ABSTRACT

Urban areas that exist under the impact of multi-industrial functions among arid and semi-arid environments witness substantial growth in environmental pollution, particularly in the water sector. Faisalabad is second largest city of Punjab and its industries dumping their wastewater in to drain without prior treatment. Farmers use this water for irrigation and its becoming part of food chain. The present study evaluated water management by determining the quality, treatment efficiency, reuse in irrigation, and related health effects in a semi-arid city Faisalabad, Pakistan. A cost-efficient method of within drain phytoremediation was conducted at field scale. For water and wastewater quality and associated health risks assessment, drinking water (n = 48), surface water (n = 37), industrial water (n = 60) and drain water (n = 30) samples were together. Physio-chemical and biological parameters as well as trace metals including Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Ni and Zn were investigated using standard procedures and multivariate water quality indices. For determining the efficiency of floating treatment wetland, aquatic macrophytes (*Typha latifolia*, *Brachiaria mutica*, and *Poa annua*) were collected from anaerobic ponds at Chokera wastewater treatment plant and their percentage removal efficiencies were evaluated for two years. To determine the risk assessment of reused wastewater in irrigation, in practice for the last 20 years, the concentrations of potentially toxic elements (Cu, Cr, Mn, Fe, Pb, Zn, Ni) and organic contaminants (including organochlorines, polycyclic aromatic hydrocarbons and polychlorinated biphenyls were analyzed by atomic absorption spectrometer and Gas chromatography- Mass spectrometer (GC-MS), respectively, in five different crops (corn, rice, wheat, sugarcane and millet), with their topsoil and sewage sludge samples collected from wastewater ponds. Multi-targeted risks analysis was conducted. A socio-economic survey based on a questionnaire presented to the farmers was conducted to determine impact of reusing wastewater on their social and economic status. Additionally, a pilot scale treatment was conducted for assessing the low-cost, within drain phytoremediation efficiency, using *Eichhornia crassipes* with its endophytic bacterial strains at the New Campus of Government College University, Kala Shah Kaku, Lahore. The results showed that many parameters including physio-chemical, biological and heavy metals, specifically As (0.03mg/L), surpassed the acceptable limit of the Punjab Environmental Quality Standards (PEQS) and the World Health Organization (WHO) standards in drinking water samples. The results of water

quality index showed that nearly 56% of samples had poor, nearly 8% having very poor, and close to 6% having inappropriate drinking water quality. Surface water quality of the Gugera Branch Canal was determined as fit for irrigation with medium range of sodium (alkalinity) and salinity hazards, however, it was found poor with Mg absorption ratio. The values of Hazard Quotient (HQ) for arsenic were found at the threshold level (HQ > 1) and carcinogenicity was found in arsenic and chromium (1×10^{-4}) in adults and children in drinking water. For wastewater, results showed that all the parameters were higher than the upper limit set by PEQs and the Environmental Protection Agency (EPA), Pakistan. Metals Pollution Index (MPI) was found to be high in textile industrial effluents (MPI > 1,000). The degree of contamination was very high than the maximum contamination level (≥ 3) in industrial effluent (33.85), followed by sewage effluent (14.05). The calculated Pollution Load showed high BOD (119.34 ton/d) and COD (376.41 ton/d) load in Pharang drain due to excessive discharges of industrial effluents. Treatment efficiency at Chokera wastewater ponds was higher (60%) in summers as compared to winters through the phytoremediation process. *Typha latifolia* was found to be the most suited plant with a high accumulation coefficient value for metals uptake. However, parameters of effluent water were still above the PEQs limits. For trace metals, mean values of Pb and Zn were higher than the Food and Agriculture Organization (FAO, 2001) in all 5 crop samples. Zinc was found to be higher in soil when compared with the European Union Standards (2006). Concentration of toxic elements in crops and soil samples were in descendent order as follows: Fe > Zn > Mn > Cr > Pb > Cu > Ni and Fe > Zn > Mn > Ni > Cu > Pb > Cr, respectively. The calculated Potential Ecological Risk Index (PERI) was found more in all samples than the acceptable limit, i.e., PERI > 600. For non-carcinogenic risk, Hazard Index (HI) values in adults were near threshold level (HI > 1) in all crop samples. In children, the HI values in corn, rice and wheat were above the threshold limit, while in sugarcane and millet, these values were near the threshold level. Cancer risk value for Cr was found to be much higher than the safe limit (1×10^{-6}) both in adult and children in all crop samples. For organic pollutants, the mean concentrations of ΣPAHs (polyaromatic hydrocarbons) in crop and soil samples ranged from 10.68±0.32 ng/g (in millet) to 19.42±0.58 ng/g (in wheat) and 8.28±0.25 ng/g (base soil of corn) to 11.65±0.34 ng/g (base soil of rice). Average concentration in sewage sludge samples ranged from 6.73±0.2 ng/g to 14.93±0.45 ng/g. In all crop and soil samples, ΣOCP (organochlorine

pesticides) ranged from 581.09±17.4 ng/g (in corn) to 6219.07±186.5 ng/g (in sugarcane) and 229.6±6.8 ng/g (corn soil) to 547.4±16.4 ng/g (rice soil), respectively. For sewage sludge samples, the mean concentration of ΣOCP ranged from 131.5±3.9 ng/g to 1107.4±33.2 ng/g. Mean ΣPCB (polychlorinated biphenyl) values in all crop samples ranged from 6.03±0.18 ng/g (corn) to 480.39±14.41 ng/g (sugarcane). In soil samples, only PCB 18 was detected, and it ranged from below the detection limit (corn soil) to 180.02±5.4 (sugarcane soil) ng/g. In sludge samples, PCB 8 and 18 were detected with values ranging from 49.42±1.48 ng/g to 386.06±11.5 ng/g. The investigated Transfer Factor (TF) was the highest in PAH and was found in Benzo[a]Anthracene in corn (1.13). For OCPs, TF ranged from 0.01 in Heptachlor epoxide to 3.89 in a-BHC. Transfer Factor of PCB 8 ranged from 0.04 (in sugarcane) to 0.39 (in millet). The maximum total health risk (ingestion, dermal, inhalation) for PAHs was found to be in adult male and female (1.04E07 and 1.5E-0, respectively) as compared to children female and male (1.02E-07 and 9.92E-08, respectively), which is near to 1×10^{-6}. Incremental Lifetime Cancer Risk (ILCR) was slightly higher in children as compared to adult. Total health risk of OCP was close to the threshold level in children (3.05E-07 to 6.39E-07) and adults (1.21E-07 to 2.60E-07) in both genders. Total risk in PCB 8 in children ranged from 3.43E-07 to 3.23E-09 and in adults from 2.20E-07 to 6.98E-09. Although all the ranges were within the safe limit, adults were at more risk as compared to children due to consumption of polluted crops. The questionnaire results indicated that farmers had a strong awareness (96.8%) about fertility value of wastewater for many aspects, but they were unaware (71.6%) about health hazards of untreated wastewater used for crop irrigation. Correlation for determining climate change factor with age and farming experience was highly significant with values of $r^2 = 0.82$ and $r^2 = 0.92$, respectively. Other variables, including livelihood assets, were also correlated with adaption measures $r^2 = 0.8$. More than 70% of the investigated farmers used different techniques to adapt to climate change, such as irrigation, seeds, fertilizer and alternate wastewater. For pilot scale treatment, the highest removal efficiency was found in case of heavy metals including Cr, Pb, Ni and Cu with values amounting to 72.4%, 83.3%, 82.35% and 63.63%, respectively. However, BOD and COD removal efficiencies were also considerable (66.67%). Reduction rate ($g\ m^{-2}\ d^{-1}$) was found higher in BOD, COD, sulphates, phosphate and TDS with values of 1442.7, 1967.3, 1148.2, 7225.4 and 911.5, respectively. Percentage increase in biomass was measured after 30 days of treatment that showed 4.2 g

day^{-1} increase. Chlorophyll a+b and carotenoid contents were decreased from 7.92 mg kg^{-1} to 5.78 mg kg^{-1}, 3.03 mg kg^{-1} to 3.01 mg kg^{-1},respectively, and total nitrogen was increased from 22 mg kg^{-1} to 27 mg kg^{-1} , while total phosphorus was decreased from 18 mg kg^{-1} to 17.1 mg kg^{-1}. Bio-concentration factor was higher than 1 for all the metals, and was found maximum for Cr. The reduction efficiency of ΣPAH in different rings was found to be up to 60%. Among two isolated bacterial strains, *Bacillus safensis* showed higher percentage reduction for BOD, nitrates, sulphates and phosphates with values of 71.3%, 76.8%, 61.2% and 72.9%, respectively, as compared to *Bacillus cereus* resulting in 69.1%, 71.5%, 58.9% and 62.4% reductions, respectively, whereas *B cereus* showed more reduction for turbidity, COD and K with values of 47.8%, 54.6% and 65.8%, respectively, as compared to *B. safensis* where values of these parameters amounted to 42.3%, 52.8% and 53.6%, respectively. The outcomes of this study have addressed basic statistics for management of water and wastewater in the utmost populated and industrial region of Punjab, Pakistan. There is no proper urban water management plan in the city. A strict policy is needed over 20 years to treat wastewater for further usage, which could serve as an alternate for the existing freshwater resources in the country.