an Experimental Fiberglass Tank

Figure 2

The constructed wetland experiment tanks after planting and initial irrigation

Figure 3

Progressive growth of experimental plants (Typha and Phragmites austrailes)