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DESIGNING AND DEVELOPING WETLAND TECHNOLOGY TO TREAT WASTEWATER FOR IRRIGATION

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ABSTRACT

In Pakistan, availability of fresh water is decreasing with time and use of treated wastewater can be a potential alternate source of fresh water for irrigation to meet food and fiber demand of its fast growing population. The direct use of wastewater for agriculture can have adverse effects on soil, plants and human health and therefore requires treatment. Wetland is an advanced technology, which has potential to treat wastewater biologically. To evaluate performance of wetland technology, a prototype study was conducted at experimental area of Water Management Research Centre, UAF. In this experiment, plants (Water lettuce and Pennywort) were used to treat wastewater by up-taking heavy metals and generating anaerobic conditions to kill pathogens under different hydraulic residence times (HRT). The experiment was laid under CRD with three treatments, each replicated three times. Three treatments comprising 3 day, 5 day and 7 day HRT were used to find optimum HRT for treating wastewater. Water quality was examined in terms of total hardness (TH), EC, pH, dissolved O_2, Ca^{++}, Mg^{++}, and heavy metals like Fe and Cu. The reduction efficiency (%) of quality parameters of wastewater was found in the range of 4 to 33, 3 to 26, 0 to 9.5, 7 to 36, 2 to 31, 0 to 90 and 0 to 68 percent for TH, EC, pH, Ca^{++}, Mg^{++}, Fe, and Cu, respectively. Similarly, concentration of dissolved O_2 was improved from 1.3 mg/L for untreated wastewater to a maximum value of 2.25 mg/L. The results indicated that 3rd treatment with 7 days HRT has the highest reduction efficiency to treat wastewater, which can be replicated at large to meet shortages of irrigation water supplies.

Keywords: Wetland, wastewater, water quality, hydraulic retention time, % reduction efficiency

1. Introduction

World at present is facing an imminent threat due to the continuous decline in its fresh water resources and food security. World agriculture is the major consumer of these fresh water supplies and now there is a dire need to save this fresh water for more pressing use by switching agriculture to alternate water sources. Wastewater may be an important alternate source to supplement fresh water supplies; however, its direct use

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for irrigation purposes poses a serious threat to public health and has led to increased concerns over water quality.

In Pakistan, water quality, over the years, has been deteriorating due to increased disposal of untreated sewerage water causing a great deal of worries to the environment. According to the population survey of Pakistan conducted in 1998 about 1.83×10^7 m^3 h^{-1} wastewater was generated from 14 cities of Pakistan (FAO, 2002). It has been reported that Pakistan produced 962,335 million gallons (4.369×10^9 m^3/yr) of wastewater, which includes 288,328 (1.309×10^9 m^3/yr) and 674,009 (3.060×10^9 m^3/yr a figure of 5.54×10^9 m^3/yr for the year 2011) million gallons from industrial and municipal use, respectively (PWSS, 2002). About 392,511 million gallons (1.782 x 109 m^3/yr) wastewater was discharged into major rivers, which is 1/3rd of total wastewater generated in Pakistan. It includes 316,740 million gallons (1.438 x109 m^3/yr) from municipal and 75,771 million gallons (0.344 x 109 m^3/yr) from industrial discharge. In Pakistan, major contribution of wastewater is from petrochemicals, food processing, tanneries, paper and pulp, refineries, sugar cane and textile industries (UNIDO, 2000). The contribution in total industrial waste of major industries like polyester yarn, cement, paper and board, sugar, textile and fertilizer is more than 80%. It has been estimated that local water bodies received 2,000 million gallons of wastewater every day in Pakistan (Pak-SCEA 2006).

Regulatory agencies are now working on to improve water quality by bringing new reclamation and pollution control initiatives in order to curb this horrible situation. Existing Facultative Lagoon (FL) system in Pakistan is providing only partial treatment to the sewerage water and after that it is either discharged into the rivers or used for agriculture purposes. This massive discharge of partially treated sewage to the surface water does not comply with regulatory requirements of the effluents regarding pathogenic microorganism and organic contaminates. Constructive wetlands (CW) as an alternate to the conventional sludge water treatment method have gained much attraction and are being widely used in a complimentary manner to treat and polish FL effluents. This not only reduces the risk associated with wastewater discharge to the public health and environment but also includes advantages like low maintenance and operation cost as well as less energy requirements.

CW treated water could be used in agriculture with numerous advantages particularly in nonfood crops as compared to the partially treated water as it provides many essential nutrients to the plants thus reducing the fertilizer requirements of the crops. This technology provides a viable solution for wastewater treatment while potentially producing biomass capable of functioning as a renewable energy source, fodder for livestock and/or other useful products. There are, however, not many studies available on use of CW facilities under tropical conditions as it is assumed to be more efficient in equatorial regions and more temperate conditions. Warm weather encourages year round plant growth and microbe activity, which results in positive effect on the treatment parameters.

This prototype study was conducted at University of Agriculture, Faisalabad within the framework of National Institute of Bioremediation (NIB, NARC Islamabad), for demonstration / validation of a constructed wetland (CW) wastewater treatment facility.

The primary objective of the study was to develop the prototype of wetland, to find optimum Hydraulic Retention Time (HRT) for getting good quality water at outlet. Reliable and consistent performance was an important criterion in the final evaluation of the CW facility. This included a thorough assessment of all data including CW sensitivity to interruptions or extreme conditions, such as those occurring during peak of the dry season or heavy hurricane-induced rainstorms during wet season.

2. Materials and methods

2.1 Study location

Experimental study was conducted at Postgraduate Agricultural Research Station (PARS), University of Agricultural, Faisalabad, Pakistan, during 2015-16 to investigate the best HRT regarding efficiency of wetland to treat wastewater. The site is at an altitude of 183 m above sea level and is of coordinates 31˚ 2' N and 73˚ 0' E. The climate of the study area touches two extremes with maximum daily summer temperature reaching 48˚C and minimum daily winter temperature of about 4.8˚C. The mean annual temperature is 24˚C with mean annual maximum of 31.6˚C and mean annual minimum of 17.6˚C. The summer season starts from April and continues till October. May, June and July are the hottest months of the year. The winter, on the other hand, starts from November and continues till March. December, January and February are relatively colder months of the year. The average precipitation at the study area is 386 mm.

2.2 Plants used

CW performance is largely dependent on the types of vegetation chosen (Kadlec et al., 2000). In this study, two varieties of native aquatic plants with contrasting tolerance to environmental conditions were evaluated. Aquatic plants used in this study were water lettuce (Pistiastratiotes L) and pennywort (Hydrocotyle Ranunculoides) obtained from the surrounding environment and NIB, NARC, Islamabad. A continuum of treatment was maintained between specific pairs of plants over free surface flow (SF) wetlands via the use of distribution boxes.

2.3 CW design

The CW system was completed in accordance with the Kadlec and Knight Method (1996), and design considerations were based on the total area necessary to remove BOD5, TSS, phosphorus, nitrogen, organic nutrients and pathogens. The CW system consisted of open water (OW) and free surface flow (SF). Experiment was designed in Randomized Complete Block Design (RCBD) with 3 treatments, while each treatment having 3 replications. Research was conducted on plastic canes with different length, width and depth according to designed parameters with different HRT for each treatment. The HRT is a measure of the average length of time that a soluble compound remains in a constructed bioreactor. The system was designed on inflow of 10 liters per day waste water with 3 canes in one replication for each treatment. First, second and third treatments having 3, 5 and 7 days HRT, respectively, while each treatment having three canes in series with size 18.5 × 10.5 × 12, 22 × 14 ×12 and 22 × 14 × 12 inches. In this way, all treatments had three canes in series in a replication with 1.35, 2.14 and 2.14 ft^3 total storage capacity. All canes were containing some volume of gravels which was 50 % of total storage volume of cane. Each treatment was equipped with one

storage tank having 16 inch diameter and 38 inch length. Storage tanks had gravel layer up to 11 inches from bottom which was also working as media filter. Gavels were arranged from smaller to lager in size as we move downward in both storage tank and canes. Storage capacity of tank was 300 liters. Each treatment was replicated thrice with each replication having three canes as explained above. These canes were working as ponds having plants within them. In each treatment and its replicates, first and last canes had water lettuce while the second one having pennywort plants. Canes and storage tanks were connected with pipes. The water flow uniformity was controlled by using valves subsequently installed and checked manually as a head of each weir. The schematic diagram of CW block having three treatments of HRT is shown in Figure 1.

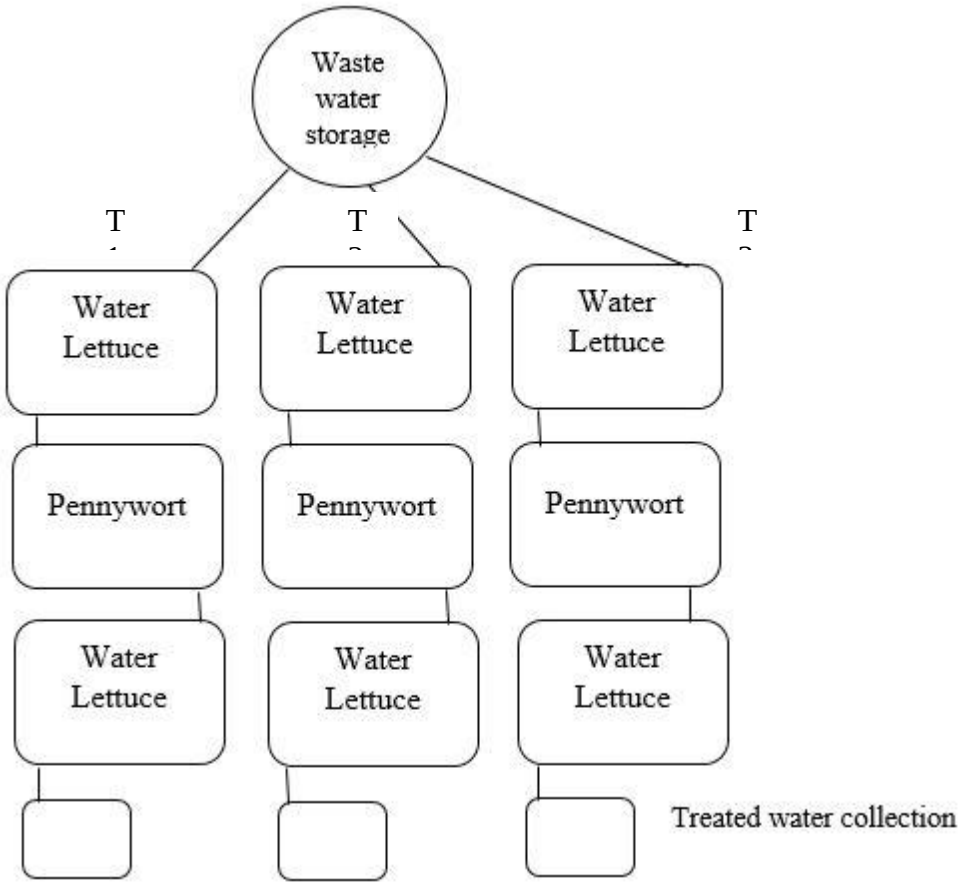


Figure 1: Schematic diagram of CW design; one block/ replicate representing three treatments.

2.4 Performance parameters

Parameters tested/ measured for evaluating performance of different treatments in this study included total hardness, electrical conductivity (EC), pH, dissolved oxygen (DO), Calcium (Ca^{++}), Magnesium (Mg^{++}), and heavy metals including Fe and Cu. Measuring or testing of physical and chemical parameters was carried out once a week. Calculated efficiency and rate of degradation, as well as minimum residence time were determined

to show the value of degradation. Percent mass removal for each constituent was calculated from the following equation (Kadlec and Knight, 1996):

$$Mass\ Removal\ (\%) = \frac{m_1 - m_2}{m_1} \times 100$$

3. Results and discussion

For data collection, analysis and compilation of results, wastewater samples were collected on the day of wastewater collection from collection point, as well as after treatment through the wetland on different dates (about once a week). Sampling parameters such as pH and EC were measured in Soil and Water Lab at WMRC, UAF, while other parameters such as Ca^{++} and Mg^{++} were determined in Soil and Water Chemistry Lab, UAF. Heavy metals (Fe, Cu) were measured in Hi-Tech. Lab at UAF. The results of the sample analysis are described and discussed in this section.

3.1 Total hardness (TH)

Total hardness is hardness of the mineral content of water that is irreversible by boiling. Therefore, total hardness can be equivalent to the total calcium and magnesium hardness. Total hardness (TH) analysis was performed before and after treatment of wastewater by using titration method. Values of TH in untreated wastewater ranged from 680 to 440 mg/L. The reduction percentage after treatment of wastewater ranged from 4 to 32 %. The reduction percentage was found more in T3 treatment having more HRT (7 days). TH calculated at sampling date on 12th November 2015 for untreated wastewater was 680 mg/L, but it decreased as water passed through the wetland up to 577.33, 504 and 458 mg/L with reduction % of 15.09, 25.88 and 32.64 in 1st, 2nd and 3rd treatments, respectively. Analysis of variance (ANOVA) under Randomized Complete Blok Design (RCBD) showed that the results were significant for treatments but non-significant within the replications.

3.2 Electric conductivity (EC)

EC analysis was performed before and after treatment of wastewater using digital meter. The values of EC in untreated wastewater ranged from 6 to 7 ds/m. The reduction percentage after treatment of wastewater ranged from 3 to 27 %. The reduction percentage was found more in T3 with more HRT (7 days). The result of EC at sampling date on 12th November 2015, showed that the value of untreated wastewater was 6.2 ds/m, but it decreased as water passed through the wetland up to 6.01, 5.51 and 5.315 ds/m with reduction % of 3.01, 11.12 and 14.27 in 1st, 2nd and 3rd treatments, respectively. Analysis of variance (ANOVA) under RCBD showed that the results were significant for treatments but non-significant within treatment replications.

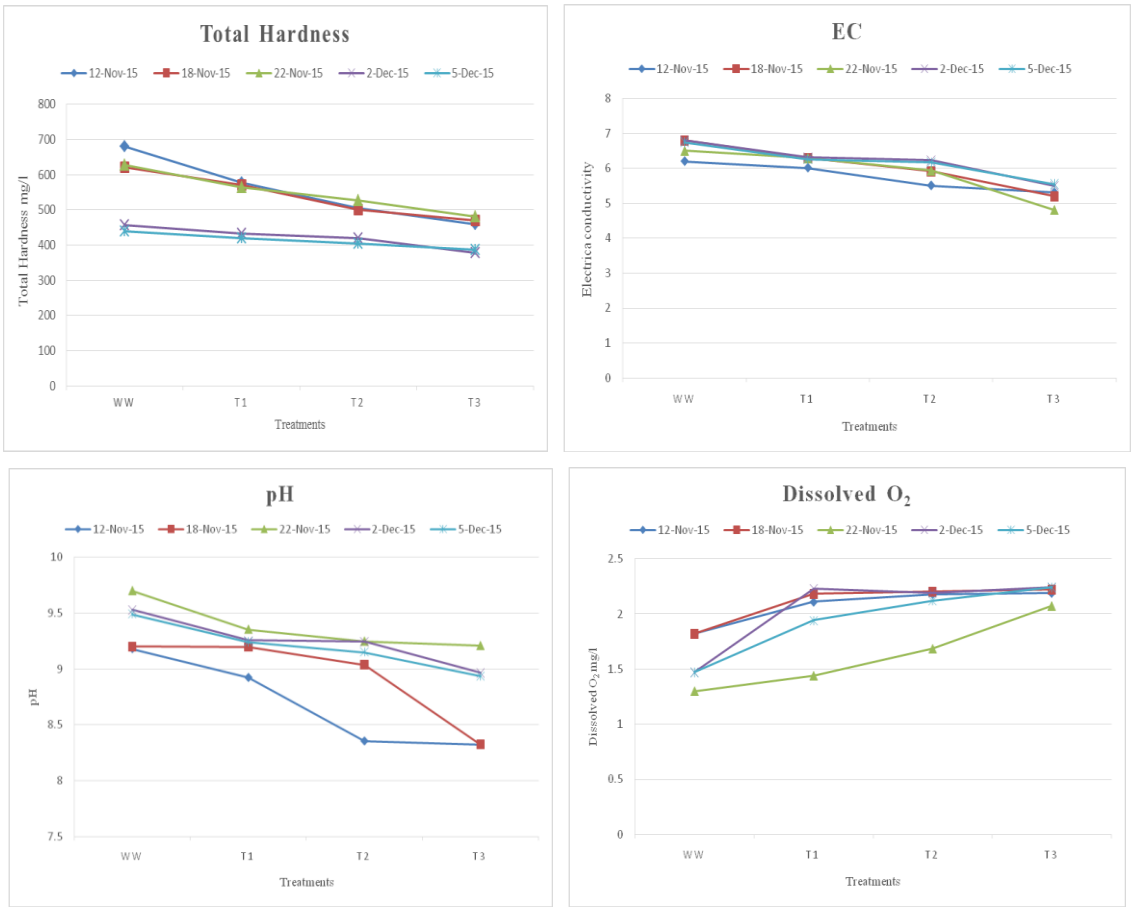


Figure 2: Line representation of total hardness, EC, pH and dissolved O_2 for different treatments.

3.3 pH

Measurement of pH is important for biological treatments of the industrial effluents. As pH decreases below 5 acidity increases and the process is affected adversely. Similarly, value of pH shifting from 5 to 9 disturbs the wastewater treatment. Chemically disinfection, coagulation and water softening are governed by the pH parameter. As pH reduces to 4 acidic taste is produced and as it increases up to 8.5 tastes become bitter. More value of pH accelerates the formation of scale in heating water apparatus and decreases the germicidal prospective of chlorine. Tri-halo-methane is produced due to high pH, which leads to cancer in human being (APHA, 2003).

Analysis of pH was performed before and after treatment of wastewater by using digital meter. Values of pH in untreated wastewater were found in the range of 9 to 10. At sampling date on 12th November 2015, we found the pH value in untreated wastewater as 9.18, but it decreased up to 8.92, 8.35 and 8.32 with reduction % of about 2.8, 4.4 and 9.3 in 1st, 2nd and 3rd treatments, respectively. Analysis of variance (ANOVA) under RCBD showed that the results were nearly significant, but not totally significant for treatments and non-significant for replications within treatments.

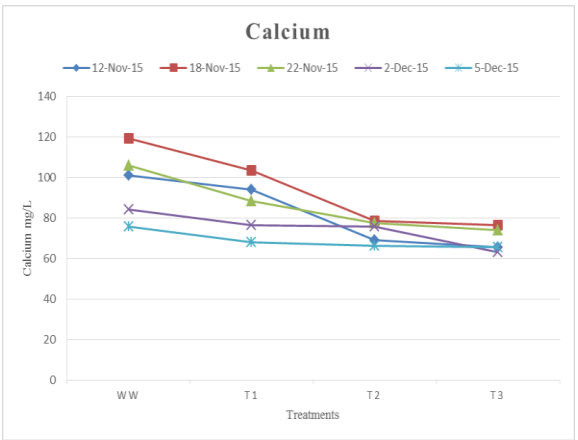
According to the NEQS standards, normal value for hydrogen ion concentration (pH) is ranging from 6.5 to 7.5 for drinking purposes and up to 8 for irrigation as described in food and agriculture organization (FAO) papers; thus, untreated wastewater was found unfit for irrigation. Bio remediated water was also not in permissible limits, but pH decreased only to some extent.

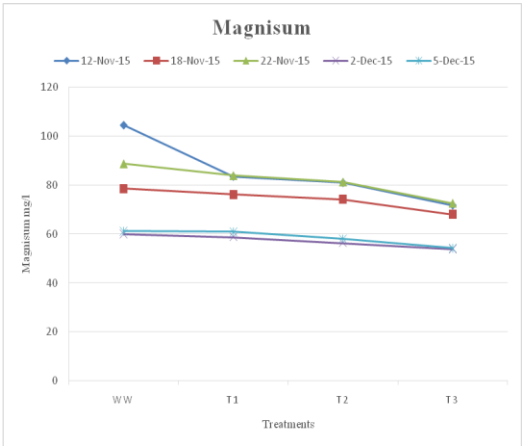
3.4 Dissolved O_2 (DO)

Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within water bodies. Analysis of dissolved O_2 was performed before and after treatment of wastewater by using dissolved O_2 digital meter. The values of DO in untreated wastewater ranged from 1.3 to 1 mg/L. The dissolving of O_2 after treatment of wastewater was found more in T3 with more HRT of 7 days, while showing less increase as we moved from higher HRT to lower HRT. As determined for sample taken on 12th November 2015, value of DO in untreated wastewater was 1.82 mg/L, but increased as water passed through wetland up to 2.11, 2.18 and 2.19 mg/L in 1st, 2nd and 3rd treatments, respectively.

3.5 Calcium (Ca^{++})

Ca^{++} analysis was performed before and after treatment of wastewater by using titration method. The values of Ca^{++} in untreated wastewater ranged from 70 to 125 mg/L. The reduction percentage after treatment of wastewater ranged from 6 to 35 %. The reduction percentage was found more in T3 with more HRT of 7 days. Reduction (%) had decreasing trend as we moved from higher HRT to lower HRT. Ca^{++} determined at sampling date on 12th November 2015 for untreated wastewater was 101, but it decreased up to 94.20, 68.97 and 65.60 mg/L with reduction % of 6.66, 31.66 and 35 in 1st, 2nd and 3rd treatments, respectively. Analysis of variance (ANOVA) under RCBD showed that the results were significant for treatments but non-significant within the replications. It is important that untreated wastewater was also in permissible range, as according to Irrigation Quality Standards (IQS's), permissible limit of Ca^{++} for irrigation water should be less than 200 mg/L. However, bio-remediated water in comparison is well within permissible Irrigation Quality Standards (IQS's).





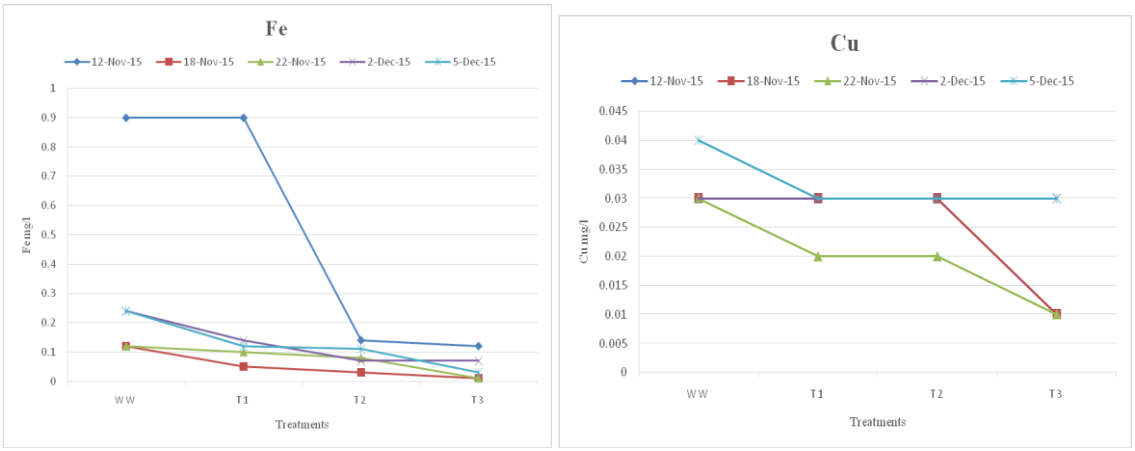


Figure 3: Line representation of Ca, Mg, Fe and Cu concentrations for different treatments.

3.6 Magnesium (Mg^{++})

Soils containing high levels of exchangeable magnesium are often thought to be troubled with soil infiltration problems. There is reasonably good agreement that magnesium acts on soils in a way which is more like calcium than sodium, and that it is preferentially adsorbed by the soil to a much greater degree than sodium but to a slightly less degree than calcium. In magnesium dominated water (ratio of Ca/Mg < 1) or magnesium dominated soil (soil-water ratio of Ca/Mg < 1), the potential effect of sodium may be slightly increased. In other words, a given SAR value will show slightly more damage if the Ca/Mg ratio is less than 1. The lower the ratio, the more damaging is the SAR (Rahman and Rowell 1979).

Mg^{++} analysis was performed before and after treatment of wastewater by using titration method. Values of Mg^{++} in untreated waste water ranged from 60 to 105 mg/L. The reduction percentage after treatment of wastewater ranged from 2 to 31 %. The reduction percentage was found more in T3 with more HRT of 7 days and it had decreasing trend as moved from higher HRT to lower HRT. Concentration of Mg^{++} calculated at sampling date on 12th November 2015 for untreated wastewater was 101, but it decreased up to 83.48, 80.95 and 71.78 mg/L with reduction % of 20.06, 22.47 and 31.26 in 1st, 2nd and 3rd treatments, respectively. Analysis of variance (ANOVA) under RCBD, showed that the results were significant for treatments but non-significant within treatment replications. Untreated wastewater was also found in permissible range, as permissible limit of Mg^{++} for irrigation water should be less than 150 mg/L according to Irrigation Quality Standards (IQS's). Bio remediated water, however, was further refined and was well within the permissible Irrigation Quality Standards (IQS's).

3.7 Heavy metals (Cu, Fe)

Heavy metals analysis was performed before and after treatment of wastewater by using atomic absorption spectrophotometer. Concentration of heavy metals in untreated wastewater ranged from 0.03 to 0.9; the concentration of Fe was found more than that of Cu. The reduction percentage after treatment of wastewater ranged from 0 to 90 %. The reduction percentage was found more in T3 with more HRT (7 days), while showing decreasing trend as we moved from higher HRT to lower HRT. The result of both heavy

metals determined for sample taken on 12th November 2015, value of Fe and Cu in untreated wastewater was found to be 0.9 and 0.03 mg/L, respectively. However, concentration of Fe decreased up to 0.9, 0.14 and 0.12 mg/L with reduction % of 0, 84.44 and 86.66 in 1st, 2nd and 3rd treatments, respectively. Concentration of Cu showed little decrease up to 0.03, 0.03 and 0.01 mg/L with reduction % of 0, 0 and 66.66 in 1st, 2nd and 3rd treatments, respectively. From results of different sampling dates, it can be seen that the results of first sampling date showed more percent of reduction. This is because, before first sampling, plants were given more time to germinate and adjust themselves according to the environment after plantation.

4. Conclusions

This study was designed to develop the prototype of wetland to investigate optimum HRT for wastewater treatments. The statistical analysis was also performed on observed values to check the significance of results. The scheme of study was based on Randomized Complete Block Design (RCBD) having three treatments with different HRT and three replications in one treatment. Inflow of wastewater was constant for all treatments. *Water Lettuce* and *Pennywort* were the plants selected for treatment of water. The statistical analysis showed that treatment effects on all parameters except pH were highly significant but non-significant for blocks/ replications. Treatment with 7 days HRT showed better results in comparison to those with 3 and 5 days HRT. Following specific conclusions were derived based on this study:

i. Direct use of waste water for irrigation is not recommended because it has large values of each parameter as compared with those under FAO standards of water for irrigation (FAO, 1976).

ii. Wastewater contained heavy metals concentration posing a direct threat to soil and groundwater and human health.

iii. Wetland is technology by which we can treat wastewater with the help of plants with some proper management.

iv. Third treatment with 7 days Hydraulic Retention Time (HRT) showed best results to treat wastewater in this study.

v. The levels of TH, EC, pH, DO, Ca^{++}, Mg^{++}, Fe and Cu in wastewater were not in permissible limits. But when this water was passed through the wetland, these levels moved towards the standards and made this water fit for irrigation.

vi. Wastewater sites can be developed into visiting places or gardens and treated water can be used for irrigation.

References

APHA. 2003. Standard Methods for the Examination of Water and Wastewater 20th Edition. Method 5210 B.

Food and Agriculture Organization (FAO). 1976. Water quality Agriculture, Irrigation and Drainage. Paper 29. Rome.

Food and Agriculture Organization (FAO). 2002. Investment in land and water in proceedings of the regional consultation Bangkok, Thailand 3-5 October, 2001. Publication 2002/09. FAO Regional Office for Asia and the Pacific, Bangkok.

Kadlec, R. H., and Knight, R. L. 1996. Treatment Wetlands, CRC Press, Boca Raton, Florida.

Kadlec, R. H., R. L. Knight, J. Vymazal, H. Brix, P. F. Cooper and R. Haberl. 2000. Constructed Wetlands for Water Pollution Control: Processes, Performance, Design and Operation, IWA Scientific and Technical Report No. 8, London.

Pakistan Water Sector Strategy (PWSS). 2002. National water sector profile, volume 5, October 2002, Ministry of Water and Power, Office of the Chief Engineering Advisor. Available at http://waterinfo.net.pk/cms/pdf/vol5.pdf

Pak-SCEA. 2006. Pakistan Strategic Country Environmental Assessment Report: Rising to the Challenges, May, 2006.

Rahman W.A. and D.L. Rowell. 1979. The influence of magnesium in saline and sodic soils: A specific effect or a problem of cation exchange. J. Soil Science 30:535–546.

United Nations Industrial Development Organization (UNIDO). 2000. Industrial Policy and the Environment in Pakistan. UNIDO, Vienna, Austria.