Bulletin of Environmental Contamination and Toxicology (2019) 102:822–828
https://doi.org/10.1007/s00128-019-02605-1

Evaluation of Potential Toxic Metals Accumulation in Wheat Irrigated with Wastewater

Kafeel Ahmad[1] · Kinza Wajid[1] · Zafar Iqbal Khan[1] · Ilker Ugulu[2] · Hafsa Memoona[3] · Madiha Sana[3] · Khalid Nawaz[4] · Ifra Saleem Malik[1] · Humayun Bashir[1] · Muhammad Sher[5]

Received: 8 December 2018 / Accepted: 29 March 2019 / Published online: 6 April 2019

Abstract

The present study was carried out to ascertain the level of various metals in wheat variety (Chagi–4) irrigated with diverse doses of wastewater. The concentration of metals in soil, water and wheat grain samples was examined through an atomic absorption spectrophotometer. In wheat grains, the mean values of metals (mg/kg) varied from 0.06 to 0.2 for Pb, 1.2 to 1.6 for Cd, 0.6 to 0.9 for Ni, 0.8 to 1.6 for Fe, 0.4 to 1.0 for Mn, 0.7 to 1.4 for Cu, 0.3 to 0.5 for Cr, 0.1 to 0.9 for Zn and 0.03 to 0.2 for Co, correspondingly. Measured concentrations were found within the permissible limit given by FAO/WHO except for cadmium whose concentration exceeded an acceptable limit 0.2 mg/kg suggested by FAO/WHO. It might be due to high soil pH, which hinders the efficient transfer of metals between different mediums. Wastewater irrigated soil, wheat and water had high metal values, but the low rate of transfer was noticed from soil to grains. Higher bioconcentration factor was obtained for manganese and cadmium; cadmium had even higher pollution load index, which could indicate the contamination status of soil. Therefore, regular monitoring of wastewater is necessary to prevent the excessive build-up of metals.

Keywords Wastewater · Permissible limit · Bioconcentration factor · Potential toxic metal · *Triticum aestivum*

Water is an indispensable part of our life, but it is a vulnerable and limited resource that has qualitative susceptibility and quantitative limits (Ugulu 2015; Khan et al. 2018a). It is predicted that, by the year of 2050 more than 60% of the world's population face the problem of water scarcity (Rijsberman 2006). The places where scarcity of freshwater is very high, wastewater is an alternative source for irrigating crops (Khan et al. 2018b). In many countries, wastewater is not legal for irrigation of croplands because wastewater is contaminated with trace metals such as Cr, Pb, Mn, Zn, Co, and Cu and causes various toxic effects on plants, animals, and humans (Ugulu et al. 2016; Khan et al. 2018c). Continuous use of treated and untreated wastewater in agricultural land considerably increases the potential toxic metal content of soil, cereals and vegetables and these metals are further transferred to food chain causing various health hazards to human (Durkan et al. 2011; Ugulu et al. 2012; Dogan et al. 2014a).

Wheat (*Triticum aestivum* L.) is a staple food in Pakistan and a major component of the diet. Wheat is grown all over the Pakistan ranging from 23° North to 37° North, from 61° East to 76° East. Wheat is cultivated over an area of 9,042,000 ha and annual production amounts to 2,300,000 tons with an average production of 2714 kg/ha in Pakistan (GOP 2012). Wheat is fulfilling the dietary needs of one third of the world's population and has more nutritional value as compared to other cereals. Wheat provides a good quantity of protein, vitamins and minerals (Shewry 2009).

Large amounts of metals are taken up by a wheat crop irrigated with wastewater and cause various health hazards to human (Ahmad et al. 2018; Nadeem et al. 2019). Toxic effects of metals result in lower energy levels, damaged or reduced mental and central nervous system functions and

✉ Kinza Wajid
knzwajid@gmail.com

1 Department of Botany, University of Sargodha, Sargodha, Pakistan

2 Buca Faculty of Education, Dokuz Eylul University, Izmir, Turkey

3 Department of Zoology, Lahore College for Women University, Lahore, Pakistan

4 Department of Botany, University of Gujrat, Gujrat, Pakistan

5 Department of Chemistry, University of Sargodha, Sargodha, Pakistan

damage to blood composition, liver, lungs, kidneys and other important organs (Dogan et al. 2014b; Unver et al. 2015).

In this study, we hypothesized that wastewater irrigation may inhibit or enhance the uptake of metals by wheat plant. Therefore, the present study was planned with the objectives: (1) to analyse the physicochemical parameters of the soil, (2) to explore potential toxic metal content in wheat irrigated with wastewater, (3) to evaluate the transfer of metals from soil to the wheat plant, (4) to determine the pollution load index (PLI).

Materials and Methods

The experiment was carried out at Botanical Garden in Sargodha City, Pakistan during 2015–2016. The district has extreme climatic conditions in summer with a maximum temperature fluctuating between 45 and 50°C. Winters are cooler with temperature ranging from 4 to 25°C.

Wheat variety (Chagi–4) grains were sown in November, 2015 in plastic pots (15 cm in height and 25 cm in diameter) and harvested in April, 2016. Each pot was filled with about 6 kg of soil. Twelve pots with three replicates of various treatments were prepared. 10 seeds were sown in each pot. These pots were irrigated with domestic wastewater with different combinations: T–I (ground water), T–II (50% ground water + 50% wastewater), T–III (25% ground water + 75% wastewater), and T–IV (wastewater). The pots were irrigated twice a week. The untreated domestic wastewater was taken from residential wastewater treatment plant in Sargodha. The experiment was laid down in completely randomized design (CRD). Threshing was done in April, 2016. Soil samples were taken from the upper profile of soil. Samples of soil and grains were dried in an oven for 48 h at 105°C. After drying grain samples were ground into powder.

The physicochemical characters of water and soil samples such as electrical conductivity (EC), pH, calcium, magnesium, and organic matter was determined. The electrical conductivity and pH of samples were calculated by EC meter and pH meter. Concentrations of Ca^{+2} and Mg^{+2} were determined by using the titration method. Soil organic matter (OM) was determined by Walkley and Black acid digestion method (Page 1982). Available K and P were calculated by following Olsen and Sommers (1982).

Acid/wet digestion method was used for chemical analysis of potential toxic metals. Water samples (50 mL) were digested with 10 mL of concentrated HNO_3 at 80°C (APHA 2005). The sample was made up to 50 mL by adding deionized water. One gram of ground powder of each soil and grains was put into a 50 mL beaker. 10 mL analytical grade H_2SO_4 and 4 mL $HClO_4$ were added in the beaker and digested. Final volume was made up to 50 mL by adding deionized water.

In this study, lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe), manganese (Mn), copper (Cu), chromium (Cr), zinc (Zn), and cobalt (Co) were analysed. The concentration of metals in all samples of soil, water, grains was analysed by flame atomic absorption spectrophotometer (AAS; GBC 932). An atomic absorption spectrophotometer equipped with a graphite furnace and D2 corrector (Perkin–Elmer Model 503) was used to determine Co contents. Operating conditions for determination of metals are given in Table 1. Precision and accuracy of analyses was guaranteed through repetitive samples against National Institute of Standard Technology, Standard reference material (SRM 1643e for water, SRM 2709 for soil, CRM-NIST 1567a for wheat) for all metals. The results were found within ± 2% of the certified value. The glass wares were placed in 10% nitric acid overnight and rinsed several times with deionized water before used to prevent it from contamination.

Bioconcentration factor (BCF) calculated in the current study was based on the total metal content of the plant and metal content of soil (Cui et al. 2004). Pollution load index (PLI) was calculated as metal content of soil against standard metal contents (Liu et al. 2005).

Analysis of variance was implemented for treatments in support of water, soil and wheat grains with the help of the software package SPSS 21. The correlation between soil and wheat grains regarding each potential toxic metal was calculated.

Table 1 Operating conditions for the analysis of metals using flame atomic absorption spectrometry

Element	Pb	Cd	Ni	Fe	Mn	Cu	Cr	Zn	Co
Wavelength (nm)	283.3	228.8	232.0	248.3	279.5	324.8	422.7	213.9	240.7
Slit width (nm)	0.7	0.7	0.2	0.2	1.0	0.7	0.7	0.7	0.2
Lamp current (mA)	10	8	12	12	9	6	10	8	7
Air flow rate (L/min)	15	15	15	15	15	15	15	15	15
Acetylene flow rate (L/min)	2.0	1.8	1.6	0.9	1.0	1.8	2.8	2.0	1.5
Burner height (mm)	7	7	7	7	7	7	9	7	7

Table 2 Physicochemical parameters of water samples (n = 12) use to irrigate wheat Sources: [a]MWE (2005), [b]FAO (1985)

Treatment	Physicochemical parameters			
	EC (dS/m)	Ca^{+2}, Mg^{+2} meq/L	Na^{+}	Cl^{-}
T–I	2.51 ± 1.3	6.46 ± 1.4	10.99 ± 1.4	6.83 ± 1.1
T–II	4.50 ± 1.8	11.36 ± 1.6	30.46 ± 1.6	20.23 ± 1.5
T–III	6.91 ± 1.4	18.33 ± 1.4	40.26 ± 1.8	31.33 ± 1.12
T–IV	8.18 ± 2.1	25.79 ± 1.7	51.13 ± 1.7	45.54 ± 1.6
Standard limits	5.1[a]	200[a], 150[a]	900[b]	–

Results and Discussion

Physicochemical parameters of water observed in the present study were showed on the Table 2. The values of EC ranged from 2.51 to 8.18 dS/m among all treatments. The values of Ca^{+2} and Mg^{+2} among four treatments were 6.46, 11.36, 18.33 and 25.79 meq/L respectively. Level of Na^{+} was highest (51.13 meq/L) at T–IV while the minimum level (10.99 meq/L) was present at T–I. The range of chloride (Cl^{-}) in four treatments was 6.83–45.54 meq/L (Table 2). Electrical conductivity determines the total ionic concentration of water. The values of EC in present investigation were lower while calcium, magnesium and sodium were higher as compared to the values reported by Kumar et al. (2015). Yang et al. (2015) reported higher values of electrical conductivity while lower concentrations of chloride ion as compared to the present investigation.

Physicochemical parameters of soil observed in the present study are showed on the Table 3. Loamy soil was observed in four treatments with pH ranging from 8 to 7.6. Highest pH value was found at T–I while the lowest values were observed at T–IV. Mean concentrations of EC among the four treatments ranged from 9.28 to 16.51 dS/m. The range of OM was between 0.76%–1.18%. The values of P were 7.56, 11.5, 14.06, 14.06 and 16.1 mg/kg respectively. The mean values of available K were 313, 329, 347, and 358 mg/kg respectively (Table 3). Organic content and pH are main physicochemical properties of soil. Soil pH directly influences the accessibility of potential toxic metals in the soil and capacity of plants to uptake metals (Zeng et al. 2011). Wastewater irrigation considerably decreases the pH of soil. Low pH values increase the availability of potential toxic metals in soil (Ugulu and Baslar 2010; Zhao et al. 2015). In the current study, values of available P and available K were lower while pH and EC were higher as compared the findings of Salakinkop and Hunshal (2014).

Treatments significantly affected concentrations of Co, Ni, Cr, Fe, Cu, Mn, Pb, Cd in grains, Cd, Zn, Co, Mn, Fe, Cu, Pb, Cr, Ni, Fe in water and Fe, Zn, Mn, Cr, Pb, Cd, Cu, Co in soil (Table 4).

In water, the mean values of potential toxic metals (mg/kg) were higher for Ni and lower for Pb (Table 5). Wastewater irrigation is common practice in developing countries and causes a metal surge in crops grown there to become the part of the food chain (Singh and Garg 2006). In the present investigation, Co, Pb, Ni, Mn, Cd, Cu, Cr, Zn, and Pb values in water were above the permissible limit suggested by WWF (2007) and (FAO 1985). The values of Pb, Cd, Ni Fe, Mn, Cu Cr, and Zn in the present investigation were higher than the values reported by

Table 3 Post-harvest physicochemical parameters of soil samples (n = 12)

Treatment	Physicochemical parameters					
	pH	EC (dS/m)	Organic matter (%)	Available phosphorus (mg/kg)	Available potassium (mg/kg)	Texture
T–I	8.0 ± 0.03	9.28 ± 0.01	0.76 ± 0.01	7.56 ± 0.12	313 ± 0.15	Loam
T–II	7.5 ± 0.12	10.25 ± 10.01	0.84 ± 0.01	11.35 ± 0.16	329 ± 0.57	Loam
T–III	7.7 ± 0.14	12.71 ± 0.08	1.12 ± 0.01	14.06 ± 0.08	347.6 ± 0.88	Loam
T–IV	7.6 ± 0.08	16.51 ± 0.18	1.18 ± 0.08	16.1 ± 0.11	358.6 ± 1.20	Loam

Table 4 Analysis of variance of potential toxic metals in water, soil and grains

Metal	Mean square								
	Pb	Cd	Ni	Fe	Mn	Cu	Cr	Zn	Co
Water	0.003***	0.024***	0.049**	37.425**	0.052**	0.027***	0.005 ns	38.211**	0.016***
Soil	0.022***	0.009***	0.070 ns	95.065**	0.004***	0.328***	0.052**	0.322**	0.020***
Wheat grains	0.023***	0.113**	0.045*	0.360**	0.249***	0.333***	0.020**	0.339 ns	0.020***

ns non–significant

*, **, ***Significant at 0.05, 0.01, 0.001 levels

Table 5 Mean concentration of metals in irrigation water, soil and in grains of *T. aestivum*
Sources: [a]WWF (2007), [b]FAO (1985), [c]USEPA (2010), [d]European Union (2006), [e]USEPA (1997), [f]FAO/WHO (2001)

Metal	Treatment				
	T–I	T–II	T–III	T–IV	Permissible limit
Irrigation water (mg/L)					
Pb	0.141 ± 0.12	0.282 ± 0.17	0.367 ± 0.23	0.51 ± 0.3	0.10[a]
Cd	1.521 ± 0.2	1.691 ± 0.27	1.856 ± 0.38	1.879 ± 0.25	0.01[a]
Ni	1.020 ± 0.11	1.046 ± 0.24	1.080 ± 0.16	1.300 ± 0.23	0.20[a]
Fe	2.212 ± 0.42	4.989 ± 0.49	7.598 ± 0.4	9.451 ± 0.7	5[a]
Mn	0.384 ± 0.2	0.463 ± 0.3	0.572 ± 0.5	0.683 ± 0.3	0.20[a]
Cu	0.542 ± 0.17	0.610 ± 0.38	0.678 ± 0.21	0.767 ± 0.32	0.20[a]
Cr	0.551 ± 0.16	0.579 ± 0.2	0.588 ± 0.27	0.653 ± 0.3	0.10[b]
Zn	1.612 ± 0.28	5.324 ± 0.6	7.789 ± 0.5	9.425 ± 0.21	2[b]
Co	0.321 ± 0.09	0.369 ± 0.13	0.450 ± 0.21	0.471 ± 0.17	0.05[a]
Soil (mg/kg)					
Pb	0.193 ± 0.07	0.301 ± 0.09	0.350 ± 0.1	0.391 ± 0.12	300[c]
Cd	1.903 ± 0.1	1.935 ± 0.14	1.968 ± 0.15	2.030 ± 0.17	3[c]
Ni	1.260 ± 0.08	1.315 ± 0.12	1.358 ± 0.12	1.605 ± 0.19	50[d]
Fe	2.795 ± 0.1	3.356 ± 0.13	3.873 ± 0.14	4.044 ± 0.2	21000[e]
Mn	0.538 ± 0.06	0.576 ± 0.09	0.600 ± 0.12	0.630 ± 0.12	2000[d]
Cu	1.198 ± 0.08	1.461 ± 0.13	1.711 ± 0.17	1.968 ± 0.21	50[c]
Cr	1.053 ± 0.09	1.146 ± 0.11	1.188 ± 0.14	1.368 ± 0.15	50[f]
Zn	1.406 ± 0.13	1.640 ± 0.15	1.696 ± 0.2	2.186 ± 0.1	200[c]
Co	0.610 ± 0.09	0.661 ± 0.11	0.708 ± 0.12	0.800 ± 0.15	100[f]
Grain (mg/kg)					
Pb	0.068 ± 0.02	0.123 ± 0.02	0.170 ± 0.04	0.273 ± 0.03	0.3[f]
Cd	1.248 ± 0.04	1.333 ± 0.05	1.396 ± 0.07	1.695 ± 0.06	0.2[f]
Ni	0.631 ± 0.04	0.721 ± 0.05	0.801 ± 0.04	0.921 ± 0.07	67[f]
Fe	0.825 ± 0.07	1.231 ± 0.07	1.326 ± 0.08	1.666 ± 0.06	425.5[f]
Mn	0.400 ± 0.06	0.696 ± 0.07	0.883 ± 0.08	1.076 ± 0.08	500[f]
Cu	0.711 ± 0.05	0.846 ± 0.08	1.108 ± 0.1	1.468 ± 0.06	73.3[f]
Cr	0.386 ± 0.03	0.423 ± 0.07	0.466 ± 0.06	0.573 ± 0.09	2.3[f]
Zn	0.101 ± 0.04	0.343 ± 0.07	0.398 ± 0.07	0.901 ± 0.09	99.4[f]
Co	0.031 ± 0.02	0.081 ± 0.04	0.148 ± 0.04	0.218 ± 0.06	50[f]

Balkhair and Ashraf (2016). Iqbal et al. (2016) reported higher values of Cr, Pb, and the lower value of Ni, Cd than the present research.

In soil samples, the mean values (mg/kg) of potential toxic metals fluctuated from 0.19 to0.39 for Pb, 1.90 to 2.03 for Cd, 1.26 to 1.60 for Ni, 2.79 to 4.04 for Fe, 0.53 to 0.63 for Mn, 1.19 to 1.96 for Cu, 1.05 to 1.36 for Cr, 1.40 to 2.18 for Zn and 0.61 to 0.80 for Co respectively (Table 5). The mean values of all metals fell within the maximum permissible limit (MPL) of Pb, Cd, Ni, Fe, Mn, Cu, Cr, Zn, and Co recommended by USEPA (1997), FAO/WHO (2001), European Union (2006) and USEPA (2010). This could be due to the high pH of soil because transfer of potential toxic metals from soil to plant mainly depends on soil pH. Availability of metals in plant decreases at pH value greater than 6.5 (Harrison and Waites 1998). Ni, Cd, and Cr contents were above and that of Zn was below the reported values by Iqbal et al. (2016). Mahmoud and Ghoneim (2016) reported high contents (mg/kg) of Fe, Zn, Mn, Cd, Pd, Ni, Cu, in soil than the present study. Liu et al. (2016) reported high contents of Pb, Cr and low contents of Cd than the present findings. Li et al. (1994) suggested that plants absorb Cd more readily as compared to other metals and the level of Cd in plants exceeds the maximum value that is dangerous to human health.

In wheat grains, the mean values of metals (mg/kg) varied from 0.06 to 0.2 for Pb, 1.2 to 1.6 for Cd, 0.6 to 0.9 for Ni, 0.8 to 1.6 for Fe, 0.4 to 1.0 for Mn, 0.7 to 1.4 for Cu, 0.3 to 0.5 for Cr, 0.1 to 0.9 for Zn and 0.03 to 0.2 for Co, correspondingly (Table 5). Concentration of Cd in the present investigation was greater than MPL 0.2 mg/kg given by FAO/WHO (2001). Due to its high mobility Cd is readily taken up by plants. To the human body, accumulation of cadmium leads to certain disorders, including liver and nervous system and cardiovascular diseases (Tataruch and Kierdorf 2003). Total concentrations of potential toxic metals detected in wheat grain were lower than the MPL except for Cd (FAO/WHO 2001). This might be due to inconsistency in physical and chemical properties of soil and variation in ability of the plant to uptake metals (Khan et al. 2018d). In current results, Cd concentration was higher and Cu, Zn were lower than the values reported by Yu et al. (2016). The results from the present study and earlier report given by Liu et al. (2005) confirmed that plants grown on wastewater irrigated soil were contaminated with potential toxic metals and cause various health hazards in human. The absorption and accumulation of potential toxic metals in plant tissue depend on many factors such as pH, OM, nutrient availability, moisture and temperature, however, the presence of organic matter content has been reported to increase the uptake of metals in wheat plants (Rupa et al. 2003; Dogan et al. 2010).

A positive and significant correlation of Pb, Cd, Ni, Fe, Mn, Cu, and Co showed a strong association (Table 6). This might be due to their common source in wastewater. The positive and non–significant relationship of Cr and Zn showed a weak relationship of metals. This showed the imbalance of Cr and Zn between soil and wheat grains. The correlation between soil and wheat grain depends on the accessibility of metals in soil. Current results were similar to the findings of Ahmad et al. (2018).

The translocation competency of potential toxic metals from soil to edible parts of plants was determined by BCF. The results illustrated that Mn showed the highest BCF value, while Co showed the lowest value among all treatments (Table 7). Bioconcentration factor is the key component to determine the human exposure to potential toxic metals via the food chain. The BCF values for Mn was higher than 1 in T–II, T–III and T–IV while those of all other metals were less than 1 in all treatments. BCF factor ≤ 1 demonstrated that the plant could just absorb metals however, did not accumulate metals; BCF > 1 demonstrated that plants might potentially and readily accumulate metals (Singh et al. 2011).

To estimate the soil contamination status with metals, PLI was determined. In the present investigation, the value of PLI for Cd was higher among all treatments (Table 8). The PLI was calculated as the concentration of metals in wastewater irrigated soil with respect to reference values. The value of PLI of all potential toxic metals was below than the reference values (mg/kg) of Pb (8.15), Cd (1.49), Ni (9.06), Fe (56.90), Mn (46.75), Cu (8.39), Cr (9.07), Zn (44.19) and Co (9.1) (Dutch Standards 2000; Dosumu et al. 2005; Singh et al. 2010). Pollution load index due to Cr was high, but due to Mn, Fe, Pb, and Cd was less at present work than given by Ashfaq et al. (2015). The value of PLI for Cd was higher than one indicating that environmental risk can be caused by Cd.

In the backdrop of reducing freshwater resources and shortage of rains due to global climate change, the focus

Table 6 Correlation between soil and grain potential toxic metal concentrations

Correlation									
Metals	Pb	Cd	Ni	Fe	Mn	Cu	Cr	Zn	Co
Soil–Grains	0.782**	0.905**	0.615*	0.891**	0.741**	0.772**	0.940 ^{ns}	0.512 ^{ns}	0.863**

ns non–significant

*, **Correlation is significant at 0.05 and 0.01 levels

Table 7 Bioconcentration factor for wheat grain/soil system

Treatment	Metal								
	Pb	Cd	Ni	Fe	Mn	Cu	Cr	Zn	Co
T–I	0.3523	0.6558	0.5453	0.2951	0.7434	0.5934	0.3665	0.0718	0.0508
T–II	0.4086	0.6888	0.5710	0.3668	1.2083	0.5790	0.3691	0.2091	0.1225
T–III	0.4857	0.7093	0.6187	0.3423	1.4716	0.6475	0.3922	0.2346	0.2090
T–IV	0.6982	0.8349	0.6189	0.4119	1.7079	0.7459	0.4188	0.4121	0.2725

Table 8 Pollution load index for potential toxic metals in soil

Treatment	Metal								
	Pb	Cd	Ni	Fe	Mn	Cu	Cr	Zn	Co
T–I	0.0236	1.2771	0.1390	0.0491	0.0115	0.1427	0.1160	0.1550	0.0670
T–II	0.0369	1.2986	0.1451	0.0589	0.0123	0.1741	0.1263	0.1808	0.0726
T–III	0.0429	1.3208	0.1498	0.0680	0.0128	0.2039	0.1309	0.1869	0.0778
T–IV	0.0479	1.3624	0.1771	0.0710	0.0134	0.2345	0.1508	0.2410	0.0879

is shifting on alternate sources of irrigation like municipal wastewater. This study has highlighted potential implications and threats of using wastewater for crop production. Bioavailability of metals to plants results in buildup of metals in edible plant tissues up to toxic levels. In wheat grains, level all metals were found within the permissible limit given by FAO/WHO, except for Cd whose concentration exceeded the permissible levels and high pollution load index was reported for Cd indicating toxicity and contamination of grains. Continuous soil monitoring is required to keep a check on metal levels in wheat crop.

References

Ahmad K, Nawaz K, Khan ZI, Nadeem M, Wajid K et al (2018) Effect of diverse regimes of irrigation on metals accumulation in wheat crop: an assessment-dire need of the day. Fresen Environ Bull 27:846–855

APHA (2005) Standard methods for the examination of water and wastewater. American Public Health Association, Washington DC

Ashfaq A, Khan ZI, Bibi Z, Ahmad K, Ashraf M, Mustafa I, Akram NA, Perveen R, Yasmeen S (2015) Potential toxic metals uptake by *Cucurbita maxima* grown in soil contaminated with sewage water and its human health implications in peri-urban areas of Sargodha city. Pak J Zoo 47:1051–1058

Balkhair KS, Ashraf MA (2016) Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. Saudi J Bio Sci 23:32–44

Cui YJ, Zhu YG, Zhai RH, Chen DY, Huang YZ, Qui Y, Liang JZ (2004) Transfer of metals from near a smelter in Nanning, China. Environ Int 30:785–791

Dogan Y, Ugulu I, Baslar S (2010) Turkish red pine as a biomonitor: a comparative study of the accumulation of trace elements in needles and barks. Ekoloji 19(75):88–96

Dogan Y, Baslar S, Ugulu I (2014a) A study on detecting heavy metal accumulation through biomonitoring: content of trace elements in plants at Mount Kazdagi in Turkey. Appl Ecol Environ Res 12(3):627–636

Dogan Y, Unver MC, Ugulu I, Calis M, Durkan N (2014b) Heavy metal accumulation in the bark and leaves of *Juglans regia* planted in Artvin City. Turkey. Biotech Biotechnol Equip 28(4):643–649

Dosumu OO, Salam NA, Oguntoy NS (2005) Trace metals bioaccumulation by some Nigerian vegetables. Centrepoint 13:23–32

Durkan N, Ugulu I, Unver MC, Dogan Y, Baslar S (2011) Concentrations of trace elements aluminium, boron, cobalt and tin in various wild edible mushroom species from Buyuk Menderes River Basin of Turkey by ICP-OES. Trace Elem Electrolytes 28:242–248

FAO (1985) Water Quality for Agriculture, FAO irrigation and drainage paper No. 29. Food and Agriculture Organization of the United Nations, Rome

FAO/WHO (2001) Food additive and contaminants. Joint FAO/WHO Food Standards Programme, ALINORM 01/12A. Codex Alimentarius Commission. Rome: Food and Agriculture Organization of the United Nations

GOP (2012) Economic Survey of Pakistan, 2011–2012. Finance Division, Advisory Wing, Islamabad

Harrison P, Waites G (1998) The Cassell Dictionary of Chemistry. Cassell, London

Iqbal HH, Taseer R, Anwar S, Mumtaz M, Qadir A, Shahid N (2016) Human health risk assessment: heavy metal contamination of vegetables in Bahawalpur, Pakistan. Bull Environ Stud 1:10–17

Khan ZI, Ugulu I, Umar S, Ahmad K, Mehmood N, Ashfaq A, Bashir H, Sohail M (2018a) Potential toxic metal accumulation in soil, forage and blood plasma of buffaloes sampled from Jhang, Pakistan. Bull Environ Contam Toxicol 101:235–242

Khan ZI, Ugulu I, Sahira S, Ahmad K, Ashfaq A, Mehmood N, Dogan Y (2018b) Determination of toxic metals in fruits of *Abelmoschus esculentus* grown in contaminated soils with different irrigation sources by spectroscopic method. Int J Environ Res 12:503–511

Khan ZI, Ugulu I, Ahmad K, Yasmeen S, Noorka IR, Mehmood N, Sher M (2018c) Assessment of trace metal and metalloid accumulation and human health risk from vegetables consumption through spinach and coriander specimens irrigated with wastewater. Bull Environ Contam Toxicol 101:787–795

Khan ZI, Ahmad K, Safdar H, Ugulu I, Wajid K, Bashir H, Dogan Y (2018d) Manganese bioaccumulation and translocation of in forages grown in soil irrigated with city effluent: an evaluation on health risk. Res J Pharm, Biol Chem Sci 9(5):759–770

Kumar V, Chopra AK, Srivastava S, Chauhan RK (2015) Accumulation of heavy metals in vegetables grown in wastewater irrigated soil in Haridwar (Uttarakhand), India. Agric Sci Res J 5:146–152

Li GC, Tarn LH, Sen LC (1994) Uptake of heavy metals by plants in Taiwan, paper from conference title: biogeochemistry of trace elements. Environ Geochem Health 2:153–160

Liu WH, Zhao JZ, Ouyang ZY, Soderlund L, Liu GH (2005) Impacts of sewage irrigation on heavy metals distribution and contamination in Beijing, China. Environ Int 31:805–812

Liu Z, Zhang Q, Han T, Ding Y, Sun J, Wang F, Zhu C (2016) Heavy metal pollution in a soil-rice system in the Yangtze River region of China. Int J Environ Res Pub Health 13:1–16

Mahmoud EK, Ghoneim AM (2016) Effect of polluted water on soil and plant contamination by heavy metals in El-Mahla El-Kobra. Egypt. Solid Earth 7:703–711

MWE (2005) National Wastewater Regulations, Section III–2.2 and 3.2.3. Riyadh, Saudi Arabia: Ministry of Water and Electricity

Nadeem M, Qureshi TM, Ugulu I, Riaz MN, An QU, Khan ZI, Ahmad K, Ashfaq A, Bashir H, Dogan Y (2019) Mineral, vitamin and phenolic contents and sugar profiles of some prominent date palm (*Phoenix dactylifera*) varieties of Pakistan. Pak J Bot. https://doi.org/10.30848/PJB2019-1(14)

Olsen SR, Sommers LE (1982) Phosphorous. In: Page AL, Miller RH, Keeney DR, (Eds.) Methods of soil analysis. Part 2. Chemical and microbiological properties. American Society of Agronomy, Madison, WI, pp 403-430

Page AL (1982) Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Agron. Monogr. 9.2. Madison, WI: Agronomy Society of America, Soil Science Society of America

Rijsberman FR (2006) Water scarcity: fact or fiction? Agric Water Manag 80:5–22

Rupa TR, Rao CS, Rao AS, Singh M (2003) Effects of farmyard manure and phosphorus on zinc transformations and phytoavailability in two alfisols of India. Bioresour Tech 87:279–288

Salakinkop SR, Hunshal CS (2014) Domestic sewage irrigation on dynamics of nutrients and heavy metals in soil and wheat (*Triticum aestivum* L.) production. Int J Recycl Org Waste Agric 3:1–11

Shewry PR (2009) The HEALTHGRAIN programme opens new opportunities for improving wheat for nutrition and health. Nutr Bull 34:225–231

Singh V, Garg A (2006) Availability of essential trace elements in Indian cereals, vegetables and spices using INAA and the contribution of spices to daily dietary intake. Food Chem 94:81–89

Singh A, Sharma RK, Agarwal M (2010) Risk assessment of heavy metal toxicity through contaminated vegetables from wastewater irrigated area of Varanasi. Trop Ecol 51:375–387

Singh J, Upadhyay SK, Pathak RK, Gupta V (2011) Accumulation of heavy metals in soil and paddy crop (*Oryza sativa*), irrigated with water of Ramgarh Lake, Gorakhpur, UP, India. Toxicol Environ Chem 93:462–473

Standards Dutch (2000) Circular on target values and intervention values for soil remediation. Ministry of Housing, Spatial Planning and the Environment, Bilthoven

Tataruch F, Kierdorf H (2003) Mammals as biomonitors. In: Markert BA, Breure MA, Zechmeister HG (eds) *Bioindicators & Biomonitors: Principles, Concepts, and Applications*. Elsevier, Amsterdam, pp 737–772

Ugulu I (2015) Determination of heavy metal accumulation in plant samples by spectrometric techniques in Turkey. Appl Spectros Rev 50(2):113–151

Ugulu I, Baslar S (2010) The determination and fidelity level of medicinal plants used to make traditional Turkish salves. J Alternative Compl Med 16(3):313–322

Ugulu I, Dogan Y, Baslar S, Varol O (2012) Biomonitoring of trace element accumulation in plants growing at Murat Mountain. Int J Environ Sci Tech 9:527–534

Ugulu I, Unver MC, Dogan Y (2016) Determination and comparison of heavy metal accumulation level of *Ficus carica* bark and leaf samples in Artvin, Turkey. Oxid Communi 39:765–775

Union European (2006) Commission Regulation (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Official J Eur Union 364:5–24

Unver MC, Ugulu I, Durkan N, Baslar S, Dogan Y (2015) Heavy metal contents of *Malva sylvestris* sold as edible greens in the local markets of Izmir. Ekoloji 24:13–25

USEPA (1997) Exposure Factors Handbook. Volume II-Food Ingestion Factors. EPA/600//P-95/002Fa. Office of Research and Development, US Environmental Protection Agency, Washington, DC

USEPA (2010) Risk-based Concentration Table. Office of Research and Development, US Environmental Protection Agency, Washington, DC

WWF (2007) Report on National Surface Water Classification Criteria, Irrigation Water Quality Guidelines for Pakistan. February-2007. Islamabad, Pakistan: Waste Water Forum

Yang B, Kong X, Cui B, Jin D, Deng Y, Zhuang X, Zhuang G, Bai Z (2015) Impact of rural domestic wastewater irrigation on the physicochemical and microbiological properties of pakchoi and soil. Water 7:1825–1839

Yu X, Wang Z, Lynn A, Cai J, Huangfu Y, Geng Y, Tang J, Zeng X (2016) Heavy metals in wheat grown in sewage irrigation: a distribution and prediction model. Pol J Environ Stud 25:413–418

Zeng FR, Ali S, Zhang HT, Ouyan Y, Qiu B, Wu F, Zhang G (2011) The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environ Pollut 159:84–91

Zhao KL, Fu WJ, Ye ZQ, Zhang CS (2015) Contamination and spatial variation of heavy metals in the soil-rice system in Nanxun County. South-eastern China, Int J Environ Res Pub Health 12:1577–1594