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Nitrogen and Sulphate Removal by Mono- and Mixed-Culture Floating Constructed Wetlands from Jawahar Lal Nehru Canal Water

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ABSTRACT
Floating constructed wetlands also known as Floating treatment wetland (FTWs) is a passively working eco-technology presently gaining popularity for their nutrient remediation efficiency from various types of water/ wastewater. This study was conducted to find how the FTWs installation influences the physicochemical properties of Jawahar Lal Nehru (JLN) canal water in a mesocosm scale experiment. The mesocosm tanks were supplied with raw water from the sedimentation tank of Kalka Water Works (Rewari). Mesocosm experimental treatments include a control without FTWs; two monoculture plantings (each planted with plant species *Typha angustata and Canna indica*); one mixed planting (with both *Typha* and *Canna* sp.) Plants were supported by poly styrofoam and bamboo shoots network raft. The study was conducted for five months and includes a total of 11 batches, each with an HRT of 7 days. Changes in physicochemical properties of water were evaluated after a 7- day HRT in the mesocosm treatment system. Mean TDS concentration in control as well as in all three FTWs mesocosms was slightly higher than influent loaded. The mean pH value was not showing any significant change in all four experimental sets. Mean percentage removal efficiency for N (nitrite-N and nitrate-N) was 28, 61.6, 69.7 and 70.5% for control, FTWs with *Canna, Typha* and mixed FTWs, respectively. FTWs showed a statistically significant difference in N removal in mesocosms than in control. Mean percentage removal efficiency for sulphate was -8.22, -3.87, -6.23 and -4.21% for control, FTWs with *Canna, Typha* and mixed, respectively. The mean percentage removal efficiency for sulphate showed negative results for control as well as FTWs treatments even though FTWs are performing better than control.

Key words: Jawahar Lal Nehru Canal, Rewari, TDS, pH, physicochemical properties

INTRODUCTION

Both point and non-point sources of pollution are well-known sources that cause impairment of river waterways carrying pollutants including sediments, chemicals, metal ions, organics and nutrients (Wang et al. 2014) that adversely affect aquatic and human life. Water from river waterways is channelized to different canals. In the state Haryana a network of canals distributes water in different districts of the state. Jawahar Lal Nehru (JLN) Canal, which supplies water in the southern part of the state, receives excess water of the Ravi and Beas rivers through the lift irrigation system. The JLN canal network and its distributaries are supplying water in villages of District Rewari and in the Rewari city. This canal supplies water for irrigation and drinking purpose in districts Rewari and Mahendragarh. During the long way through the canal channel, the water gets loaded with silt, suspended particles and excess nutrients. Their concentration becomes high during the rainy season due to runoff water. When the water reaches at Kalka Waterworks (Rewari), it has silt, clay particles, and nutrients in excess of permissible limits for drinking water. This includes nitrates, chlorides, fluoride, iron, sulphate, phosphate, and other metals. Before supply in the district, raw canal water is treated chemically using aluminium phosphate, which is a flocculant that has been in use from a long time for purification of drinking water at Kalka Waterworks, Rewari.

Floating Constructed Wetlands (FCWs) also named Floating Treatment Wetlands (FTWs) have been used in many studies to reduce the nutrient load in various types of wastewater at microcosm, mesocosm, and pilot scale as this technology significantly improves water quality and removes pollutants from water with limited cost (Rigotti et al. 2020, de Queiroz et al. 2020, Garcia Chance et al. 2020, Wang and Sample 2014, White and Cousins 2013, Boonsong and Chansiri 2008, Ghosh and Gopal 2010, Minakshi et al. 2021, Toet et al. 2005, Shruthi and Shivashankara 2022). However, no record was found related to canal water treatment using FCWs. FCWs could be a suitable alternative for the treatment of canal water as it is cost-effective, eco-friendly and green technology, which also have aesthetic value (Tanner et al. 2011).

Floating Constructed Wetlands (FCWs) is an innovative phyto-technology designed to grow macrophytes hydroponically on a buoyant raft of variable size, keeping the macrophyte's roots permanently in contact with water for nutrients uptake from water. Macrophyte roots in the water column provide surface for formation of microbial biofilm. Also the physical processes such as precipitation, sedimentation and entrapment of suspended particulate matter enhances the process of pollutants remediation (Borne 2014, Di Luca et al. 2019, Vymazal 2007, Borne et al. 2013, Headley and Tanner 2012).

In this regard, the present study was aimed to find out the effect of FTWs on various physicochemical parameters of canal water in mesocosm experimental units at 7 days HRT. The primary objective was to assess effect of FTWs installation on physicochemical properties of the canal water using two different plant species in monoculture and mixed culture than the control treatment. The second objective is to evaluate the percentage removal efficiency of mesocosm scale FTWs for TDS, Nitrogen and Sulphate.

MATERIAL AND METHODS

Study area

The study was conducted at Kalka Water Works (27°46' to 28°28' N latitudes and 76°15' to 76°51' E longitudes) at Kalka village, District Rewari (Haryana) India (Fig. 1a,b). The Kalka water pump station receives water from the Jawahar Lal Nehru (JLN) canal which brings water by lift irrigation system (Fig. 1c).

Selection of plant species

Two plant species *Canna indica L.* and *Typha angustifolia L.* were selected for the present study based on the following criteria developed for species selection: (1) native and non-invasive species, (2) perennial macro-phytic plant species either terrestrial or emergent rooted hydrophytes, (3) plant parts with aerenchyma tissue, and (4) aesthetic value. Selection of plant species is the most important step, some invasive species have higher nutrient removal efficiency but later on, can negatively affect ecosystem integrity (Tanner et al. 2011, Wang et al. 2014). Both *Typha* and *Canna* plant species can perform better in low nutrient conditions (Polomski et al. 2007, Di Luca et al. 2019). Also both have aesthetic value, easy availability, rhizomatous stem, adventitious root system and significant nutrient removal rate in previous studies were the reasons for the selection of these species (White and Cousins 2013, Ge et al. 2016, Saeed et al. 2016, Keizer-Vlek

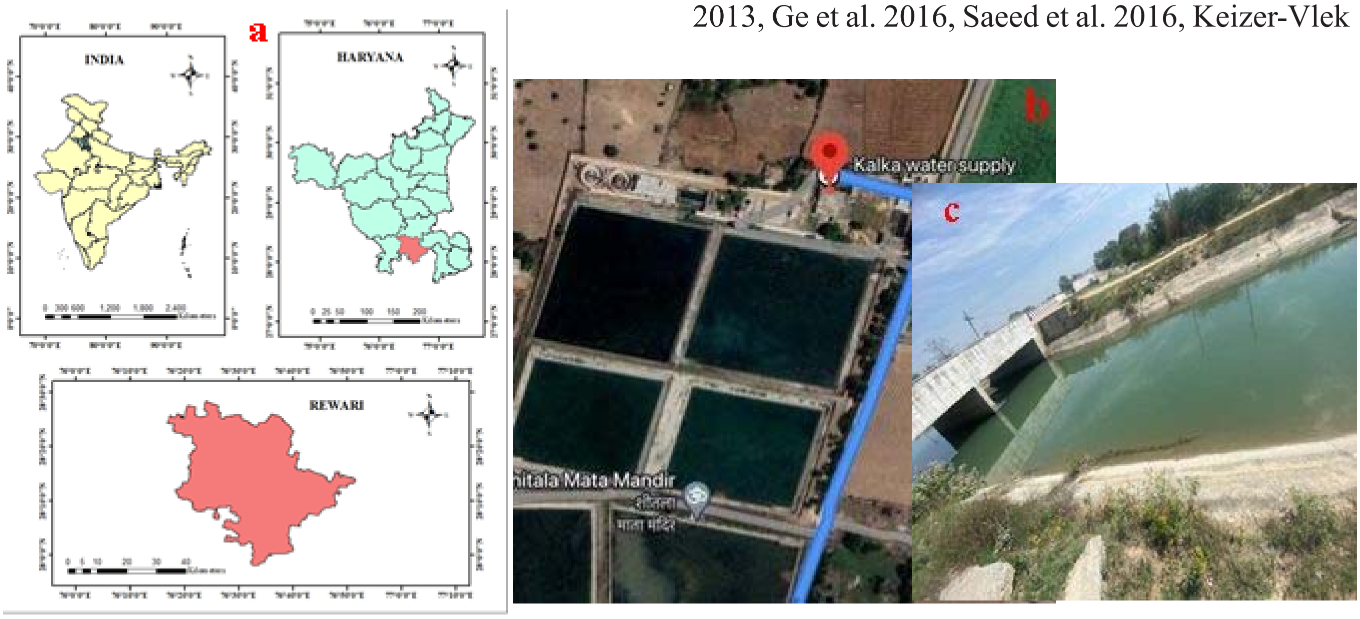

Figure 1. (a) Location of study site District Rewari, Haryana (Source: Wikimedia commons), (b) Satellite image of Kalka Water Works at village Kalka, District Rewari (Source: Google Eartch, (c) JLN canal at village Kalka

et al. 2014). *Typha* plant saplings were selected from plants growing in the channel which supplies water from sedimentation tank to water pump. *Canna* plant species were taken from the garden of the Kalka water plant. Healthy individuals with uniform sizes were selected for mesocosm experiments.

Mesocosms and experimental treatments

A batch-loaded mesocosm study was conducted from January 2022 to May 2022. In the present study, four mesocosm tanks labelled as control, CW1, CW2 and CW3 where the latter three tanks with 496 L capacity and dimensions of 78 × 90 cm (height × diameter) filled up to 67 cm height. The final filled volume of each tank was 388 L. The control tank was of smaller size with dimensions 60 × 70 cm (height × diameter) with 230 L capacity, filled volume of control tank was 219 L. This was kept open and without a mat. Water in each mesocosm was pumped from the raw water supply coming from the sedimentation tank. After an interval of seven days of Hydraulic Retention Time (HRT), the tanks were washed thoroughly and supplied with fresh raw water from the sedimentation tank supply. The floating mats with dimensions 57 ×59 ×8 cm made from poly styrofoam material which is used in the packaging, provides buoyancy with a supportive base of bamboo shoots network to hold the weight of growing plants, and both were joined through wires (Fig. 2a). Each mat had equally spaced holes where the plants were fixed in specially designed perforated plastic cups which allow macrophytic roots to hang down in the water column while shoots remain above the water column (McAndrew et al. 2016, White and Cousins 2013). Saplings of 10 cm size were selected for both plant species. Roots of saplings were rinsed thoroughly to remove soil particles and then potted in specially designed plastic aeration cups of size 200 ml. A mat of dried grass was used to cover each FTWs for fixation of pots in holes, and a gunny bag was covered over it to prevent deterioration of grass. In mesocosm tanks CW1 and CW2, macrophyte plant of *Typha* and *Canna* were planted as monoculture, respectively, and in CW3 tank, both plant species, five saplings of each, were planted as mixed culture (Fig. 2 a,b,c,d).

Figure 2. (a) Constructed floating treatment wetland raft with mixed plantings (*Canna* and *Typha*, five of each), (b) Mesocosm FTWs and control tank showing outlet at bottom for effluent collection and growth of macrophytes in winter season (Jan 2022 to Feb 2022), (c) Influent supply to tanks (the pipe in blue uplifting water from sedimentation tank) and growth of macrophyte shoots in spring and summer season (March 2022 to May 2022), (d) Root growth in *Canna* plants.

Hydraulic Retention Time (HRT)

HRT is an experimental variable that reflects the contact period of macrophyte roots with treatment water (Toet et al. 2005). The performance of FTWs largely depends on HRT. Previous studies showed that increasing HRT shows increased pollutant and nutrient removal but to a certain limits (Ghosh and Gopal 2010, Minakshi et al. 2021, Toet et al. 2005, Shruthi and Shivashankara 2022). The present study was conducted for 5 months (from January 2022 to May 2022) in total 11 batches. In each batch the HRT of 7 days was maintained. On day zero, influent water (raw water of sedimentation tank) was filled in control and each FTWs. On day 7 effluent water samples were collected from these tanks for physico-chemical parameter testing. After removing all the existing water, both the control and FTWs were filled with fresh raw water from sedimentation tank. In this manner for total 11 batches study was conducted.

Water sampling and analysis

Initial water samples collected on day zero were representing the initial concentration (influent) and the final sample on day seven represents the final concentration i.e. effluent from each mesocosm tank. Each water sample was collected in a 300 ml sample collection water bottle from the outlet valve, fitted 5 cm above the base of the tank. The bottles were acid-washed and rinsed with distilled water before each sampling event (White and Cousins 2013). The physicochemical parameters pH and TDS of each sample were done *in situ* using Hanna HI98130 multiprobe meter. After collection, all water samples were placed in an ice box and transported to Water testing laboratory of Public Health and Engineering Department (PHED Lab), Rewari for further analysis of other physicochemical properties i.e. NO_2^--N, NO_3^--N, SO_4^{2-}-S. The guidelines of standard methods of APHA (2017) and USEPA methods were followed for sample testing (Table 1). Tests were performed using testing kits of HACH for nitrate and nitrite. Quality assurance and quality control were ensured according to APHA methods (Lipps et al. 2012).

The nutrient removal efficiency of control and each mesocosm treatment was calculated in terms of percentage removal by the following equation:

Removal Efficiency (%) = $((C_{in}-C_{eff})/C_{in})X100$

C_{in} = Concentration of influent

Table 1. Methods used to analyse various physicochemical parameters of collected water samples

Parameters	Analysis method
Total dissolved solids(TDS)	APHA (2017)
pH	APHA (2017) -4500-H+ Method B
Nitrite and Nitrate nitrogen	USEPA Method 8039
Sulphate	APHA (2017)- 4500-SO_4 Method D and E (Gravimetric and Turbidimetric Method)

C_{eff} = Concentration of effluent

Statistical analysis

Results were statistically analysed using SPSS 16 and Microsoft excel. Comparison of amount of nutrient removed by different mesocosms and control was done using one way ANOVA. For Nitrogen removal, post hoc analysis was performed using Tukey's test with 95% significance level of difference and $p < 0.05$.

RESUTLS AND DISCUSSION

Performance evaluation of FTWs

FTWs planted with *Typha* and *Canna* in monoculture and Mixed culture performed well for nitrite-N and nitrate-N reduction during the study period. The mean concentration of influent loaded and changes in the effluent after a regular HRT of 7 days from control and FTWs mesocosms for the study period January 2022 to May 2022 is shown in Table 2.

Effect on pH

The mean pH value of control was 7.67 ± 0.44 slightly higher than all other treatments and influents. pH of control was ranging from 7.2 to 8.7 (Fig. 3). All FTWs mesocosms showed lower pH levels than control. Similar observations were also reported by Spangler et al. (2019). The lower pH in treatments could be the result of the release of acidic exudates from plant roots that may include organic acids, phenolic compounds higher nitrification process in FTWs and the protons in ammonia are released

Table 2. Mean concentration of influent loaded and the effluent from control and FTWs mesocosms after a regular HRT of 7 days for the study period January 2022 to May 2022.

Treatment	pH	TDS	NO_2^-	NO_3^-	SO_4^-
Influent	7.62±0.56	236.3±85	1.65±0.45	7.5±1.8	51.6±7.5
Control	7.67±0.44	234.0±50	1.20±0.56	5.0±2.6	53.5±4.5
CW1(*Canna)*	7.63± 0.41	238.5±33.4	0.66±0.64	2.9±2.8	51.3±4.0
CW2(*Typha*)	7.54±0.44	255.9±38.4	0.51±0.41	2.2±1.8	52.5±4.3
CW3(Mixed)	7.59±0.42	247.5±36.7	0.45±0.30	2.0±1.3	51.4±3.9

Table 3. Removal efficiency (%) of TDS of influent in control and FTWs for 11 sampling batches after 7 days of HRT

Control	*Canna*	*Typha*	Mixed
-4.85	-15.53	-21.36	-16.9

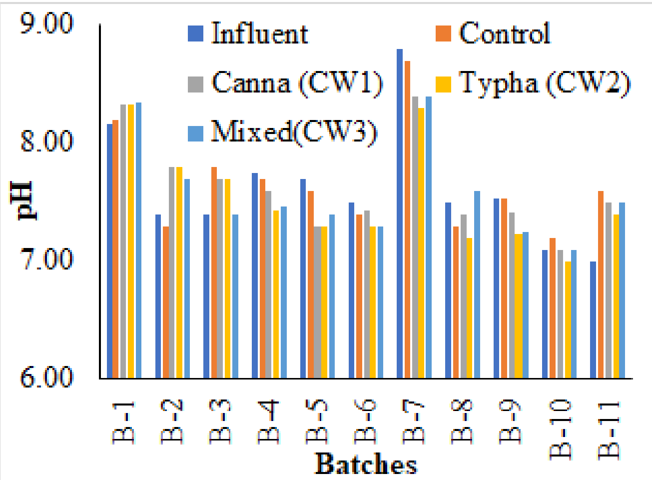

Figure 3. Changes in pH during January to May 2022 of influent, control, CW1, CW2 and CW3 at 7 days HRT.

during nitrification process might also be contributing to the acidic pH (Blossfeld et al. 2011, Spangler et al. 2019).

Total dissolved solids (TDS) removal

The TDS concentration of the influent ranged from 163 to 478 mg/l during the study period. Mean TDS concentration differences results after control treatment were slightly more positive than all three experimental FTWs mesocosms (Table 3). The percentage removal efficiency of control ranged from -23.9 to 26.9%. All three experimental FTWs showed negative results in most of the batches except batch nine. In batch nine, TDS removal efficiency (%) of control was 26.9%, FTWs with *Canna* 45.2%, *Typha* 40.2% and Mixed was 42.9% where influent TDS concentration was 478mg/l (Fig. 4a, b). This shows that FTWs performed better in higher nutrient concentration than in lower.

Statistical analysis by one way ANOVA showed there is no significant difference between control and mesocosm treatments for TDS after 7 days HRT (Table 4).

Nitrogen removal

Influent concentration of NO_2^--N and NO_3^--N was 1.65 ± 0.56 mg/l and 7.46 ± 1.8 mg/l, respectively. The removal efficiency (%) for N (nitrite-N and nitrate- N) ranged between 7 to 50% for control, 11 to 94.74% for FTWs with *Canna*, 41 to 94.74% for FTWs with *Typha*, 50 to 94.74% for FTWs mixed with both *Canna* and *Typha* sp. In the present research work, the nitrogen removal efficiency was in the moderate to a higher range which is in line with previous studies performed using FTWs with plants (Garcia Chance et al. 2020, Wang and Sample 2014, White and Cousins 2013, Boonsong and Chansiri 2008, Ghosh and Gopal 2010, Minakshi et al. 2021, Toet et al. 2005, Shruthi and Shivashankara 2022). Mean percentage removal efficiency for N (NO_2^- and NO_3^--N) was 29.5, 61.1, 69.2 and 71.8% for control, FTWs with *Canna* (CW1)*, Typha* (CW2) and mixed (CW3), respectively (Figs. 5a,b, 6a,b). During the initial period (week 1-3) N removal efficiency was comparatively lesser than remaining weeks that is due to low environmental temperature during January month, similar results were found with N in other studies also (van de Moortel et al. 2010, Wang et al. 2015).

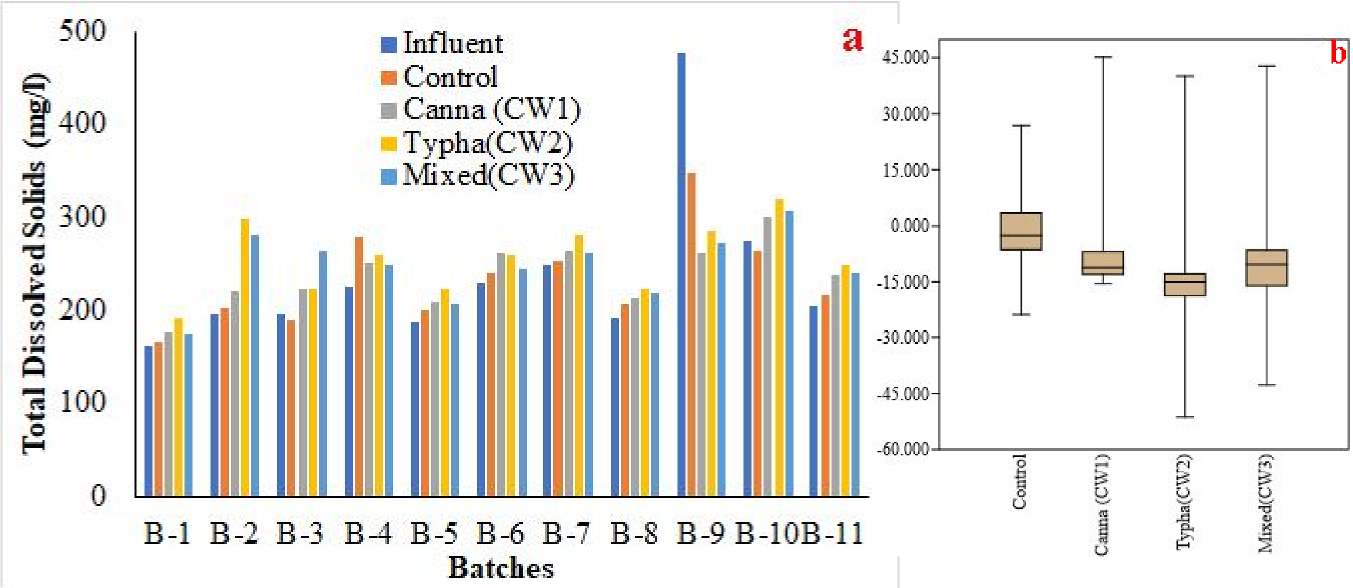

Figure 4. (a) Effect on influent TDS concentration in control and FTWs systems, (b) TDS removal efficiency (%) of control and FTWs experimental systems.

Table 4. One way ANOVA and post hoc Tukey's test result, p-value for TDS, Nitrogen (nitrite- N and nitrate-N) and Sulphate removal during the study period for HRT of 7 days

Treatment	TDS	Nitrogen	Sulphate
One way ANOVA			
p value	0.972	0.00	0.830
Tukey's HSD test (p< 0.05)			
Control	-	0.410	-
Canna	-	0.003	-
Typha	-	0.000	-
Mixed	-	0.000	-

Statistical analysis of mean influent and effluent N concentration was done by one way ANOVA. A statistically significant difference was found between control and all three mesocosm FTWs (Table 4). For further analysis, post hoc Tukey's test was performed. The results of Tukey's test showed all three treatments showed statistically significant difference for N removal however, control does not show statistically significant difference. Therefore, the influent N concentration was significantly reduced in all three FTWs. Among all three FTWs *Typha* and Mixed FTWs performed better than *Canna* (Table 4).

Sulphate removal

Influent concentration of sulphate ranged between 36 to 61mg/l, respectively. Sulphate removal efficiency was ranged between -30.95 to 8.6% for control, -26.19 to 11.48% for FTWs with *Canna*, and -30.95 to 8.93% for FTWs with *Typha*, -26.19 to 13.11% for FTWs mixed with both *Canna* and *Typha*. Mean percentage removal efficiency for sulphate was -8.22, -3.87, -6.23 and -4.21% for control, FTWs with *Canna* (CW1), *Typha* (CW2) and both mixed (CW3), respectively (Fig. 7a,b). Results showed higher sulphate removal efficiency in FTWs than in control, with maximum by *Canna* FTWs. Similar results were also found in other studies (Maine et al. 2007, Wu et al. 2012, Gupta et al. 2020). In the present work, sulphate removal efficiency was negative in eight batches of control and six batches of all three FTWs. Further research is needed to get more insights into the sulphate removal mechanism and sulphide toxicity. It was found that there was statistically no significant difference between control and FTWs for reducing sulphate concentration (Table 4) but from the comparison of per week data for 11 batches, it was evident that FTWs were removing more sulphate than control in nine batches.

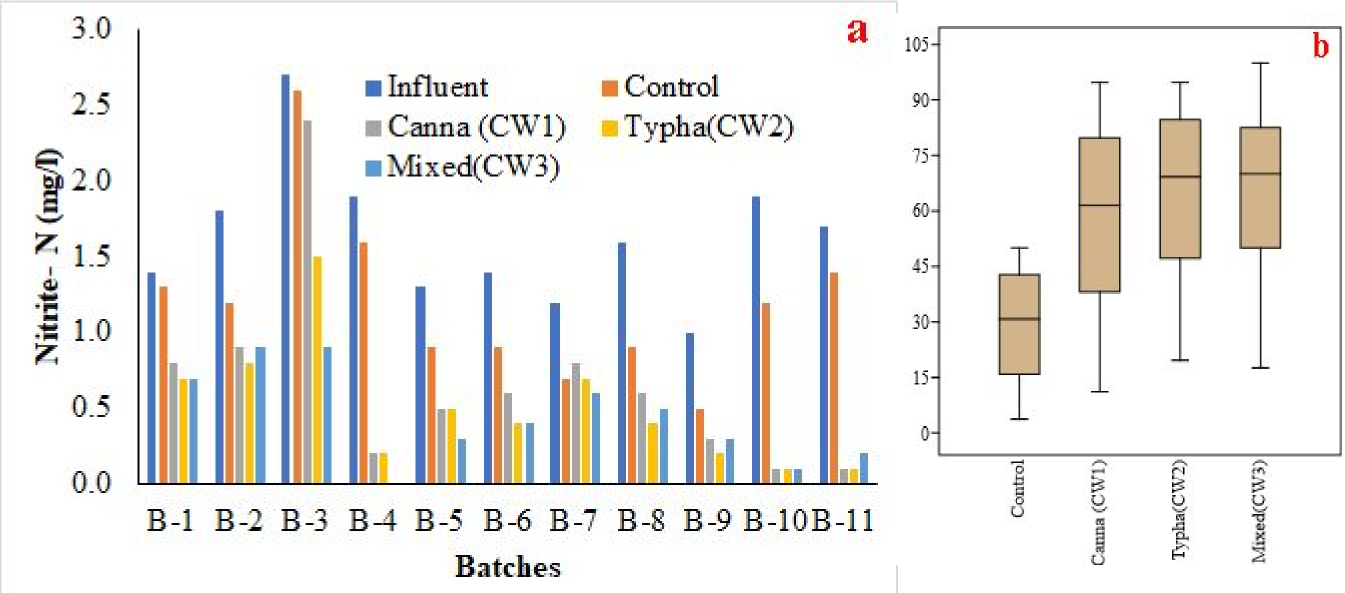

Figure 5. (a) Change in NO_2-N concentration of influent after FTWs installation at 7-days HRT for 11 batches, (b) Removal efficiency (%) of NO_2-N in control and FTWs treatments.

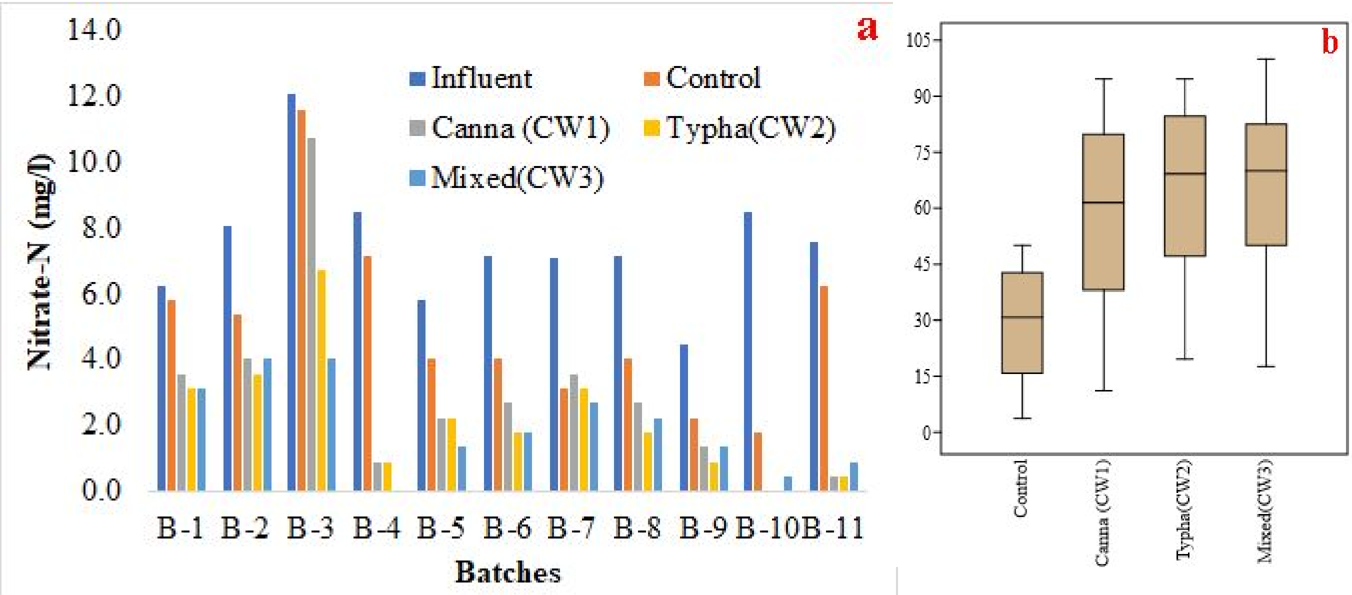

Figure 6. (a) Change in NO_3^--N concentration of influent after FTWs installation at 7-days HRT for 11 batches, (b) Removal efficiency (%) of NO_3^--N) in control and FTWs treatments.

CONCLUSIONS

FTWs are eco-friendly and low-cost technology for nutrient remediation in canal water. The N and S removal efficiencies were higher in FTWs mesocosms but not much difference between *Typha* and *Canna* species performance. Among all mesocosms, Mixed FTWs were top performers in N removal with 71.4 % efficiency while *Canna* FTWs in S removal. The TDS concentration reduction was best in control than all three FTWs. Since the TDS, N and S removal was not significantly much different among *Canna* and *Typha* sp., thus, both plant species can be used as monoculture. FTWs with mixed plantings performed well during the study period even though the shoot growth was not much better for both species in mixed FTWs than in monoculture. For better results at pilot scale, harvesting should be done regularly after a specific height growth. It increases nutrient uptake and also increases longevity

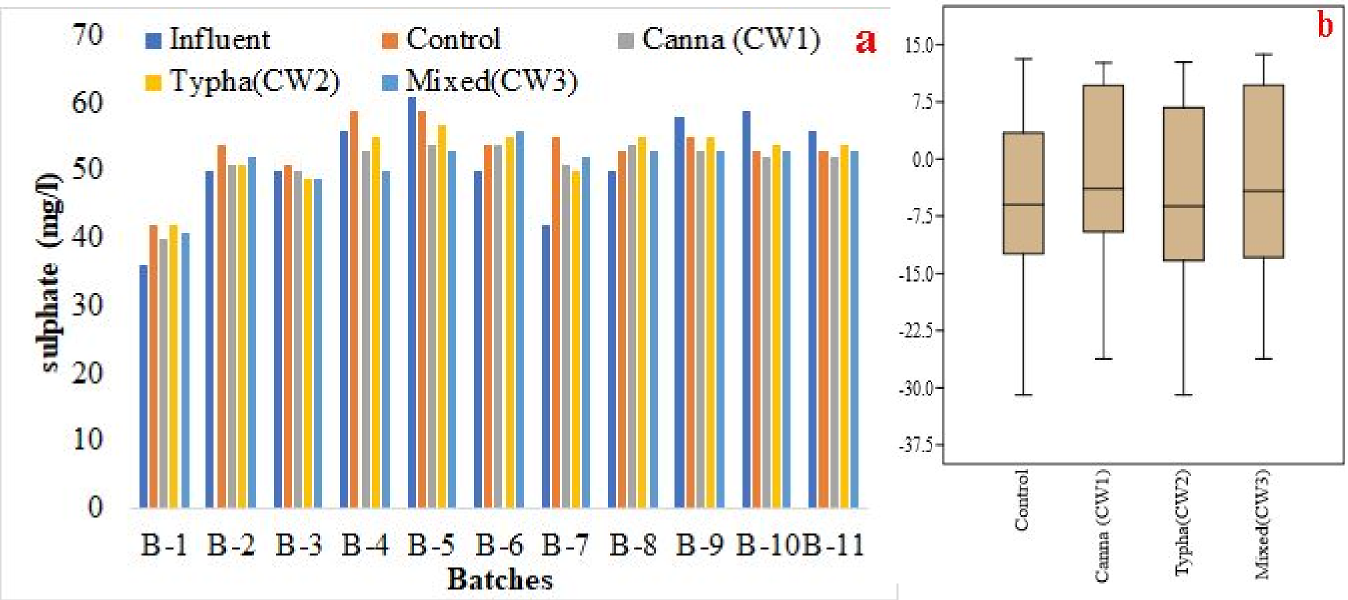

Figure 7. (a) Effect of FTWs on S concentration, (b) Removal efficiency (%) of S in control and FTWs treatments

of FTWs raft by decreasing shoot load.

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Authors' contributions: Vinay Kumar guided the present research work helped in framing the manuscript and Bindu Sharma edited the manuscript. Monika Kumari did experimentation in present research work, statistical analysis of data and manuscript writing .

Conflict of interest: Authors declare no conflict of interest

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