Pak. j. sci. ind. res. Ser. A: phys. sci. 2024 **67A**(1) 28-37

# Drinking Water Quality Improvement by Removal of Salinity Using Wetland

**Saud Hashmi[a], Asim Mushtaq[a]*, Raza Muhammad Khan[a], Rafiq Ahmed[a] and Zaeem Uddin Ali[b]**

[a]Polymer and Petrochemical Engineering Department, NED University of Engineering and Technology, Karachi, Sindh, Pakistan

[b]Chemical Engineering Department, NED University of Engineering and Technology, Karachi, Sindh, Pakistan

(received January 18, 2022; revised February 19, 2023; accepted March 7, 2023)

**Abstract.** The majority of developed countries suffer from water contamination because they have no control over the discharge of chemical waste into the water. In contrast, developing countries contaminate clean from water due to the discharge of agricultural waste. Contaminated water is a threat to human life as it causes many waterborne diseases that can be prevented by making efforts at an individual level. An effort has been made in this research to find an alternative method to treat water using wetlands. A further attempt has also been made to reduce total dissolved solids from water using wetlands. The development of constructed wetlands that can effectively treat saline water is the goal of this study. Because they can thrive in a salty environment, phragmites have been planted in every constructed wetland (CW). Eight pots were developed and worked under conditions reenacting diversely built wetlands. A relative report shows that total dissolved solids (TDS) content between 1000-3000 ppm in the water in flow developed wetland with in growth estate having gel soil gives the most elevated decline in conductivity of saline water at gushing. For effluent water with a salinity content of 1500 ppm, this artificially assembled system is extremely effective. As a result, this study demonstrates that the construction of a wetland using gel soil and carbon nanotube will offer an effective method for lowering water salinity.

**Keywords:** salinity removal, wetland, phragmites, total dissolved solids

## Introduction

Water is a great blessing as well as an essential element of life. In ancient times people used to migrate from place to place and resided near those areas where there was easy access to water. They usually settled near rivers, lakes or oceans and when water was scarce, they moved to new places in search of them. The progress of industrialization and urbanization of water reservoirs which started depleting. The majority of the water sources became polluted due to industrial and sewage waste mixing up in those water reservoirs. Various waterborne diseases made people look for ways to treat polluted water and make it suitable for drinking. The standard values after water purification are pH between 6.5 and 8.5, TDS is 1000 ppm, turbidity 5 ppm, dissolved oxygen concentrations above 6.5-8 mg/L and alkalinity 200 mg/L (Almuktar *et al*., 2018; Ghernaout, 2018).

A good advancement has been made in the water treatment sector. However, much more effort is still required because many of those technologies are quite expensive and a huge investment is required for setting them up. In contrast, others have the limitation of water purity. Treatment of water is not only essential for drinking but if untreated wastewater is discharged into the atmosphere, then it is a significant threat to the life of living things. Presently the world is facing this issue. Large water reservoirs have been polluted and many plants and aquatic habitats have been destroyed. Different organizations like Environmental Protection Agency (EPA) and others have regulated standards for water purity (Ghernaout, 2018; Fountoulakis *et al*., 2017).

Nowadays, different industries have set up plants for water treatment. Usually, those plants consist of Reverse Osmosis (RO) and Ultra-filtration (UF) for treating water. RO and UF have high operational costs in electricity and backwash chemicals. This project has been made to find an alternative method to treat drinking water using wetlands. It is an efficient method to treat water and it also has a minimum cost compared to other advanced technologies. Out of total water reserves present globally, saline water comprises 97%, present in the seas and oceans. In comparison, 2.5-2.75% is

*Author for correspondence;
E-mail: engrasimmushtaq@yahoo.com

freshwater, including 1.7-2% present in the frozen glaciers and the remaining 0.5-0.75% of water is available as fresh groundwater. These estimates show that the quantity of fresh water in nature is already less than saline water as shown in Fig. 1 (Wang *et al*., 2021; Shingare *et al*., 2019).

Generally, there are four kinds of contaminants related to water pollution, organic, inorganic, biological and radiological pollutants (Kataki *et al*., 2021, Sijimol and Joseph, 2021). Since the 1980s, water usage has increased globally by about 1% per year. There are various reasons for it like, driven by socio-economic development, population growth and changing consumption patterns. Universally interest for water is relied upon to increment at an equivalent rate until 2050, representing an increment of 20 to 30% over the momentum level of water utilization. The primary driver of this interest is rising interest in the mechanical and home-grown areas. Now, the majority of the countries are experiencing high water stress and feelings of anxiety will keep on expanding with more interest in water. Statistics show that freshwater withdrawals for agriculture, industry and municipal uses have increased almost six-fold since 1900 (Oliveira *et al*., 2021; Rusinol *et al*., 2020).

For the most part, utilized water sanitization strategies are; sedimentation or settling, boiling /refining, substance treatment (precipitation/coagulation/adsorbents), sterilization, filtration and wetlands. The presence of Ca and Mg as far as carbonate, bicarbonate, sulphate and chloride causes the hardness of the water. This hardness can be eliminated from water by adding proper chemicals that make it soft. When calcium hydroxide $Ca(OH)_2$ is added to hard water, it forms precipitates with bicarbonate and sulphate, which settles down (Sijimol and Joseph, 2021; Wang *et al*., 2020).

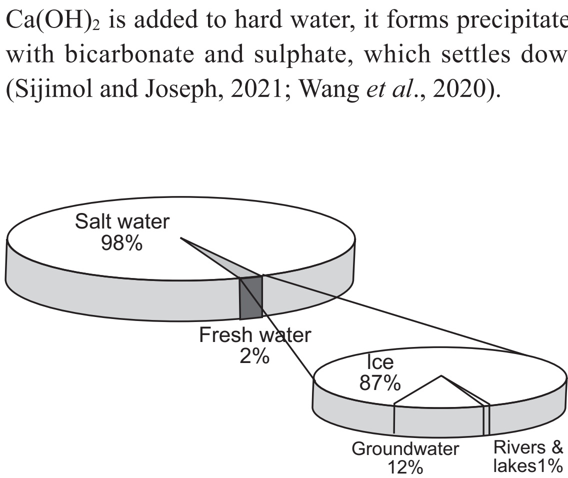


**Fig. 1.** Water distribution in the world.

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O \text{ .......... } (1)$$

$$MgSO_4 + + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4 \text{ .......... } (2)$$

When sodium-aluminate is added to hard water, it forms hydroxide precipitates with sulphate and chloride.

$$MgSO_4/Cl_2 + Na_2Al_2O_4 + 4H_2O \rightarrow Mg(OH)_2 + Na_2SO_4/NaCl + 2Al(OH)_3 \text{ .......... } (3)$$

As a new microbial source for treating saline wastewater, investigate how intertidal wetland sediments (IWS) remove phosphorus from constructed wetlands (CWs). Phragmites Australis planted CW substrates were infused with IWS. Plants and CWs without IWS served as the control groups. The microbial community was examined in a salty environment and the phosphorus removal *via* plant uptake, substrate accumulation and microbial transformation was evaluated (Wang *et al*., 2021).

**Wetlands.** They are a natural way of treating contaminated water. Soil layers and plants serve as channels for water falling off the land, lessening residue and synthetics before going into untamed water. Wetlands treat water by decreasing its stream so that suspended residue exits and settles to the wetland floor. Plants present in wetlands also aid in the filtration process by absorbing nutrients from excrement, sewage frameworks and different squander for leaf and stem development. The remaining waste is caught in the dirt and is debased by micro-organisms. Artificial wetlands are also being constructed with proper design calculations to counter water contamination problems. Hence it is an alternative method to water purification (Priya *et al*., 2021; Ghimire *et al*., 2019). It is a very cost effective technique as compared to all other methods. Less operational costs and less work force are required. It can easily handle fluctuations in influent water as compared to other techniques. Wetlands can trap sediments and a wide range of impurities. Capture nutrients through the adsorption of soil particles and plant uptake. Wetlands degrade harmful contaminants into harmless forms. Deduction of pathogens is possible by using wetlands. Proper designing of wetlands is essential for high purity. Proper vegetation is necessary for the intake of nutrients by plants. A large area is required as compared to other techniques. It is not a continuous process.

Built wetlands are water treatment systems that are planned by utilizing engineering practices. It is filled with substrates like soil and gravel and planted with vegetation lenient toward that soaked condition. The water dealt with is presented towards one side and streams over the surface or substrate emerge from the opposite end through a weir-like design that directs the profundity of water level in the wetland. A wetland contains water, substrate, plants (vascular and algae), litter (principally fallen plant material), spineless creatures (for the most part creepy crawly hatchlings and worms) and a variety of micro-organisms (in particular microscopic organisms). The system by which wetlands treat water is various and regularly interrelated. These components are settling of suspended particles, filtration of water with the substrate and litter, compound change, adsorption and particle trade of particles on the surfaces of plants, substrate, dregs and micro-organism's breakdown and change poisons and take-up of supplements by plants, predation and regular vanish of microbes. An effective wetland planning is finished considering this load of variables that can encourage these instruments (Ghimire *et al*., 2019; Almuktar *et al*., 2018). To purify wastewater from aquaculture, non-toxic iron was added to constructed wetlands. Additionally, the wastewater treatment capabilities of CWs were investigated under various plant species and ferrous ion dosages and treatment conditions (Zhimiao *et al*., 2019).

Wetlands can ingest significant amounts of carbon from the climate above multiple times from tropical forests. Because of this, it is a substantial arrangement in the future environment. Wetlands are adjusted because of the system of geochemical cycles. Because of the floods expanding dependent on environmental change, the decline in drinking water and the expanding human populace, the insurance of normal wetlands is significantly more significant. It is assessed that somewhere around 64 of the worldwide wetlands have vanished since 1900 because of urban communities and human populace development (Oliveira *et al*., 2021; Page *et al*., 2018).

Wetlands can be sorted dependent on hydrology, kinds of macrophytic development and stream way. Wetlands can be ordered by and large as surface stream wetlands, subsurface stream wetlands and cross over frame works that consolidate surface and subsurface stream wetlands. Built wetland systems can likewise be joined with conventional treatment advances to improve cleaning. A constructed wetland includes an appropriately planned bowl that contains water, a substrate and most regularly vascular plants. These segments can be controlled in developing a wetland. Other significant features of wetlands, like the networks of organisms and sea-going spineless creatures, usually grow. Constructed wetlands offer an economical method to treat wastewater and make it environment friendly. However, an effort has been made in this research to test wetlands to treat saline water. In addition to wetlands, chemical Gels have been used to enhance the TDS removal efficiency of constructed wetlands (Priya *et al*., 2021; Almuktar *et al*., 2018).

The objective of this research is to develop constructed wetlands that must be efficient to treat saline water. Phragmites have been planted in all CW due to their ability to survive in a saline environment. Phragmites australis was found to be active against eight soil-borne pathogens thanks to its ability to penetrate the hyphae and degrade the cytoplasm during the microscopic examination. In addition, chemical gels have been used to enhance the TDS removal efficiency of wetlands. The objective and scope of this research; are to decrease the salinity of influent water and remove pathogens from drinking water.

Developed wetland planted with *Canna indica* has high expulsion rates for nitrogen (N) and phosphorous (P). The expulsion rate for N is about 100% at both low and high influent burdens. P is about ~100% and 93.8% at low and high influent loads, individually at an electrical conductivity (EC) of 7 mS/cm (25 °C). Saltiness level-affected plants' digestion of nitrogen and phosphorus *Canna indica* can be utilized to adequately eliminate N and P under various saltiness levels (EC at 7, 10 and 15 mS/cm, 25 °C). Expanding the saltiness level to about EC 30 mS/cm repressed the evacuation of the two supplements in-built wetlands. At explicit conditions (the appropriate nutrient concentration and N/P proportions), the take-up of nutrients by plants expanded (Ezzat and Moustafa, 2020).

The optimal conditions for constructed wetlands (CWs), including the C/N ratio and initial contaminant concentration in influents were found to be used to remove contaminants from coastal wastewater. The results of high through put sequencing revealed that thio-alkalivibrio is responsible for encouraging de-nitrification. Ferrous ions improved the structure of the microbial community under salt stress and encouraged the enrichment of particular bacteria for wastewater treatment (Zhimiao *et al*., 2020). The presentation of developed wetlands in treating saline wastewater can be upgraded by utilizing intertidal wetland silt (IWS). IWS upgrades COD expulsion in CWs for saline wastewater. Since, it contains rich halophilic and an aerobic microbes. The gathering of halophilic and chemical related microbes expands the pressure resilience of plants present in CWs. In this way, IWS gives a definitive immunization source to CWs that treat saline wastewater (Sakurai *et al*., 2021).

Even subsurface stream-built wetland HSSFCW can treat natural matter present in wastewater to diminish boundaries like ($BOD_5$ and COD), TDS and nutrients (TN and TP) evacuation. CWs that were vegetated showed preferable execution over non-vegetated ones. It showed the dynamic part of macrophytes in wastewater treatment. Two accessible plants, *Pennisetum clandestinum* and *Pennisetum purpureum* were planted in two of three cells, while one unplanted cell was filled in as the control. In both the vegetated cells, they showed no considerable contrast in their exhibition, affirming that the two plant species are reasonable for use in developed wetlands for wastewater treatment. The treated profluent met the quality acceptable for release into untamed water holds in Nigeria at a short hydraulic retention time (Kotsia *et al*., 2020).

Built wetlands can viably eliminate nitrate from debased Santa Ana river water, which can be utilized as a powerful pre-treatment venture before counterfeit re-energize of groundwater in Orange county. The outcomes showed that nitrate mass evacuation rates as high as 1,000 mg/m$^2$/day were found in certain parts of the frame work and normal expulsion productivity of practically 80% was noticed. During the development phase of the wetland, nitrate misfortunes were most noteworthy, which shows that vegetation and accessible carbon assumed significant parts simultaneously. Perception of the interaction showed that bacterial de-nitrification was the essential component of the noticed nitrate misfortune. The framework worked successfully under generally hefty water-driven stacking going from 0.04 to 0.55 ha/m$^3$/s (2-33 sections of land for every 106 gallons/day) and low home occasions from 0.3 to 9.6 days (Lamori *et al*., 2019).

After looking at the biomass, debris rate and debris organization of six oceanic plants, it is presumed that *Typha* spp. *Phragmites communis* and *Potamogeton crispus* are the best plants for eliminating saltiness and saline farmland waste in Chagan lake. It is additionally tracked down that 10-26% of the all-out salt of sodium was eliminated in the wetland by collecting haloduric plants. It is proposed to grow the current wetland region by 6-9 times if the evacuation proficiency of six particles arrives at over 80% (Dillon *et al*., 2020). The development rate and net photosynthesis (ANET) of phragmites were unaltered during the present moment (0-7 days) openness to direct saltiness. In any case, at 300 mM NaCl, the development rate diminished because of decreased net absorption rate, intercellular carbon dioxide concentration (Ci) and stomatal conductance (gs). Nonetheless, during long term (15-30 days) exposure to natural saltiness, the development rate diminished. Under short term exposure to high salinity, photosynthesis was diminished by stomatal impediment and by both stomatal and biochemical constraints during long-haul openness (Gaballah *et al*., 2020).

## Material and Method

**CW setup and operation.** In the 20$^{th}$ century, the European phragmites first established themselves along the Atlantic coast before spreading across the continent. *Phragmites australis* known as the normal reed, is a type of plant. It is an extensively dispersed wetland grass that can grow up to 20 feet (6 m) tall. *Phragmites australis* was used for plantation because of its ability to survive in saline water. Eight pots were constructed and operated under conditions simulating differently constructed wetlands are shown in Fig. 2. Each pot was made using plastic tanks of a capacity of around 1.5 L each. All pots were vegetated with *Phragmites australis* except one pot which contained only soil. Out of eight pots, three pots contained gel mixed with soil. Each of them varied in gel concentration (0.3%, 0.5% and 1% gel, respectively). Similarly, three pots contained carbon nanotube CNT Gel mixed with soil and each of them varied in the concentration of CNT gel (0.3%, 0.5%, and 1% CNT gel respectively), one pot contained only plant with soil and no gel and the remaining one pot contained only soil with no plant and gel. Each pot has an effective height of 13 cm and a width of 11 cm. Each pot is comprised of three layers. The bottom layer comprises gravels (dia 4-8 mm) of height 4 cm. The next layer above the gravel comprises soil of a height of 6 cm. Between these two layers, a geo-textile is used to filtrate influent water. Above the soil, there is a free board area of a height of 3 cm.

The influent water is loaded onto the surface of a substrate and trickled down through the substrate. After a specific time interval, effluent is evacuated from the

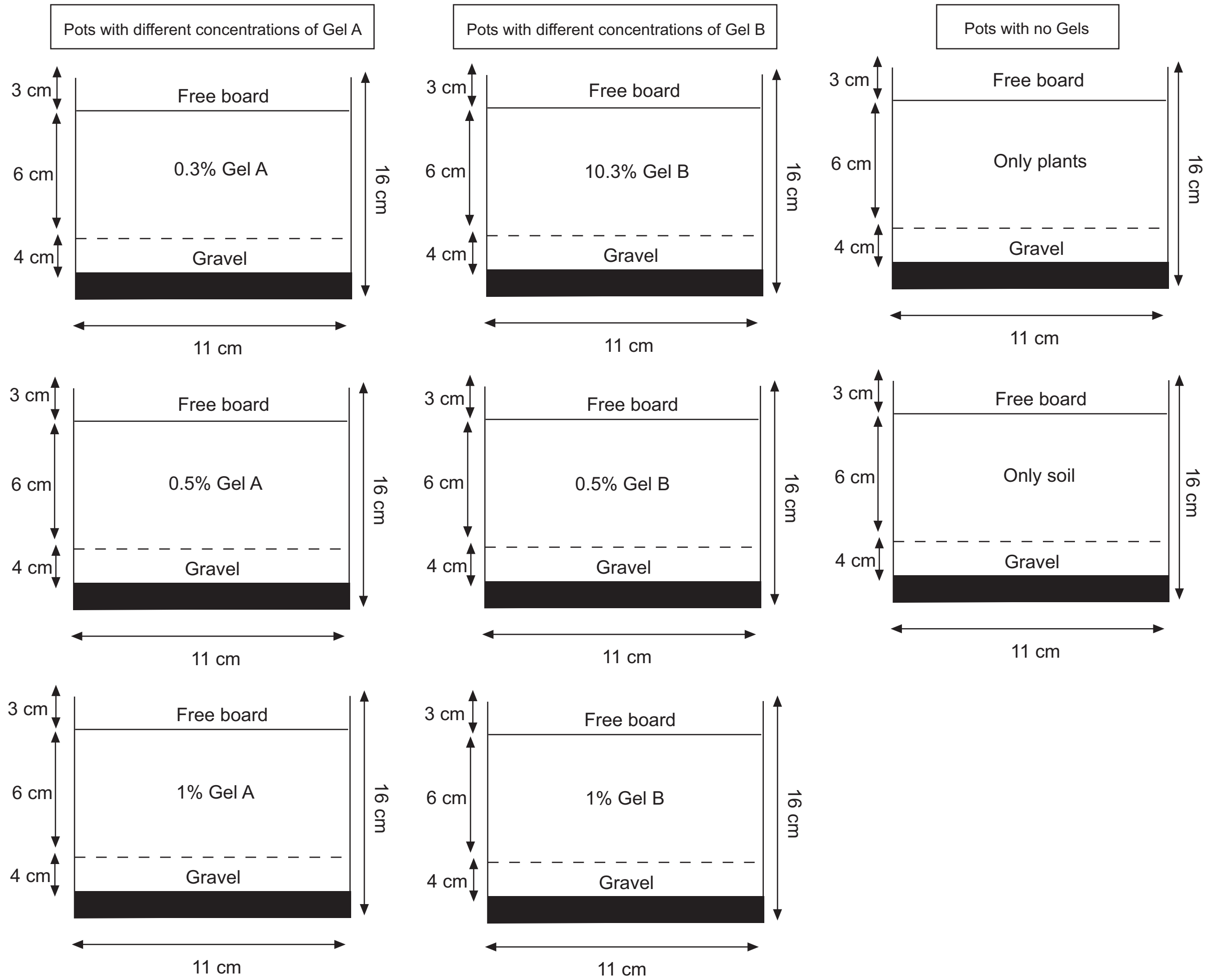


**Fig. 2.** Different designs of pots.

bottom outlet. After the setup, plants were allowed to grow in pots for around one month with fresh water to develop their roots properly before using saline water as shown in Fig. 3. Once the plants were stabilized in pots, salinity gradually increased in influent water. Tests were performed with influent water having TDS values of 1000, 2000 and 3000 ppm, respectively. Influent water was prepared by dissolving sodium chloride salt in fresh water to have the required TDS value. Between each loading, there was a rest time of an average of 2 days during which the pots became dry. At the end of each cycle, all pots were recycled with fresh water multiple times so that there was no accumulation of salt within the pots. The batch experiment was conducted in natural environmental conditions and repeated tests were performed to monitor results accurately.

## Result and Discussion

**Test 1.** Test 1 was performed with influent water having TDS of 1000 ppm and a 200 mL sample of influent water was fed to all pots. Samples were analyzed after each 2 h interval. The volume obtained corresponds to the approximate volume of the sample obtained at the outlet during one cycle. After analysis, the samples were fed back gain to the pots for the next examination. The average TDS results of all the pots analyzed are shown in Fig. 4.

The TDS value of the outlet sample after each 2 h interval of time was analyzed as presented in Fig. 5. In all the pots, there is a reduction in outlet TDS value but in pots containing gels, there is a greater reduction of TDS than in pots containing only plants and only soil. It can be seen that the TDS value of outlet water is high

**Fig. 3.** Construction of pots.

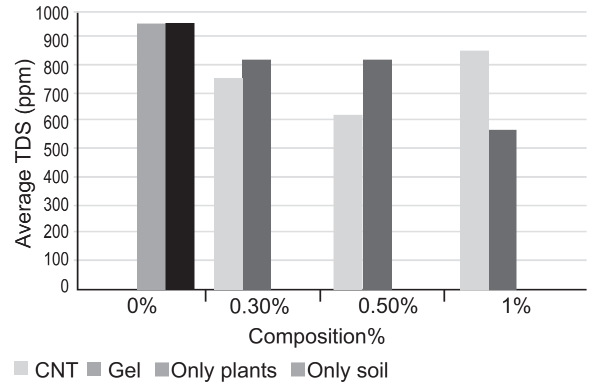


**Fig. 4.** Average TDS value comparison of different pots when influent 1000 ppm.

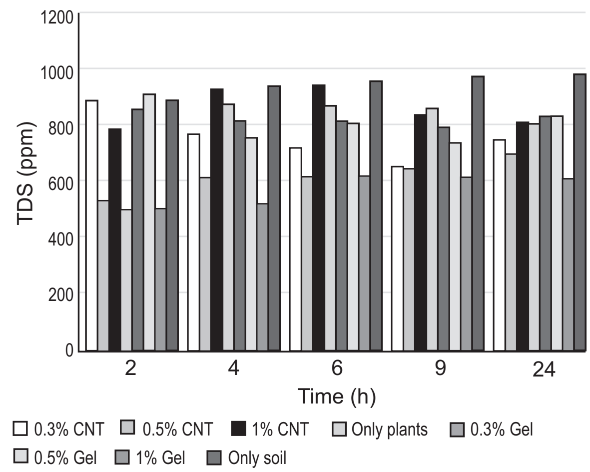


**Fig. 5.** TDS value comparison of different pots at 2 h interval of time.

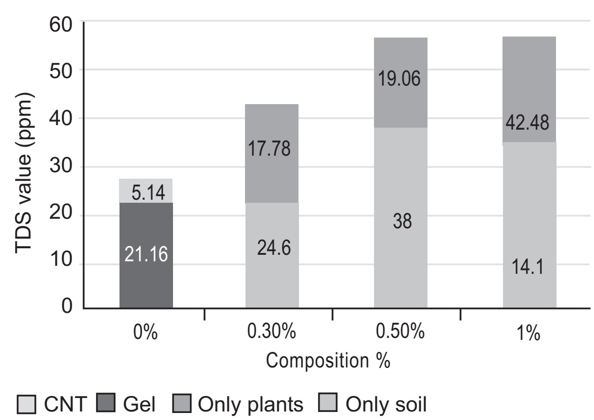


**Fig. 6.** Percentage decrease in TDS value.

in pots that have only plants and soil. In pots containing CNT gel, there is a reduction in TDS value from 0.3 to 0.5% CNT concentration but the TDS value increased in a pot containing 1% CNT concentration. Similarly, in pots containing simple gel, there is a reduction in TDS value with an increase in gel concentration from 0.3% to 1% gel concentration. The highest reduction of TDS is obtained in the pot containing 1% gel concentration. So, the presence of chemical Gels effectively aided in reducing the TDS value of the outlet sample (Kataki *et al*., 2021; Otter *et al*., 2020). The percentage decrease in TDS value at the outlet sample is shown in Fig. 6. Around 42% decrease in TDS value is obtained in a pot containing 1% gel concentration which is relatively high compared to the pots containing only plant and soil.

**Test 2.** Test 2 was performed with influent water having a TDS of 1500 ppm and a 200 mL sample of influent water was fed to all pots. Samples were analyzed after each 2 h interval. The volume obtained corresponds to the approximate volume of the sample obtained at the outlet during one cycle.

After analysis, the samples were fed back gain to the pots for the next examination. The average TDS results of all the pots analyzed are shown in Fig. 7. The TDS value shows in Fig. 8 and the outlet sample after each 2 h interval of time. In all the pots, there is a reduction in outlet TDS value but in pots containing gels, there is a greater reduction of TDS than in pots containing only plants and only soil. It can be seen that the TDS value of outlet water is high in pots that have only plants and only soil. In pots containing CNT gel, there is a reduction in TDS value at 0.3% CNT concentration but then TDS value increased in a pot containing 0.3% and 1% CNT concentration.

Similarly, in pots containing simple gel, there is a reduction in TDS value with an increase in gel concentration from 0.3% to 1% gel concentration. The highest reduction of TDS is obtained in the pot containing 0.5% gel concentration. So, the presence of these gels effectively reduced the TDS value of the outlet sample (Latrach *et al*., 2018; Saggai *et al*., 2017).

Figure 9 shows the percentage decrease in TDS value at the outlet sample. Around 65% decrease in TDS value is obtained in the pot containing 0.5 % gel concentration, which is quite high compared to the pots containing only plant and soil.

**Test 3.** Test 3 was performed with influent water having TDS of 3000 ppm, 350 mL sample of influent water was fed to all pots. Samples were analyzed after each 2 h interval. The volume obtained corresponds to the approximate volume of the sample obtained at the outlet during one cycle. After analysis, the samples were fed back gain to the pots for the next examination. The average TDS results of all the pots analyzed are shown in Fig. 10.

The TDS value shows in Fig. 11 and the outlet sample after each 2 h interval of time. In pots containing gels, there is a greater reduction of TDS than the pots containing only plants and only soil which gives an in effective increase in the saline value of water. It can be

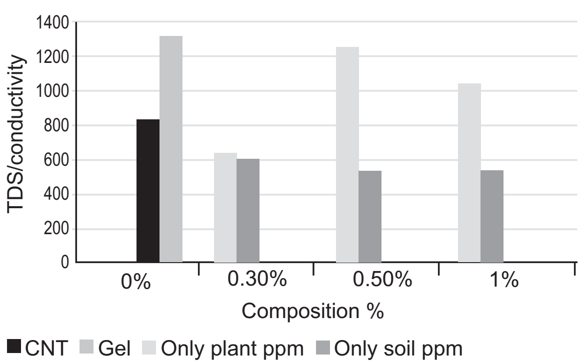


**Fig. 7.** Average TDS value comparison of different pots when influent 1500 ppm.

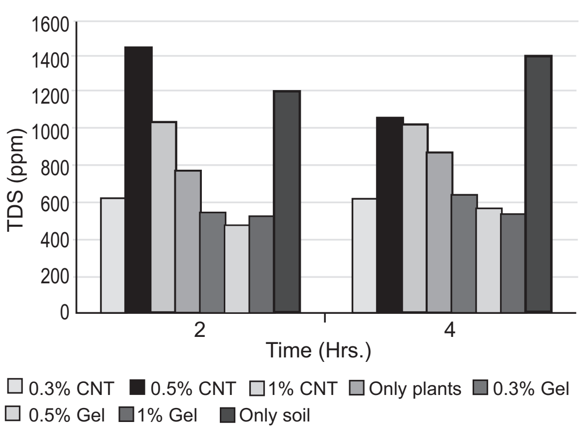


**Fig. 8.** TDS value comparison of different pots at 2 h interval of time.

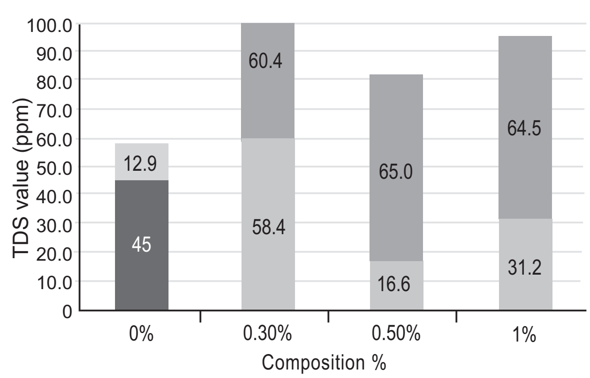


**Fig. 9.** Percentage decrease in TDS value.

seen that the TDS value of outlet water is increasing in pots that contain only plants and only soil with a high retention time. In pots containing CNT gel there is a reduction in TDS value with an increase in the concentration of CNT from 0.3% to 1% CNT concentration. Similarly, in pots containing simple gel, there is a reduction in TDS value with an increase in gel concentration from 0.3% to 1% gel concentration. The highest reduction of TDS is obtained in a pot containing 1% gel concentration. So, the presence of these gels effectively aided in reducing the TDS value of the outlet sample (Priya *et al*., 2021; López *et al*., 2019).

Figure 12 shows the percentage decrease in TDS value at the outlet sample. Around 18% decrease in TDS value is obtained in a pot containing 1% gel concentration. In contrast, in pots containing only plant and soil, there is an increase in TDS value at the outlet as compared to the inlet sample which shows that gels helped in decreasing the TS of the influent sample. Each test was repeated twice and the standard deviation obtained is 0.99.

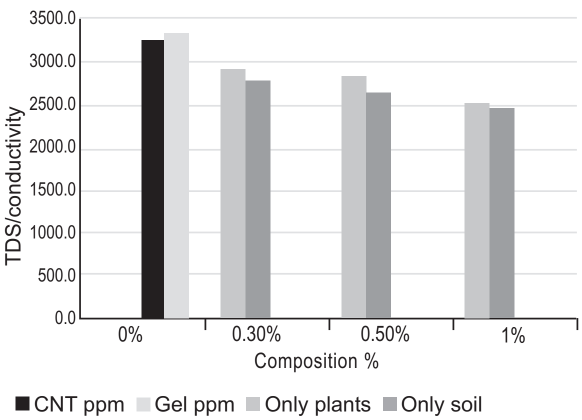


**Fig. 10.** Average TDS value comparison of different pots when influent 3000 ppm.

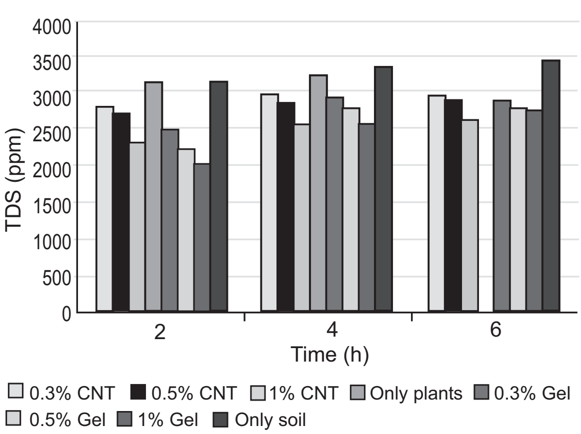


**Fig. 11.** TDS value comparison of different pots at 2 h interval of time.

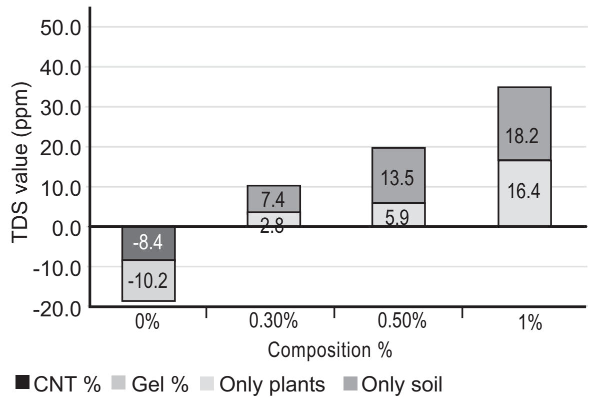


**Fig. 12.** Percentage decrease in TDS value

## Conclusion

Constructed wetlands (CW) preserve and refine water quality and provide an eco-friendly environment for natural habitats with the capacity for storing excess water and balancing groundwater flow. In this research, a batch process of groundwater filtration with the aid of vegetation of *Phragmites australis*, gel soil and CNT is made up. As seen from the tests conducted, the salinity content in the influent water and the time retained in CW affect the filtration process of the groundwater. But there is a very slight change in TDS content observed with the retention time for all the CW. Compared to CW with only plant or soil, both gel soil with and without CNT effectively reduces the TDS content of the water. A comparative study shows that TDS content between 1000-3000 ppm in the water inflow constructed wetland with in growth plantation having gel soil gives the highest decrease in conductivity of saline water at effluent. This artificially assembled system is highly effective for affluent water having a salinity content of 1500 ppm. Thus, this study shows that the construction of a wetland with gel soil and CNT will provide an operational technique for reducing salinity in water.

## Acknowledgment

The authors would like to acknowledge the Department of Chemical Engineering and Department of Polymer and Petrochemical Engineering, NED University of Engineering and Technology, Karachi, Pakistan, for supporting this research work.

**Conflict of Interest.** The authors declare that they have no conflict of interest.

## References

Almuktar, S., Abed, S.N., Scholz, M. 2018. Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. *Environmental Science and Pollution Research International*, **25:** 23595-23623. https://doi.org/10.1007/s11356-018-2629-3

Dillon, P., Fernández, E.E., Megdal, S.B., Massmann, G. 2020. Managed aquifer recharge for water resilience. *Water*, **12:** 1-11. https://doi.org/10.3390/w12071846

Ezzat, S.M., Moustafa, M.T. 2020. Treating wastewater under zero waste principle using wetland mesocosms. *Frontiers of Environmental Science and Engineering*, **15:** 1-14. https://doi.org/10.1007/s11783-020-1351-9

Fountoulakis, M.S., Sabathianakis, G., Kritsotakis, I., Kabourakis, E.M., Manios, T. 2017. Halophytes as vertical-flow constructed wetland vegetation for domestic wastewater treatment. *Science of the Total Environment*, **583:** 432-439. https://doi.org/10.1016/j.scitotenv.2017.01.090

Gaballah, M.S., Abdelwahab, O., Barakat, K.M., Aboagye, D. 2020. A novel horizontal subsurface flow constructed wetland planted with Typha angustifolia for treatment of polluted water. *Environmental Science and Pollution Research International*, **27:** 28449-28462. https://doi.org/10.1007/s11356-020-08669-5

Ghernaout, D. 2017. Increasing trends towards drinking water reclamation from treated wastewater. *World Journal of Applied Chemistry*, **3:** 1-9. https://doi:10.11648/j.wjac.20180301.11

Ghimire, U., Nandimandalam, H., Martinez-Guerra, E., Gude, V.G. 2019. Wetlands for wastewater treatment. *Water Environment Research*, **91:** 1378-1389. https://doi.org/10.1002/wer.1232

Kataki, S., Chatterjee, S., Vairale, M.G., Dwivedi, S.K., Gupta, D.K. 2021. Constructed wetland, an eco-technology for wastewater treatment: a review on types of wastewater treated and components of the technology (macrophyte, biolfilm and substrate). *Journal of Environmental Management*, **283:** 1-31. https://doi.org/10.1016/j.jenvman.2021.111986

Kotsia, D., Deligianni, A., Fyllas, N.M., Stasinakis, A.S., Fountoulakis, M.S. 2020. Converting treatment wetlands into treatment gardens: use of ornamental plants for greywater treatment. *Science of the Total Environment*, **744:** 1-9. https://doi.org/10.1016/j.scitotenv.2020.140889

Lamori, J.G., Xue, J., Rachmadi, A.T., Lopez, G.U., Kitajima, M., Gerba, C.P., Pepper, I.I., Brook, J.P., Serchan, S. 2019. Removal of fecal indicator bacteria and antibiotic resistant genes in constructed wetlands. *Environmental Science and Pollution Research International*, **26:** 10188-10197. https://doi.org/10.1007/s11356-019-04468-9

Latrach, L., Ouazzani, N., Hejjaj, A., Mahi, M., Masunaga, T., Mandi, L. 2018. Two-stage vertical flow multi-soil-layering (MSL) technology for efficient removal of coliforms and human pathogens from domestic wastewater in rural areas under arid climate. *International Journal of Hygiene and Environmental Health*, **221:** 64-80. https://doi.org/10.1016/j.ijheh.2017.10.004

López, D., Leiva, A.M., Arismendi, W., Vidal, G. 2019. Influence of design and operational parameters on the pathogens reduction in constructed wetland under the climate change scenario. *Reviews in Environmental Science and Bio/Technology*, **18:** 101-125. https://doi.org/10.1007/s11157-019-09493-1

Oliveira, G.A., Colares, G.S., Lutterbeck, C.A., Dell'Osbel, N., Machado, E.L., Rodrigues, L.R. 2021. Floating treatment wetlands in domestic wastewater treatment as a decentralized sanitation alternative. *Science of the Total Environment*, **773:** 1-15. https://doi.org/10.1016/j.scitotenv.2021.145609

Otter, P., Hertel, S., Ansari, J., Lara, E., Cano, R., Arias, C., Gregersen, P., Grischek, T., Benz, F., Goldmaier, A., Alvarez, J.A. 2020. Disinfection for decentralized wastewater reuse in rural areas through wetlands and solar driven onsite chlorination. *Science of the Total Environment*, **721:** 1-12. https://doi.org/10.1016/j.scitotenv.2020.137595

Page, D., Bekele, E., Vanderzalm, J., Sidhu, J. 2018. Managed aquifer recharge (MAR) in sustainable urban water management. *Water*, **10:** 1-16. https://doi.org/10.3390/w10030239

Priya, A.K., Pachaiappan, R., Kumar, P.S., Jalil, A.A., Vo, D.N., Rajendran, S. 2021. The war using microbes: a sustainable approach for wastewater management. *Environmental Pollution*, **275:** 1-15. https://doi.org/10.1016/j.envpol.2021.116598

Rusinol, M., Hundesa, A., Cardenas-Youngs, Y., Fernandez-Bravo, A., Perez-Cataluna, A., Moreno-Mesonero, L. 2020. Microbiological contamination of conventional and reclaimed irrigation water: evaluation and management measures. *Science of the Total Environment*, **710:** 1-11. https://doi.org/10.1016/j.scitotenv.2019.136298

Saggai, M.M., Ainouche, A., Nelson, M., Cattin, F., El Amrani, A. 2017. Long-term investigation of constructed wetland wastewater treatment and reuse: selection of adapted plant species for meta-remediation. *Journal of Environmental Management*, **201:** 120-128. https://doi.org/10.1016/j.jenvman.2017.06.040

Sakurai, K.S.I., Pompei, C.M.E., Tomita, I.N., Santos-Neto, A.J., Silva, G.H.R. 2021. Hybrid constructed wetlands as post-treatment of blackwater: an assessment of the removal of antibiotics. *Journal of Environmental Management*, **278:** 1-9. https://doi.org/10.1016/j.jenvman.2020.111552

Shingare, R.P., Thawale, P.R., Raghunathan, K., Mishra, A., Kumar, S. 2019. Constructed wetland for wastewater reuse: role and efficiency in removing enteric pathogens. *Journal of Environmental Management*, **246:** 444-461. https://doi.org/10.1016/j.jenvman.2019.05.157

Sijimol, M.R., Joseph, S. 2021. Constructed wetland systems for greywater treatment and reuse: a review. *International Journal of Energy and Water Resources*, **5:** 357-369. https://doi.org/10.1007/s42108-021-00129-1

Wang, J., Wang, W., Xiong, J., Li, L., Zhao, B., Sohail, I., He, Z. 2021. A constructed wetland system with aquatic macrophytes for cleaning contaminated runoff/storm water from urban area in Florida. *Journal of Environmental Management*, **280:** 1-9. https://doi.org/10.1016/j.jenvman.2020.111794

Wang, Y., Cai, Z., Sheng, S., Pan, F., Chen, F., Fu, J. 2020. Comprehensive evaluation of substrate materials for contaminants removal in constructed wetlands. *Science of the Total Environment*, **701:** 1-14. https://doi.org/10.1016/j.scitotenv.2019.134736

Wang, Q., Ding, J., Xie, H., Hao, D., Du, Y., Zhao, C., Xu, F., Kong, Q., Wang, B. 2021. Phosphorus removal performance of microbial-enhanced constructed wetlands that treat saline wastewater. *Journal of Cleaner Production*, **288:** 1-12. https://doi.org/10.1016/j.jclepro.2020.125119

Zhimiao, Z., Xiao, Z., Zhufang, W., Xinshan, S., Mengqi, C., Mengyu, C., Yinjiang, Z. 2019. Enhancing the pollutant removal performance and biological mechanisms by adding ferrous ions into aquaculture wastewater in constructed wetland. *Bioresource Technology*, **293:** 1-9. https://doi.org/10.1016/j.biortech.2019.122003

Zhimiao, Z., Zhufang, W., Mengyu, C., Xinshan, S., Mengqi, C., Yinjiang, Z. 2020. Adding ferrous ions improved the performance of contaminant removal from low C/N coastal wastewater in constructed wetlands. *Environmental Science: Water Research and Technology*, **6:** 3351-3360. https://doi.org/10.1039/D0EW00223B