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Characterization of wastewater and soil and vegetable plants exposed to long-term wastewater irrigation

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Abstract

In recent years, wastewater irrigation is getting popularity, particularly in those regions where freshwater is insufficient to meet the water demand. However, wastewater contains toxic substances which may deteriorate soil properties, plant quality, and subsequently compromise the public health, particularly when used without adequate management. The current investigation was undertaken to characterize wastewater used for growing vegetables as well as the impact of its long-term use on soil properties and plant elemental composition in Sargodha district. Each sampling site was marked with Global Positioning System. Wastewater characterization indicated electrical conductivity (EC), 1.19-3.15 dS m^{-1}; sodium adsorption ratio (SAR), 5.22-12.67 (mmol $L^{-1})^{1/2}$; residual sodium carbonate (RSC), 1.04-2.70 meq L^{-1}; biological oxygen demand (BOD), 38.4-77.5 mg L^{-1}; chemical oxygen demand (COD), 165.3-199.9 mg L^{-1}; total nitrogen (N), 33.09-99.09 mg L^{-1}; total phosphorus (P), 6.92-20.31 mg L^{-1}; lead (Pb), 2.45 to 4.07 mg L^{-1}; arsenic (As), 0.04-0.16 mg L^{-1}; nickel (Ni), 0.06-0.27 mg L^{-1}; cadmium (Cd), 0.006-0.023 mg L^{-1}, and chromium (Cr), 0.052-0.109 mg L^{-1}; Soil characterization revealed EC, 2.14-6.04 dS m^{-1}; SAR, 7.64-18.59 (mmol $L^{-1})^{1/2}$; organic matter, 0.68-1.15%; N, 1.12-1.85 mg g^{-1}; available P, 7.68-12.73 mg kg^{-1}; Pb, 6.02-15.67 mg kg^{-1}; As, 2.21-6.43 mg kg^{-1}; Ni, 7.09-20.60 mg kg^{-1}; Cd, 0.65-1.90 mg kg^{-1}; and Cr, 54.96-142.24 mg kg^{-1}; Plant characterization of major vegetables grown in Sargodha district indicated N, 22.29-32.4 mg g^{-1}; P, 5.21-8.43 mg g^{-1}; K, 14.52-21.12 mg g^{-1}; Pb, 0.283-0.576 mg kg^{-1}; As, 0.121-0.352 mg kg^{-1}; Ni, 30.3-81.9 mg kg^{-1}; Cd, 0.219-0.434 mg kg^{-1} and Cr, 0.109-0.316 mg kg^{-1}. Wastewater used for irrigation in Sargodha district was found mostly unfit in terms of salt index, As and Cd, and continuous use of such wastewater without adequate management may cause public health dilemma by deteriorating soil, water and food quality.

Keywords: Heavy metals, plant elemental composition, salinity, sodicity, vegetables, wastewater

Introduction

Water is considered as fluid of life as it is involved in all growth and development processes in living organisms. The sufficient availability of standard quality water is needed to meet the domestic needs, industrial and agricultural activities, and recreation purposes. Of the total natural water resources, share of freshwater is only 3%, while remaining 97% is salty water. Only 1% of freshwater is available for ecosystem maintenance and human consumption because 70% is in frozen form and remaining is too deep in soil to be accessible for extraction. Agriculture is the main consumer of freshwater. About 70-72% of freshwater is being used in agriculture (Sato *et al*., 2013). It has been reported that daily water requirement for a person is 2-4 L for drinking while 2000-5000 L for food production (FAO, 2013). However, increasing urbanization and industrialization in recent years has shrunk the freshwater supplies for agricultural activities (Raschid-Sally *et al*., 2005). The gap between water needs and supply is wider in arid and semi-arid climate where freshwater supply is unevenly distributed in time and space (Selim, 2006). It has been reported that about 1.8 billion people all over the world may face a severe water shortage by the year 2025 (Falkenmark, 2013).

Water deficiency in agriculture can be overcome either by efficient use of existing freshwater resources or supplementing them with an additional water supply (Ashraf *et al*., 2017). In this context, wastewater can be a promising option because of its constant and reliable supply, easy access, low energy and treatment requirements when

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used in agriculture (Hussain *et al*., 2002). According to IWMI (2003), key drivers that promote the use of wastewater in agriculture include growing population and urbanization, rapid industrialization, poverty, increasing water stress and growing food demands. In addition, wastewater contains varying amount of plant nutrients, particularly nitrogen (N), phosphorus (P) and micronutrients. Thus, utilization of wastewater in agriculture may reduce the fertilizer needs of crops (El-Kheir *et al*., 2007). At present, a major portion of freshwater is being used in agriculture to meet growing food requirements. The use of wastewater in agricultural programs not only spares freshwater for other sectors but also minimizes the surface and groundwater contamination. According to Ramos *et al*. (2019), about 70% of freshwater supplied for domestic and industrial activities is returned back as wastewater. Wastewater, when not reused for any purpose, would be released into the different bodies of surface water or land, contaminating the water and land resources (Murtaza *et al*., 2010). Mkhinini *et al*. (2018) also reported that being high in organic matter, wastewater use in agriculture may improve structural stability and microbial activities of soil.

Wastewater being originated from industrial, institutional and domestic activities may have different salts and metals, particularly lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg), nickel (Ni) chromium (Cr) and copper (Cu). These metals when accumulate in soil beyond the permissible limit may enter the food chain, thus becoming toxic to plants and human beings (Papaioannou *et al*., 2019). Regardless of the great importance of using wastewater in urban and peri-urban agriculture, it may also cause severe health risks to humans (Handa *et al*., 2019). Lu *et al*. (2015) reported that wastewater irrigation without appropriate measures may cause the deposition of varying amounts of metals and salts in soil, and subsequently their entrance to plants. Chung *et al*. (2011) reported that about 10% people throughout the world have to use the food produced by contaminated wastewater. In Pakistan, wastewater is mostly used in untreated form to raise vegetables around the cities, and it may constitute an important public health dilemma due to the entry of poisonous metals including Cu, Pb, Hg, Cr, As, Cd and other toxic substances to food chain. Khan *et al*. (2013) reported that the use of untreated wastewater may cause different diseases related to skin, stomach, lungs, liver and kidneys in humans due to the presence of heavy metals, salts, pathogenic organisms and organic compounds such as pesticides.

Despite the major concerns associated with the use of wastewater to contaminate the soil, groundwater and food plants, its use in agriculture is getting more popularity in recent years due to widening of gap between water need and supply. The objective of present investigation was to characterize the wastewater used for irrigation, and the impact of its long-term application on soil properties and plant elemental composition, particularly the nutrient and metal status of soils and vegetables in Sargodha district.

Materials and Methods

Due to acute shortage of freshwater supplies, wastewater is being utilized by farming community for different agricultural activities, particularly around the cities. However, maintenance of food quality standards, public health as well as soil and water quality might be a big challenge in wastewater irrigation system. The current investigation was undertaken to characterize wastewater used for growing vegetables as well as the impact of its long-term use on soil properties and plant elemental composition in seven tehsils of Sargodha district namely Sargodha, Bhawal, Bhera, Kot-Momin, Shahpur, Sillanwali and Sahiwal. Six sites from each tehsil irrigated with wastewater for around 10 years were sampled for water, soil and vegetable plants. Each sampling site was regarded as a treatment set, and three samples collected from each sampling site were considered as replicates. Soil sampling was done up to the depth of 15 cm. The sampling sites were marked with GPS.

Wastewater analysis

Wastewater samples were collected from 42 sites (06 sampling sites from each of 07 tehsils of Sargodha district), with three samples from each site. Before collecting the sample, clean plastic bottles were rinsed twice with same wastewater. The bottles were caped tightly after collecting the sample and shifted to the laboratory. After filtration, EC, pH and SAR of wastewater were determined in accordance with US Salinity Lab Staff (1954). Total dissolved N in wastewater was determined using the method of Bowman and Delfino (1982), total P using Spectrophotometer (Shimadzu UV–1600, UK) by the method of Olsen and Sommers (1982), K and Na using Flame Photometer (Jenway PFP 7, ELE Instrument Co. Ltd. Felsted, UK) as described by Hald (1947) while Pb, As, Ni, Cd, and Cr by Atomic Absorption Spectroscopy (Hitachi Polarized Zeeman AAS, Z–8200, Japan) as described by Parker (1972). COD and BOD were determined by Dissolved Oxygen Meter (Ohaus Starter 300D) in accordance with APHA (1998).

Soil analysis

Each sampling site comprised of 5.0 hectares. Three composite soil samples up to 15 cm depth were collected by making 5 bores for each soil sample. Soil was analyzed for textural class (Gee and Bauder, 1986), EC and pH (Bigham, 1996), SAR (US Salinity Lab Staff, 1954), cation exchange capacity (Thomas, 1982), saturation percentage (Wilcox, 1951), calcium carbonates (Bouyoucos, 1962), organic matter (Nelson and Sommers, 1982), total N (Nelson and Sommers, 1982), available P (Olsen *et al*., 1954), extractable K (Soltanpour and Worker, 1979), Pb, As, Ni, Cd, and Cr (Lindsay and Norvell, 1978).

Plant analysis

Plant sampling of different vegetables growing with wastewater was done from the same sites used for water and soil collection. Plant samples were washed with deionized water, air dried, oven dried and ground to 40 mesh. The plant digestion was made with di-acid mixture of HNO_3 and $HClO_4$ (2:1 v/v) at 250ºC using hot plate according the method of Miller (1998). Plant K and Na were measured by Flamephotometer while, Pb, As, Ni, Cd, and Cr by Atomic Absorption Spectroscopy. Plant N concentration was determined using Kjeldhal method (Kjeldhal, 1883).

Statistical analysis

The computer-based software Statistix 8.1 was used for data analysis, and the analysis of variance test was performed according to split-plot design. Duncan multiple range test was employed to determine the significance at $p \leq 0.05$.

Results

Wastewater characterization

Wastewater characteristics in terms of EC, SAR, RSC, BOD, COD, total N and total P are presented in Table 1. Wastewater EC ranged from 1.19 to 3.15 dS m^{-1}. Overall, all wastewater samples were unfit with respect to EC being beyond 1.0 dS m^{-1} (acceptable limit). The SAR ranged from 5.22 to 12.67 (mmol $L^{-1})^{1/2}$ at different sampling sites in seven tehsils of Sargodha district. About 31% wastewater samples were found within the safe limit having SAR less than 8 (mmol $L^{-1})^{1/2}$. Wastewater RSC ranged from 1.04 to 2.70 me L^{-1} at different sampling sites in seven tehsils of Sargodha district. About 21% of wastewater samples were found within safe limits having RSC < 1.25 me L^{-1} while, 15% marginally fit (RSC 1.25 to 2.50 me L^{-1}) and 64% unfit (RSC >2.50 me L^{-1}) for the irrigation of field crops. Biological oxygen demand of wastewater varied from 38.4 to 77.5 mg L^{-1}, indicating that all wastewater samples had BOD above 30 mg L^{-1} (permissible limit). Chemical oxygen demand varied from 165.3 to 199.9 mg L^{-1} at different sampling sites in seven tehsils of Sargodha district, and 100% wastewater samples were unfit with respect to COD. The N content in wastewater samples differed from 33.09 to 99.09 mg L^{-1}. Tehsil wise data showed that maximum average N content of 85.20 mg L^{-1} were found in tehsil Shahpur while lowest value 52.45 mg L^{-1} in Bhera. Total P content in wastewater varied from 6.92 to 20.31 mg L^{-1} at different sampling sites of seven tehsils of Sargodha district.

The concentration of different heavy metals Pb, As, Ni, Cd and Cr in wastewater is presented in Table 2. It was observed that concentration of Pb ranged between 2.45 to 4.07 mg L^{-1} at different sampling sites in seven tehsils of Sargodha district. Arsenic concentration in wastewater varied from 0.04 to 0.16 mg L^{-1} at different sampling sites in seven tehsils of Sargodha district, with maximum value 0.16 mg L^{-1} in tehsil Sargodha. Nickel concentration ranged from 0.06 to 0.27 mg L^{-1} in wastewater, with highest average value 0.203 mg L^{-1} in tehsil Shahpur. Cadmium concentration in wastewater varied from 0.006 to 0.023 mg L^{-1}, with maximum average value 0.018 mg L^{-1} in tehsil Sillanwali. The concentration of Cr in wastewater varied from 0.052 to 0.109 mg L^{-1} at different sampling sites in seven tehsils of Sargodha district, with maximum average Cr concentration of 0.095 mg L^{-1} in tehsil Sahiwal.

Soil characterization

Results regarding physicochemical properties of soils irrigated with wastewater in seven tehsils of Sargodha district are presented in Table 3. With respect to saturation percentage, 23.81% soil samples showed saturation percentage > 40% while, 40.48% soil samples 35 to 40% and rest of the soil samples showed saturation percentage of 29.50 to 34.50%. Electrical conductivity varied from 2.14 dS m^{-1} in tehsil Bhera to 6.04 dS m^{-1} in Sahiwal. Overall, 43% soil samples showed salts accumulation above the permissible limit (>4.0 dS m^{-1}) in different tehsils of Sargodha. More accumulation of salts by the use of wastewater was found in tehsil Sahiwal and Sillanwali compared to other tehsils. Soil pH varied in the range of 7.31 to 8.63 at different sampling sites in seven tehsils of Sargodha district. The content of soil organic matter was in the range of 0.68 to 1.15% at different sampling sites in seven tehsils of Sargodha district, with maximum average organic matter content of 0.92% in tehsil Sargodha while, minimum 0.76% in tehsil Bhera. Cation exchange capacity ranged from 16.07-28.56 cmolc kg^{-1} soil, with maximum average value of 26.03 cmolc kg^{-1} soil in tehsil Bhalwal while, minimum value of 19.25 cmolc kg^{-1} soil in Sillanwali. $CaCO_3$ ranged from 4.80-8.70%, with maximum average value of 7.37% in tehsil Shahpur while minimum 5.52% in tehsil Bhalwal. Sodium adsorption ratio ranged from 7.64-18.59 (mmol $L^{-1})^{1/2}$, with maximum average value of 16.51 (mmol $L^{-1})^{1/2}$ in tehsil Sahiwal while, minimum 8.36 (mmol $L^{-1})^{1/2}$ in Bhalwal.

Table 1: Characteristics of wastewater used for growing vegetables in Sargodha district

Tehsil		EC (dS m^{-1})	SAR (mmol L^{-1})$^{1/2}$	RSC (meq L^{-1})	BOD (mg L^{-1})	COD (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
Sargodha	Range	1.8-3.01	7.08-9.78	1.23-2.17	53.8-69.9	177.6-185.8	46.6-93.3	9.59-17.26
	Mean	2.45	8.96	1.74	62.7	181.6	65.5	12.96
	SD	0.45	1.03	0.35	6.91	3.23	18.2	3.02
Bhalwal	Range	2.08-272	5.22-9.01	1.04-1.43	43.9-64.8	168.3-186.2	34.8-88.2	7.14-16.12
	Mean	2.55	7.24	1.21	52.23	176.9	60.8	11.88
	SD	0.29	1.55	0.15	7.93	7.57	19.21	3.42
Bhera	Range	1.99-3.07	5.48-11.39	1.13-2.70	46.2-62.8	172.3-187.4	33.1-75.2	6.92-15.49
	Mean	2.56	8.30	1.78	53.43	180.0	52.45	10.80
	SD	0.42	2.35	0.72	7.28	5.42	18.31	3.75
Kot-Momin	Range	1.78-3.02	8.46-10.51	1.78-2.51	54.5-75.0	184.6-199.8	41.1-78.9	8.48-16.16
	Mean	2.61	9.43	2.04	64.9	191.3	57.58	11.64
	SD	0.44	0.78	0.25	8.57	6.51	12.73	2.69
Sillanwali	Range	2.18-3.15	6.88-10.03	1.09-2.69	66.4-77.5	178.3-199.9	38.5-98.6	7.85-17.23
	Mean	2.54	8.59	1.77	71.48	190.7	65.62	12.74
	SD	0.40	1.25	0.54	4.04	7.59	25.5	4.16
Shahpur	Range	1.19-2.90	7.45-10.56	1.61-2.64	38.4-57.8	180.9-198.8	67.2-99.1	13.9-20.31
	Mean	2.25	8.61	2.08	48.95	187.3	85.20	16.72
	SD	0.59	1.21	0.42	7.21	6.96	13.0	2.35
Sahiwal	Range	2.40-3.12	9.87-12.67	1.60-2.54	45.9-55.1	165.3-178.2	54.6-74.1	9.37-13.34
	Mean	2.79	10.85	2.03	51.71	173.4	58.96	11.84
	SD	0.28	0.97	0.32	4.37	5.84	9.62	1.47

Mean is the average of eighteen values in each tehsil of Sargodha district. (EC: Electrical conductivity, SAR: Sodium adsorption ratio, RSC: Residual sodium carbonates, BOD: Biological oxygen demand, COD: Chemical oxygen demand, TN: Total nitrogen, TP, Total phosphorus).

Table 2: Heavy metals status of wastewater in different tehsils of Sargodha district

Tehsil		Pb	As	Ni	Cd	Cr
		mg L^{-1}				
Sargodha	Range	2.65-2.69	0.06-0.16	0.13-0.19	0.012-0.020	0.059-0.099
	Mean	3.10	0.11	0.16	0.016	0.085
	SD	0.34	0.035	0.025	0.03	0.16
Bhalwal	Range	2.96-4.07	0.09-0.16	0.06-0.22	0.013-0.021	0.074-0.091
	Mean	3.38	0.11	0.13	0.016	0.078
	SD	0.45	0.027	0.05	0.003	0.011
Bhera	Range	2.46-3.33	0.04-0.13	0.14-0.19	0.012-0.017	0.07-0.089
	Mean	3.06	0.09	0.18	0.015	0.081
	SD	0.45	0.035	0.032	0.004	0.007
Kot-Momin	Range	2.7-3.67	0.04-0.10	0.13-0.22	0.015-0.021	0.052-0.088
	Mean	3.17	0.078	0.163	0.017	0.073
	SD	0.35	0.020	0.036	0.002	0.014
Sillanwali	Range	2.92-3.64	0.06-0.12	0.16-0.22	0.015-0.023	0.085-0.092
	Mean	3.27	0.08	0.186	0.018	0.087
	SD	0.25	0.02	0.02	0.002	0.002
Shahpur	Range	2.40-2.73	0.06-0.13	0.13-0.27	0.006-0.014	0.066-0.105
	Mean	2.61	0.091	0.203	0.008	0.085
	SD	0.133	0.027	0.048	0.003	0.016
Sahiwal	Range	2.57-3.18	0.05-0.11	0.11-0.18	0.009-0.019	0.087-0.109
	Mean	2.92	0.076	0.143	0.013	0.095
	SD	0.32	0.021	0.028	0.003	0.009

Mean is the average of eighteen values in each tehsil of Sargodha district. Pb: Lead, As: Arsenic, Ni: Nickel, Cd: Cadmium, Cr: Chromium.

Results regarding N, P, K and heavy metals (Pb, As, Ni, Cd and Cr) status in soil are presented in Table 4. It was observed that total soil N concentration varied from 1.12 to 1.85 mg g^{-1}, with maximum average concentration of total N (1.53 mg g^{-1}) was recorded in tehsil Bhalwal while, minimum (1.32 mg g^{-1}) in tehsil Bhera. Soil available P varied from 7.68 to 12.73 mg kg^{-1}, with maximum average value of 10.57 mg kg^{-1} in tehsil Bhalwal while, minimum (9.12 mg L^{-1}) in Bhera.

Table 3: Physicochemical properties of soils irrigated with wastewater in Sargodha district

Tehsil		Saturation percentage	EC (dS m^{-1})	pH	Organic matter (%)	CEC (cmolc kg^{-1} soil)	$CaCO_3$ (%)	SAR (mmol $L^{-1})^{1/2}$
Sargodha	Range	34.5-39.5	2.28-5.04	7.31-8.35	0.77-1.11	18.43-28.56	5.80-6.53	7.64-9.05
	Mean	37.54	3.65	7.98	0.92	21.54	6.30	8.40
	SD	2.83	0.95	0.36	0.14	3.75	0.48	0.46
Bhalwal	Range	33.5-43.0	3.08-4.89	7.67-8.31	0.73-1.15	23.12-28.11	4.94-6.65	7.90-8.83
	Mean	40.75	4.16	7.92	0.91	26.03	5.52	8.36
	SD	3.61	0.69	0.27	0.16	1.97	0.63	0.39
Bhera	Range	32.7-38.0	2.14-4.89	7.79-8.63	0.68-0.90	17.08-24.65	4.97-8.25	8.47-10.23
	Mean	35.54	3.32	8.28	0.76	20.12	7.20	9.40
	SD	1.97	0.92	0.30	0.09	2.52	1.27	0.72
Kot-Momin	Range	34.5-44.0	2.85-3.80	7.40-8.46	0.77-0.95	16.89-27.98	4.84-6.93	7.87-12.75
	Mean	38.25	3.29	7.93	0.86	20.59	5.61	9.46
	SD	3.82	0.40	0.44	0.07	4.11	0.76	1.98
Sillanwali	Range	29.5-38.0	4.75-5.12	7.43-8.43	0.78-1.02	16.07-21.54	4.84-7.81	8.75-18.48
	Mean	33.29	5.02	8.15	0.87	19.25	6.29	14.81
	SD	3.34	0.14	0.38	0.09	2.08	1.16	3.51
Shahpur	Range	33.0-42.5	2.76-4.01	7.45-8.42	0.79-1.03	19.43-25.78	5.96-8.70	7.78-16.77
	Mean	36.83	3.22	8.15	0.90	22.56	7.37	10.90
	SD	3.68	0.42	0.37	0.10	2.23	0.99	3.68
Sahiwal	Range	32.7-44.0	4.99-6.04	7.58-8.38	0.71-1.10	18.9-27.43	4.80-6.57	13.42-18.59
	Mean	37.3	5.54	7.97	0.89	21.74	5.66	16.51
	SD	4.10	0.43	0.30	0.13	3.03	0.60	1.98

Mean is the average of eighteen values in each tehsil of Sargodha district. EC: Electrical conductivity, CEC: Cation exchange capacity, $CaCO_3$: Calcium carbonate, SAR: Sodium adsorption ratio.

Table 4: N, P, K and heavy metals status of soils irrigated with wastewater in Sargodha district

Tehsil		N	P	K	Pb	As	Ni	Cd	Cr
		mg g^{-1}	mg kg^{-1}						
Sargodha	Range	1.2-1.6	8.3-11.2	160-201	8.9-15.4	2.9-5.7	11.9-14.8	1.0-1.9	79.5-142.2
	Mean	1.41	9.69	175.3	11.63	4.16	11.63	1.38	100.9
	SD	0.15	1.07	18.9	2.45	1.12	2.51	0.38	24.3
Bhalwal	Range	1.3-1.8	9.2-12.7	168-215	7.8-15.4	3.0-5.2	9.2-20.5	0.6-1.3	54.9-98.1
	Mean	1.53	10.57	188.8	11.18	4.38	13.53	0.97	71.69
	SD	0.20	1.42	20.63	3.22	0.81	4.51	0.26	15.7
Bhera	Range	1.1-1.5	7.7-10.4	139-189	7.9-14.2	2.9-5.7	9.8-18.2	0.7-1.6	66.9-98.1
	Mean	1.32	9.12	165.6	11.06	4.25	14.7	1.17	81.96
	SD	0.13	0.93	17.0	2.62	1.18	3.09	0.32	10.54
Kot-Momin	Range	1.2-1.7	8.4-11.7	153-208	6.9-15.7	2.5-5.0	9.3-18.5	1.0-1.3	56.05-85.1
	Mean	1.50	10.34	186.1	10.44	4.02	12.71	1.12	72.15
	SD	0.17	1.22	20.2	3.12	0.86	3.23	0.14	10.5
Sillanwali	Range	1.3-1.6	9.7-11.3	166-206	7.9-15.4	2.9-6.4	9.3-18.1	0.9-1.3	69.65-114.23
	Mean	1.48	10.19	185.1	12.01	3.86	14.15	0.93	87.31
	SD	0.11	0.77	13.9	2.83	1.37	3.33	0.25	17.2
Shahpur	Range	1.2-1.7	8.2-11.6	149-210	9.1-15.0	2.2-6.4	10.7-20.6	0.8-1.7	95.1-121.1
	Mean	1.42	9.78	177.5	11.55	4.22	14.76	1.32	107.0
	SD	0.21	1.45	26.3	2.15	1.56	3.82	0.28	13.4
Sahiwal	Range	1.2-1.6	8.0-10.9	145-197	6.0-17.5	3.3-5.1	7.1-14.9	0.7-1.3	72.6-96.12
	Mean	1.36	9.40	170.5	11.05	4.23	11.69	1.08	82.4
	SD	0.15	1.04	19.0	3.92	0.70	2.81	0.24	8.50

Mean is the average of eighteen values in each tehsil of Sargodha district. N: Nitrogen, P: Phosphorus, K: Potassium, Pb: Lead, As: Arsenic, Ni: Nickel, Cd: Cadmium, Cr: Chromium.

Soil extractable K varied from 139 to 215 mg kg^{-1}, with maximum average value of 188.8 mg kg^{-1} in tehsil Bhalwal while, minimum 165.6 mg kg^{-1} in Bhera. Lead concentration ranged from 6.02 to 15.67 mg kg^{-1} with maximum average value of 12.01 mg kg^{-1} in tehsil Sillanwali while, minimum (10.44 mg kg^{-1}) in Kot-Momin. Arsenic concentration varied from 2.21 to 6.43 mg kg^{-1}, with maximum average value of 4.38 mg kg^{-1} in tehsil Bhalwal while, minimum (3.86 mg kg^{-1}) in Sillanwali. Nickel concentration ranged from 7.09 to 20.60 mg kg^{-1}, with maximum average Ni concentration (14.76 mg kg^{-1}) in tehsil Shahpur while, minimum (11.69 mg kg^{-1}) in Sahiwal. Cadmium concentration ranged from 0.65 to 1.90 mg kg^{-1}, with maximum average value of 1.38 mg kg^{-1} in tehsil Sargodha while, minimum (0.93 mg kg^{-1}) in Sillanwali. Chromium concentration ranged from 54.96 to 142.24 mg kg^{-1}, with maximum average concentration of 107.0 mg kg^{-1} in tehsil Shahpur whereas, minimum (71.69 mg kg^{-1}) in Bhalwal.

Plant characterization

In the present study, five different vegetables i.e., cauliflower, spinach, tomato, radish and eggplant were sampled for the determination of N, P, K and Na concentration (Table 5). Nitrogen concentration in plant samples varied from 22.29 to 32.4 mg g^{-1} in vegetables, with maximum average N concentration of 29.45 mg g^{-1} tehsil Bhalwal whereas, minimum average N (25.55 mg g^{-1}) in Bhera. Overall, the order of N concentration in vegetables was cauliflower > tomato > spinach > radish > eggplant. Phosphorus concentration differed from 5.21 to 8.43 mg g^{-1}, with maximum average P concentration of 7.72 mg g^{-1} in tehsil Bhalwal whereas, minimum average P (6.63 mg g^{-1}) in Sahiwal. Overall, the order of P concentration in vegetables was tomato > cauliflower > radish > spinach > eggplant. Potassium concentration varied from 14.52 to 21.12 mg g^{-1}, with maximum average K concentration (19.59 mg g^{-1}) in tehsil Bhalwal whereas, minimum (16.87 mg g^{-1}) in Sahiwal. Overall, the order of vegetables was tomato > cauliflower > radish = spinach > eggplant. Sodium concentration ranged from 6.18 to 12.40 mg g^{-1}, with maximum average Na concentration 9.56 mg g^{-1} was in tehsil Bhera whereas, minimum 7.43 mg g^{-1} was in Bhalwal. With respect to Na concentration, vegetables were ordered as eggplant > spinach > radish > cauliflower > tomato. Sodium: potassium (Na:K) ratio ranged from 0.30 to 0.86 in vegetable samples, with maximum average Na:K ratio of 0.56 in tehsil Bhera whereas, minimum (0.38) in Bhalwal.

The results regarding the concentration of heavy metals in vegetable plants grown with wastewater in different tehsils of Sargodha district are given in Table 6. Lead concentration in vegetable plants ranged from 0.283 to 0.576 mg kg^{-1}, with maximum average Pb concentration (0.449 mg kg^{-1}) in tehsil Bhalwal whereas, minimum (0.385 mg kg^{-1}) in Shahpur. With respect to Pb concentration, different vegetables were ranked as spinach > cauliflower = tomato > eggplant > radish. Arsenic concentration in vegetable plants irrigated with wastewater in Sargodha district ranged from 0.121 to 0.352 mg kg^{-1}, with maximum average As concentration of 0.238 mg kg^{-1} in tehsil Bhera whereas, minimum (0.198 mg kg^{-1}) in tehsil Sargodha. With respect to As accumulation, different vegetables were ranked as eggplant > spinach > Radish > cauliflower > tomato. Nickel concentration ranged from 30.3 to 81.9 mg kg^{-1}, with maximum average concentration of 61.6 mg kg^{-1} in vegetable samples from tehsil Sahiwal whereas, minimum (54.8 mg kg^{-1}) in tehsil Kot-Momin. With respect to Ni accumulation, vegetables were ranked as spinach > eggplant > cauliflower > tomato > Radish. Cadmium concentration in vegetable plants ranged from 0.219 to 0.434 mg kg^{-1}, with maximum average concentration of 0.355 mg kg^{-1} in vegetable samples from tehsil Sargodha whereas, minimum average concentration of 0.300 mg kg^{-1} in tehsil Shahpur. With respect to Cd accumulation, vegetables were ranked as cauliflower > spinach > tomato > eggplant > Radish. Chromium concentration in vegetable plants ranged from 0.109 to 0.316 mg kg^{-1}, with maximum average concentration of 0.236 mg kg^{-1} in vegetable samples collected from tehsil Shahpur whereas, minimum average value of 0.185 mg kg^{-1} in tehsil Sargodha. With respect to Cr, vegetables were ranked as cauliflower > eggplant > spinach > Radish > tomato.

Discussion

Salinity is expressed in term of EC, and irrigation water should have < 1.0 dS m^{-1} for safe use in agriculture. All wastewater samples had EC higher than permissible limit indicating higher concentration of soluble salts in water which could cause soil salinization. Selim (2006) reported that EC of wastewater in the range of 3.10 dS m^{-1} could be quite enough to cause soil salinization when such wastewater was consistently used for long time without appropriate management. Sodium adsorption ratio and RSC indicate the amount of Na and CO_3 in water, respectively, which are important quality standards for irrigation water. Long-term use of wastewater having higher SAR and RSC could cause soil sodicity. The permissible limit for BOD is 10 mg L^{-1} for crops used as uncooked while 30 mg L^{-1} for non-food and food crops being used as processed. The permissible limit for COD is 150 mg L^{-1}. Higher BOD and COD of wastewater in present investigation indicated higher amount of organic matter which may have positive effect on soil properties by adding organic matter to soil. The wastewater used in agriculture in Sargodha district contained high concentration of salts and heavy metals due to its origin of industrial and domestic sources, particularly from leather industry.

Table 5: Shoot nutrients concentration of vegetables grown with wastewater in Sargodha district

Tehsil		N	P	K	Na	Na: K ratio	Vegetables sampled
Sargodha	Range	23.7-32.4	6.19-8.27	15.9-21.1	6.48-11.3	0.31-0.69	Cauliflower, Spinach, Radish, Eggplant
	Mean	27.52	7.19	18.12	8.88	0.50	
	SD	3.28	0.78	1.99	2.01	0.16	
Bhalwal	Range	26.8-31.6	6.99-8.43	18.0-21.1	6.36-8.84	0.30-0.49	Cauliflower, Spinach, Radish
	Mean	29.4	7.72	19.6	7.43	0.38	
	SD	1.67	0.49	1.06	0.92	0.07	
Bhera	Range	23.7-27.9	6.17-7.27	15.9-18.0	7.61-12.2	0.45-0.77	Eggplant, Cauliflower, Spinach, Radish
	Mean	25.55	6.66	16.91	9.56	0.56	
	SD	1.38	0.36	0.76	1.59	0.11	
Kot-Momin	Range	26.5-29.1	6.90-7.58	17.9-19.7	6.23-8.79	0.32-0.52	Tomato, Cauliflower, Radish
	Mean	28.25	7.35	18.77	7.62	0.41	
	SD	0.96	0.25	0.66	1.41	0.08	
Sillanwali	Range	22.3-29.1	5.78-7.53	14.5-19.6	6.18-12.4	0.32-0.85	Eggplant, Tomato, Cauliflower, Spinach
	Mean	26.29	6.83	17.44	8.34	0.49	
	SD	2.52	0.64	1.80	2.22	0.19	
Shahpur	Range	22.5-30.1	5.86-7.84	15.0-20.1	6.18-10.3	0.31-0.69	Cauliflower, Spinach, Eggplant
	Mean	26.71	6.96	17.74	7.72	0.45	
	SD	3.48	0.90	2.23	1.77	0.16	
Sahiwal	Range	25.0-31.4	5.21-8.18	13.1-21.0	6.2-11.3	0.31-0.86	Tomato, Cauliflower, Spinach, Radish, Eggplant
	Mean	26.98	6.63	16.87	8.42	0.52	
	SD	2.72	1.02	2.65	2.28	0.22	

Mean is the average of eighteen values in each tehsil of Sargodha district. N: Nitrogen, P: Phosphorus, K: Potassium, Pb: Lead, As: Arsenic, Ni: Nickel, Cd: Cadmium, Cr: Chromium.

Table 6: Heavy metals concentration in shoots of vegetables grown with wastewater in Sargodha district

Tehsil		Pb	As	Ni	Cd	Cr	Vegetables sampled
		(mg kg^{-1} dry matter)					
Sargodha	Range	0.31-0.57	0.14-0.25	40.8-73.9	0.24-0.43	0.14-0.22	Cauliflower, Spinach, Radish, Eggplant
	Mean	0.42	0.20	55.5	0.35	0.18	
	SD	0.10	0.04	14.2	0.06	0.05	
Bhalwal	Range	0.40-0.51	0.16-0.35	46.4-75.3	0.27-0.41	0.16-0.28	Cauliflower, Spinach, Radish
	Mean	0.45	0.23	61.1	0.33	0.20	
	SD	0.06	0.08	11.1	0.06	0.04	
Bhera	Range	0.30-0.50	0.17-0.31	30.3-78.9	0.22-0.40	0.12-0.26	Eggplant, Cauliflower, Spinach, Radish
	Mean	0.41	0.24	56.0	0.32	0.19	
	SD	0.08	0.06	19.3	0.06	0.05	
Kot-Momin	Range	0.39-0.50	0.16-0.31	46.7-60.3	0.27-0.42	0.14-0.28	Tomato, Cauliflower, Radish
	Mean	0.43	0.23	54.8	0.35	0.21	
	SD	0.04	0.05	5.25	0.06	0.05	
Sillanwali	Range	0.30-0.51	0.16-0.28	43.4-80.4	0.30-0.39	0.14-0.28	Eggplant, Tomato, Cauliflower, Spinach
	Mean	0.39	0.24	61.1	0.33	0.20	
	SD	0.07	0.06	14.1	0.04	0.05	
Shahpur	Range	0.28-0.44	0.18-0.30	49.8-80.1	0.24-0.36	0.17-0.31	Cauliflower, Spinach, Eggplant
	Mean	0.38	0.23	56.8	0.30	0.23	
	SD	0.05	0.04	11.9	0.04	0.05	
Sahiwal	Range	0.37-0.48	0.12-0.35	46.5-81.9	0.23-0.37	0.11-0.25	Tomato, Cauliflower, Spinach, Radish, Eggplant
	Mean	0.41	0.22	61.6	0.31	0.19	
	SD	0.04	0.08	12.7	0.06	0.05	

Mean is the average of eighteen values in each tehsil of Sargodha district. N: Nitrogen, P: Phosphorus, K: Potassium, Pb: Lead, As: Arsenic, Ni: Nickel, Cd: Cadmium, Cr: Chromium.

FAO permissible limit for N in wastewater is 5-30 mg L^{-1} (Pedrero *et al*., 2010) and this limit has been set according to the crop N requirement. All wastewater samples in Sargodha district contained higher N content than the permissible limit. Excessive N may cause a rapid increase in vegetative growth, delay in maturity, and subsequently resulting in poor yield and quality. Phosphorus is another essential plant nutrient, and the permissible limit for P in wastewater is 3.5 to 13 mg L^{-1} (Pedrero *et al*., 2010). About 45% wastewater samples from Sargodha district showed higher P content than the permissible limit. Continuous and long-term use of wastewater having higher P and N may result in high accumulation in soil or its movement to groundwater and surface water bodies, and thus may cause eutrophication (Liu *et al*., 2016).

Lead is a toxic metal causing mental retardation in humans. The most common sources of Pb in wastewater may include paint residues, automobile exhausts and urban dust. The permissible limit of Pb for irrigation water is 5000 µg L^{-1} (WHO, 1989). No wastewater sample in Sargodha district contained Pb concentration beyond permissible limit, probably due to the fact that there is no paint and automobile industry in Sargodha district. The permissible limit of As is 100 µg L^{-1} (WHO, 1989). Most of the wastewater samples in Sargodha district contained As above the permissible limit mainly due to high use of pesticides and higher As content in groundwater. Kahlown *et al.* (2006) also reported high As concentration in wastewater in some cities of Punjab province. Nickel is also an important metal to cause toxicity to plant growth and quality. The permissible limit of Ni is 200 µg L^{-1} (WHO, 1989). Some wastewater samples contained higher Ni content, and injudicious use of such wastewater, particularly for food crops may result in transmission of Ni to food chain. The permissible limit of Cd is 10 µg L^{-1} (WHO, 1989). All wastewater samples contained higher Cd content. The main reasons for higher Cd content in wastewater may be ore processing, metallurgical industries and high use of phosphatic fertilizers. Chromium at 200 µg day^{-1} is required for human health, and its deficiency may cause cardiovascular diseases and reduction in glycogen reserves. The permissible limit of Cr is 100 µg L^{-1} (WHO, 1989). Higher Cr content in wastewater, though mostly below the permissible limit, may be due to high usage of phosphatic fertilizers, metal plating, dyes, ceramics, glass, glues, wood preserving, textile and tanning.

Soil properties in term of EC, SAR, organic matter content, CEC, N, P, K and heavy metals Pb, As, Ni, Cd and Cr were closely related to corresponding wastewater characteristics. The permissible limit for soil in case of EC is 4 dS m^{-1}, SAR, 13 (mmol $L^{-1})^{1/2}$; P > 7 mg kg^{-1}; K >80 mg kg^{-1}, while Pb, 500 mg kg^{-1}; As, 30 mg kg^{-1}; Ni, 20 mg kg^{-1}; Cd, 1.0 mg kg^{-1} and Cr, 100 mg kg^{-1}) (Alloway, 1990). In present investigation, wastewater contained sufficient amount of N, P and K which being essential plant nutrients could improve soil fertility. Libutti *et al.* (2018) observed that wastewater irrigation could markedly enhance the accumulation of different plant nutrients in soil. Soil EC and SAR are also important quality indicators for soil, and indicated the salinity and sodicity index, respectively. High wastewater EC indicated the accumulation of soluble salts in soil which deteriorated soil properties and plant productivity. High SAR of wastewater could lead to Na accumulation in soil which destabilized the soil structure and reduced soil drainage. Mkhinini *et al*. (2018) found that long-term irrigation with wastewater may cause heavy buildup of salts, particularly Na in soil which dispersed the soil, and caused soil crusting, leading to reduced soil porosity. The heavy metal load in wastewater deposited these metals in soil, damaging the soil properties. Handa *et al*. (2019) reported a marked increase in the accumulation of Cu, Ni, Cr, Zn and Al in soils with the use of wastewater, particularly when used in untreated form.

Plant elemental composition measured in terms of the concentration of N, P, K, Na and heavy metals including Pb, As, Ni, Cd and Cr was also correlated with wastewater characteristics. The permissible level for N, 10-50 mg kg^{-1}; P, 10-40 mg kg^{-1}; K, 10-40 mg kg^{-1}; Pb, 0.30 mg kg^{-1}; As, 0.43 mg kg^{-1}; Ni, 68 mg kg^{-1}; Cd, 0.20 mg kg^{-1} and Cr, 2.30 mg kg^{-1} (FAO/WHO, 2001). The sufficient concentration of N, P and K in vegetable plants was associated with the high concentration of these nutrients in wastewater. Among heavy metals, Pb and Cd accumulation in vegetable plants were found higher than the permissible limit in almost all the plant samples analyzed which was associated with metals concentration of wastewater. Murtaza *et al*. (2010) reported that wastewater contained high concentration of N, P, K, and heavy metals, and when such wastewater is used consistently in agricultural activities for long period of time without appropriate measures, plant nutrients, salt and metal ions would transfer to plants. Papaioannou *et al*. (2019) reported the accumulation of heavy metals at toxic level in plants grown with the use of wastewater.

Conclusions

Wastewater quality expressed in term of EC, SAR, RSC, BOD and COD was found unfit to use in agricultural activities, particularly for growing vegetables at all sampling sites in seven tehsils of Sargodha district. With respect to heavy metals including Pb, As, Ni, Cd and Cr, almost all wastewater samples contained heavy metals within the permissible limit except for Cd which was beyond the permissible limit in 86% wastewater samples. Soil characterization indicated that about 40% soils had higher salinity, 29% higher sodicity than the permissible level, pH ranged from 7.31-8.63 and organic matter 0.68-1.15%. While heavy metals Pb, As, Ni and Cr were within the permissible level, but Cd was beyond the permissible level in 64% soils. Plant elemental composition of major vegetables revealed sufficient concentration of N, P and K. With respect to heavy metals, Pb and Cd were found higher than permissible levels in almost all vegetable samples. High salt concentration of wastewater may lead to soil salinity and sodicity. Although, wastewater being rich in organic matter and plant nutrients could improve soil properties and plant growth, but it might cause the build-up of metal ions in soil and transfer to plants. It is recommended that wastewater should not be used for growing vegetables without adopting an appropriate management measure.

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