

## Heavy Metal Contamination in Vegetables Grown in Rawalpindi, Pakistan

<sup>1</sup>WAQAS AHMED, <sup>1</sup>ANWAAR AHMED, <sup>1</sup>ASIF AHMAD, <sup>2</sup>MUHAMMAD ATIF RANDHAWA,  
<sup>3,4</sup>RIAZ AHMAD AND <sup>5</sup>NAUMAN KHALID\*

<sup>1</sup>Department of Food Technology, PMAS -Arid Agriculture University, Rawalpindi, 46300, Pakistan

<sup>2</sup>National Institute of Food Science & Technology, University of Agriculture, Faisalabad 38040, Pakistan

<sup>3</sup>Department of Soil Science & Soil Water Conservation, PMAS-Arid Agriculture University,  
Rawalpindi 46300, Pakistan.

<sup>4</sup>Director Quality Enhancement Cell, PMAS-Arid Agriculture University, Rawalpindi 46300, Pakistan.

<sup>5</sup>Department of Global Agriculture, Graduate School of Agriculture and Life Sciences,  
The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan.

nauman\_khalid120@yahoo.com\*

(Received on 20<sup>th</sup> January 2012, accepted in revised form 20<sup>th</sup> March 2012)

**Summary:** Copper (Cu), cadmium (Cd), chromium (Cr) nickel (Ni), lead (Pb), Iron (Fe), Manganese (Mn) and zinc (Zn) contents of various vegetables (bitter melon, tomato, eggplant, lettuce, cucumber and bell pepper) produced in Rawalpindi, Pakistan was determined using Atomic absorption spectrophotometer (AAS). These plants are the basis of human nutrition in the study area. All vegetables grown at sewage water by farmers showed the highest contamination of heavy metals, followed by local market, Progressive farmers and hydroponic plant. The concentration ranges in mg/kg were (1.45 -2.55) for Cd, (3.10 to 4.92) Cr, (12.15- 20.50) Cu, (25.00-51.00) for Fe, (7.80 to 15.60) for Mn, (10.16 to 15.42) for Ni, (2.12 to 5.41) Pb and (16.58 to 24.08) for zinc. The contamination was above the Maximum Residue Limits (MRLs), set out by WHO. Irregular trends in concentration were also observed in vegetables obtained from local market, progressive farmers and hydroponic plant.

Key words: Heavy metals, Contamination, Vegetables, Concentrations.

### Introduction

Food safety is a major public concern throughout the world. Consumption of nutritious and wholesome food has increased the demand of safe food. During the last few decades there is increase in research and efforts regarding the risk and health hazards associated with foodstuffs contaminated with heavy metals and pesticides [1]. Heavy metals in general are non-biodegradable, long biological half-lives and have high potential to accumulate in various body parts. Being water soluble they are highly toxic and have adverse effects on life even at low concentrations. Higher amounts of toxic heavy metals are found in waste water. Because of their excessive use in industrial applications, they are found everywhere [2, 3].

There are many factors which contribute to heavy metal contamination such as contaminated irrigation water, fertilizers and pesticides applications, emissions of different waste materials from industries, lack of good transportation facilities, harvesting process and storage. The main sources of heavy metals are natural inputs like parent material weathering and anthropogenic inputs like metalliferous industries, mining, vehicle exhaust and agronomic practices [4]. An alarming situation is that human input has greatly exceeded the natural input of these metals due to pedogenic processes in soils [5]. The heavy metals availability to plants is regulated

by many characteristics of soil like pH, cation exchange capacity, organic matter content, redox conditions and chloride content. In soil, increasing salinities has been reported to accelerate heavy metals mobilization and promote the metals uptake by plants [6-8]. Plants absorb these heavy metals either from contaminated soils or from parts of the plants exposed to the air in polluted environments on which the heavy metals are deposited [9, 10]. Plants accumulation with heavy metal relies on plant species and the metal absorbing efficiency of different plants [11].

Nature has bestowed upon Pakistan a land and climate conducive to the growth of a wide spectrum of fruits and vegetables. The Agriculture sector continues to play a central role in Pakistan's economy. It is the second largest sector, accounting for over 21 percent of GDP [12]. Pakistan is producing thousands of tons of vegetables like potato, okra, bitter melon, eggplant, tomato, cucumber, bell pepper, spinach, cauliflower, pumpkin, carrots etc. But these vegetables are contaminated with heavy metal because of untreated city effluent and usage of sewage water especially in big cities [13]. Vegetables are the most important components of human diet [14] and are rich in vitamins, minerals and fibers. But these vegetables are contaminated with heavy metal and intake of

---

\*To whom all correspondence should be addressed.

these contaminated vegetables has shown risk to the human health. Toxic heavy metals are associated with cardiovascular, kidney, nervous and bone diseases [15-18]. Vomiting, diarrhea, stomach irritation, decreases in reaction time, kidney problems, anemia and blood disorders in humans are some of the diseases associated with heavy metals [19]. They may also cause respiratory tract cancer and mucodermal ulceration [20]. Current scenario demands to assess heavy metal contamination in soil, their bioaccumulation in vegetables and finally entering into the food chain that affects human health. Therefore a research work was planned to quantify the heavy metal accumulation in different vegetables.

### Results and Discussion

The statistical results indicated that the cadmium, chromium, copper, iron, manganese, nickel, lead and zinc were affected significantly ( $P < 0.05$ ) due to differences in sources. Similarly, differences in vegetables regarding heavy metals content were found to be significant. The interaction between sources and vegetables were also found to be significant.

#### Cadmium

The mean values for cadmium have been presented in Table-1. The results showed significantly the highest content of cadmium in sewage water ( $1.930 \text{ mg kg}^{-1}$ ) followed by the samples collected from local market ( $0.650 \text{ mg kg}^{-1}$ ), progressive farmers ( $0.016 \text{ mg kg}^{-1}$ ) and hydroponic plant ( $0.006 \text{ mg kg}^{-1}$ ). The difference for cadmium content in the vegetables collected from progressive farmers and hydroponic plant was non-significant. The results further substantiated that cadmium content was found to be significantly highest in eggplant ( $0.912 \text{ mg kg}^{-1}$ ) and significantly lowest in bitter melon ( $0.466 \text{ mg kg}^{-1}$ ), however, variation in vegetables for cadmium in eggplant and bell pepper was non-significant.

#### Chromium

The mean values for chromium have been presented in Table-2. The results showed significantly ( $P < 0.05$ ) highest content of chromium in sewage water ( $3.810 \text{ mg kg}^{-1}$ ) followed by the samples collected from local market ( $1.356 \text{ mg kg}^{-1}$ ), hydroponic plant ( $0.152 \text{ mg kg}^{-1}$ ) and progressive farmers ( $0.134 \text{ mg kg}^{-1}$ ). The difference for chromium content in the vegetables collected from progressive farmers and hydroponic plant was non-significant. The results further demonstrated that chromium content was found to be significantly

higher in eggplant ( $1.725 \text{ mg kg}^{-1}$ ) and significantly lower in cucumber ( $0.937 \text{ mg kg}^{-1}$ ). However, variation in vegetables for chromium in eggplant and tomato was non-significant.

#### Copper

The mean values for copper have been presented in Table-3. The results showed significantly highest content of copper in sewage water ( $15.840 \text{ mg kg}^{-1}$ ) followed by the samples collected from local market ( $12.770 \text{ mg kg}^{-1}$ ), hydroponic plant ( $0.180 \text{ mg kg}^{-1}$ ) and progressive farmers ( $0.112 \text{ mg kg}^{-1}$ ). The difference for copper content in the vegetables collected from progressive farmers and hydroponic plant was non-significant. The results further substantiated that variation in vegetables for copper in eggplant and bell pepper was non-significant, however copper content was found to be significantly higher in bell pepper ( $8.625 \text{ mg kg}^{-1}$ ) and significantly lower in cucumber ( $5.465 \text{ mg kg}^{-1}$ ).

#### Iron

The mean values for iron have been presented in Table-4. The results showed significantly highest content of iron in sewage water ( $36.600 \text{ mg kg}^{-1}$ ) followed by the samples collected from local market ( $16.274 \text{ mg kg}^{-1}$ ), progressive farmers ( $0.839 \text{ mg kg}^{-1}$ ) and hydroponic plant ( $0.704 \text{ mg kg}^{-1}$ ). The difference for iron content in the vegetables collected from progressive farmers and hydroponic plant was non-significant. The results further substantiated that iron content was found to be higher in eggplant ( $19.742 \text{ mg kg}^{-1}$ ) and lower in tomato ( $9.150 \text{ mg kg}^{-1}$ ). However, variation in vegetables for iron content was found to be significant in all vegetables.

#### Manganese

The mean values for manganese have been presented in Table-5. The results showed significantly highest content of manganese in sewage water ( $11.170 \text{ mg kg}^{-1}$ ) followed by the samples collected from local market ( $5.160 \text{ mg kg}^{-1}$ ), hydroponic plant ( $0.183 \text{ mg kg}^{-1}$ ) and progressive farmers ( $0.063 \text{ mg kg}^{-1}$ ). The difference for manganese content in the vegetables collected from progressive farmers and hydroponic plant was non-significant. The results further substantiated that manganese content was found to be higher in eggplant ( $6.104 \text{ mg kg}^{-1}$ ) and lower in tomato ( $3.037 \text{ mg kg}^{-1}$ ). However, variation in vegetables for manganese in tomato, cucumber and bitter melon was non-significant.

Table-1: Mean detection of cadmium ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	Local Market	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	2.100±0.100	1.500±0.100	0.041±0.002	0.007±0.002	0.912 <sup>A</sup>
Tomato	1.450±0.250	0.700±0.050	0.009±0.001	0.005±0.001	0.541 <sup>B</sup>
Bell Pepper	2.550±0.200	0.850±0.110	0.004±0.001	0.007±0.002	0.853 <sup>A</sup>
Cucumber	1.800±0.050	0.100±0.010	0.015±0.003	0.008±0.003	0.481 <sup>BC</sup>
Bitter melon	1.750±0.050	0.100±0.010	0.012±0.002	0.003±0.001	0.466 <sup>C</sup>
Mean	1.930 <sup>A</sup>	0.650 <sup>B</sup>	0.016 <sup>C</sup>	0.006 <sup>C</sup>	

Table-2: Mean detection of chromium ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	Local Market	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	4.140±0.100	2.190±0.020	0.235±0.004	0.334±0.011	1.725 <sup>A</sup>
Tomato	4.920±0.010	1.730±0.140	0.137±0.008	0.000±0.000	1.697 <sup>A</sup>
Bell Pepper	3.390±0.070	1.770±0.050	0.077±0.007	0.000±0.000	1.309 <sup>B</sup>
Cucumber	3.100±0.010	0.330±0.030	0.113±0.001	0.207±0.006	0.937 <sup>D</sup>
Bitter melon	3.500±0.400	0.760±0.040	0.108±0.007	0.217±0.011	1.146 <sup>C</sup>
Mean	3.810 <sup>A</sup>	1.356 <sup>B</sup>	0.134 <sup>C</sup>	0.152 <sup>C</sup>	

Table-3: Mean detection of copper ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	LocalMarket	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	20.500±0.500	13.200±0.700	0.308±0.006	0.089±0.003	8.524 <sup>A</sup>
Tomato	14.900±0.400	13.400±0.300	0.041±0.002	0.338±0.008	7.169 <sup>B</sup>
Bell Pepper	18.450±0.100	15.700±0.400	0.105±0.005	0.246±0.004	8.625 <sup>A</sup>
Cucumber	12.150±0.070	9.650±0.030	0.039±0.003	0.024±0.002	5.466 <sup>D</sup>
Bitter melon	13.200±0.400	11.900±0.500	0.065±0.002	0.204±0.003	6.342 <sup>C</sup>
Mean	15.840 <sup>A</sup>	12.770 <sup>B</sup>	0.112 <sup>C</sup>	0.180 <sup>C</sup>	

Table-4: Mean detection of iron ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	LocalMarket	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	51.000±1.500	26.760±0.100	0.470±0.005	0.740±0.003	19.742 <sup>A</sup>
Tomato	25.000±0.400	10.700±0.200	0.120±0.010	0.782±0.004	9.150 <sup>E</sup>
Bell Pepper	38.000±0.500	12.860±0.110	0.212±0.005	0.897±0.002	12.992 <sup>C</sup>
Cucumber	27.000±1.000	13.600±0.600	0.214±0.003	0.011±0.001	10.206 <sup>D</sup>
Bitter melon	42.000±1.100	17.450±0.100	3.181±0.006	1.088±0.003	15.930 <sup>B</sup>
Mean	36.600 <sup>A</sup>	16.274 <sup>B</sup>	0.839 <sup>C</sup>	0.704 <sup>C</sup>	

Table-5: Mean detection of manganese ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	Local Market	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	15.600±0.200	8.500±0.400	0.115±0.005	0.201±0.001	6.104 <sup>A</sup>
Tomato	10.750±0.060	1.400±0.200	0.000±0.000	0.000±0.000	3.037 <sup>C</sup>
Bell Pepper	12.250±0.040	8.800±0.400	0.075±0.007	0.331±0.002	5.364 <sup>B</sup>
Cucumber	7.800±0.600	4.550±0.060	0.030±0.003	0.184±0.005	3.141 <sup>C</sup>
Bitter melon	9.450±0.070	2.550±0.050	0.096±0.004	0.200±0.005	3.074 <sup>C</sup>
Mean	11.170 <sup>A</sup>	5.160 <sup>B</sup>	0.063 <sup>C</sup>	0.183 <sup>C</sup>	

### Nickel

The mean values for nickel have been presented in Table-6. The results showed significantly highest content of nickel in sewage water (12.060  $\text{mg kg}^{-1}$ ) followed by the samples collected from local market (6.020  $\text{mg kg}^{-1}$ ), progressive farmers (0.056  $\text{mg kg}^{-1}$ ) and hydroponic plant (0.036  $\text{mg kg}^{-1}$ ). The difference for nickel content in the vegetables collected from progressive farmers and hydroponic plant was non-significant. The results further substantiated that nickel content was found to be higher in bitter melon (5.275  $\text{mg kg}^{-1}$ ) and lower in eggplant (2.909  $\text{mg kg}^{-1}$ ); however, variation in vegetables for nickel was significant in all vegetables.

### Lead

The mean values for lead have been presented in Table-7. The results showed significantly highest content of lead in sewage water (3.838  $\text{mg kg}^{-1}$ ) followed by the samples collected

from local market (1.526  $\text{mg kg}^{-1}$ ), progressive farmers (0.099  $\text{mg kg}^{-1}$ ) and hydroponic plant (0.043  $\text{mg kg}^{-1}$ ). The results further substantiated that lead content was found to be higher in eggplant (2.025  $\text{mg kg}^{-1}$ ) and lower in cucumber (0.837  $\text{mg kg}^{-1}$ ). However, variation in vegetables for lead in all vegetables was significant.

### Zinc

The mean values for zinc have been presented in Table-8. The results showed significantly highest content of zinc in sewage water (18.964  $\text{mg kg}^{-1}$ ) followed by the samples collected from local market (9.150  $\text{mg kg}^{-1}$ ), hydroponic plant (0.823  $\text{mg kg}^{-1}$ ) and progressive farmers (0.247  $\text{mg kg}^{-1}$ ). The results further substantiated that zinc content was found to be higher in bell pepper (8.501  $\text{mg kg}^{-1}$ ) and lower in tomato (6.197  $\text{mg kg}^{-1}$ ), however, variation in vegetables for zinc in all vegetables was significant.

Table-6: Mean detection of nickel ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	Local Market	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	10.180±0.060	1.400±0.300	0.000±0.000	0.058±0.002	2.909 <sup>D</sup>
Tomato	15.420±0.060	5.400±0.080	0.114±0.004	0.011±0.003	5.236 <sup>AB</sup>
Bell Pepper	10.160±0.090	6.300±0.050	0.116±0.003	0.000±0.000	4.144 <sup>C</sup>
Cucumber	12.100±0.200	8.500±0.500	0.000±0.000	0.000±0.000	5.150 <sup>B</sup>
Bitter melon	12.440±0.090	8.500±0.200	0.052±0.002	0.110±0.004	5.275 <sup>A</sup>
Mean	12.060 <sup>A</sup>	6.020 <sup>B</sup>	0.056 <sup>C</sup>	0.036 <sup>C</sup>	

Table-7: Mean detection of lead ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	Local Market	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	5.410±0.040	2.430±0.030	0.165±0.004	0.093±0.002	2.025 <sup>A</sup>
Tomato	4.820±0.070	1.260±0.040	0.059±0.005	0.000±0.000	1.535 <sup>B</sup>
Bell Pepper	3.310±0.020	1.640±0.010	0.157±0.003	0.064±0.002	1.293 <sup>C</sup>
Cucumber	2.120±0.010	1.140±0.040	0.067±0.006	0.022±0.003	0.837 <sup>E</sup>
Bitter melon	3.530±0.040	1.160±0.050	0.047±0.002	0.034±0.003	1.193 <sup>D</sup>
Mean	3.838 <sup>A</sup>	1.526 <sup>B</sup>	0.099 <sup>C</sup>	0.043 <sup>D</sup>	

Table-8: Mean detection of zinc ( $\text{mg kg}^{-1}$ ) in different vegetables collected from different sources.

	Sewage Water	Local Market	Progressive Farmers	Hydroponic Plant	Mean
Eggplant	19.560±0.030	9.250±0.040	0.301±0.003	0.907±0.001	7.505 <sup>B</sup>
Tomato	16.580±0.080	7.250±0.020	0.067±0.006	0.893±0.002	6.198 <sup>E</sup>
Bell Pepper	24.080±0.070	8.750±0.050	0.243±0.003	0.929±0.002	8.501 <sup>A</sup>
Cucumber	16.860±0.120	10.700±0.400	0.240±0.040	0.440±0.001	7.060 <sup>D</sup>
Bitter melon	17.740±0.060	9.800±0.070	0.386±0.003	0.946±0.005	7.218 <sup>C</sup>
Mean	18.964 <sup>A</sup>	9.150 <sup>B</sup>	0.247 <sup>D</sup>	0.823 <sup>C</sup>	

The results of analysis revealed that cadmium, chromium, copper, iron, manganese, nickel, lead and zinc content in vegetables samples collected from sewage water were higher than the Maximum Residue Limits (MRLs) prescribed by WHO [24]. It has been observed that environmental contamination and naturally occurrence of cadmium in local soils is the cause of accumulation of cadmium in vegetables [25, 26]. Ward [27] also described the sewage and industrial effluents as the cause of metal enrichment in agricultural fields near urban areas. Long term use of wastewater for vegetable production has shown elevation of heavy metals in vegetables [28-30]. The heavy metal concentration in sewage water may not only cause soil contamination as well as their uptake by crops may deteriorate food quality and safety [31]. A number of different studies have indicated the presence of toxic metal in waste water and also in soil irrigated with waste water [2, 27, 32, 33].

Vegetable samples collected from local market have cadmium, iron, lead and zinc content above than Maximum Residue Limits (MRLs) set by WHO [24]. Three samples of vegetables i.e. eggplant ( $2.19 \pm 0.02$ ), tomato ( $1.73 \pm 0.14$ ) and bell pepper ( $1.77 \pm 0.05$ ) have chromium content above the critical limit, whereas the bitter melon and cucumber were below the permissible limit. Copper content in local market vegetables were also observed to be higher than the permissible limit except cucumber. Two samples of vegetables i.e. eggplant ( $8.50 \pm 0.40$ ) and bell pepper ( $8.80 \pm 0.40$ ) have manganese content above the critical limit, whereas bitter melon,

tomato and cucumber were below the critical limit. Whereas all the vegetable samples collected from local market have nickel content below the recommended value given by WHO. Transportation and marketing systems of vegetables has great impact on contamination of vegetables with heavy metals. The similar results were observed in vegetables collected from markets by Jassir *et al.* [34]. The elevated level of iron in vegetables samples collected from local market may because of air pollution. Air pollution can become a threat during transportation and marketing to post-harvest vegetables, cause to increase heavy metals concentration in vegetables [20, 35].

Vegetable samples collected from progressive farmers have chromium, copper, iron, manganese, nickel and zinc below the maximum permissible limit described by WHO [24]. Three samples of vegetables i.e. eggplant ( $0.04 \pm 0.002$ ), bitter melon ( $0.01 \pm 0.002$ ) and cucumber ( $0.02 \pm 0.003$ ) have cadmium content above the critical limit, whereas the tomato and bell pepper cucumber have cadmium content below the maximum permissible limit. Zinc content in progressive farmers vegetables i.e. eggplant ( $0.91 \pm 0.001$ ) and bell pepper ( $0.93 \pm 0.002$ ) were found to be above the critical limit, whereas bitter melon, tomato and cucumber have zinc content below the critical limit. All the vegetable samples collected from hydroponic plant have cadmium, chromium, copper, iron, manganese, nickel, lead and zinc content below the Maximum Residue Limits (MRLs) given by WHO [24].

## Experimental

### Collection of Samples

The fresh samples of five vegetables; bitter melon (*Momordica charantia*), eggplant (*Solanum melongena*), tomato (*Lycopersicon esculentum*), cucumber (*Cucumis sativus*) and bell pepper (*Capsicum annuum*), were collected from four different localities in Rawalpindi region i.e.; Hydroponics plant (Farmers Market Pvt. Ltd. PMAS-Arid Agriculture University Rawalpindi), farms of progressive farmers, local market and farmers who grow vegetables on sewage water. After collection of vegetable samples they were transported to laboratory in Department of Food Technology, PMAS-Arid Agriculture University, Rawalpindi and stored at low temperature (4-8°C) until use.

### Vegetables Preparation for Analysis

Vegetable samples were digested for analysis of heavy metals according to the method reported by Richard [21]. The fresh samples of vegetables collected were washed with deionized water to eliminate air-borne contaminants. After washing uneatable portions of the vegetable were removed and eatable portions were chopped into small pieces. The test portion was then dried in an oven at 100 °C to remove moisture. 0.5g of the test portion were taken in 100 ml conical flask with the addition of 10 ml HNO<sub>3</sub> at 60-70 °C for 20 minutes and then the samples were digested with 5 ml HClO<sub>4</sub> at 60-70 °C for 20 minutes. Finally the temperature was raised to 195 °C till the samples were transparent and reduced to 1-2 ml. The digested samples were diluted in a volumetric flask with deionized water.

### Heavy Metals Estimation

The digested samples were tested for heavy metals i.e.; cadmium, chromium, copper, iron, nickel, lead, manganese and zinc through Atomic Absorption Spectrophotometer (GBC 932 PLUS) according to the procedure given in AOAC [22]. Hollow Cathode Lamps used for determination of these heavy metals. Cadmium, chromium, copper, iron, nickel, lead, manganese and zinc at wavelengths of 228.8 nm, 357.9 nm, 324.7 nm, 248.3 nm, 232.0 nm, 217.0 nm, 279.5 nm and 213.9 nm respectively.

### Statistical Analysis

The data obtained from each parameter was analyzed statistically to assess the changes in various parameters of the study as described by Steel *et al.* [23]. Completely Randomized Design was applied on the data to assess the significance of different sources of variation and the differences among the means

were compared with Duncan's Multiple Range test (DMR) using Statistical Package (MSTAT C Software).

## Conclusion

The study concluded that there is significant buildup of heavy metals in vegetables irrigated with sewage water. Urban activities have also elevated the level of heavy metals concentration in local market vegetables. So there is a need to create an awareness program for the farmers not to use wastewater for irrigating vegetables. Appropriate precautions should also be adopted during transportation, marketing and storage of local market vegetables.

## References

1. J.P.F. D'Mello. Food Safety: Contaminants and Toxins. Wallingford, Oxon, Cambridge, UK: CABI Publishing (2003).
2. K.P. Singh, D. Mohan, S. Sinha, R. Dalwani. Chemosphere, 5, 227-255 (2004).
3. Y. Chen, C. Wang, Z. Wang. Environment International, 31, 778-783 (2005).
4. C. Zhang. Environmental Pollution, 142, 501-511 (2006).
5. A.E. Facchinelli, E. Sacchi, L. Mallen. Environmental Pollution, 313, 313-324 (2001).
6. W.A. Norvell, J. Wu, D.G. Hopkins, R.H. Welch. Soil Science Society of America Journal, 64, 2162-2168 (2000).
7. K. Weggler, M.J. McLaughlin, R.D. Graham. Journal of Environmental Quality, 33, 496-504 (2004).
8. A.R.A. Usman, Y. Kuzyakov, K. Stahr. Soil and Sediment Contamination, 14, 329-344 (2005).
9. T. Khairiah, M.K. Zalifah, Y.H. Yin, A. Aminah. Pakistan Journal of Biological Sciences, 7, 1438-1442 (2004).
10. K. Chojnacha, A. Chojnacki, H. Gorecka, H. Gorecki. Science of the Total Environment, 337, 175 (2005).
11. R. K. Rattan, S. P. Datta, P. K. Chhonkar, K. Suribabu and A. K. Singh. Agriculture Ecosystems and Environment. 109, 310 (2005).
12. GOP. Economic Survey of Pakistan. 2009-10. Islamabad: Economic affairs wing, Finance Division (2010).
13. M. Qadir, A. Ghafoor, S. I. Hussain, G. Murtaza and M. Mahmood. Environmental Pollution" Third National Symposium on Modern Trends in Contemporary Chemistry; p 89-92, Islamabad, Pakistan (1998).

14. N. Zheng, Q. C. Wang, X. M. Zhang, D. M. Zheng, Z. S. Zhang and S. Q. Zhang. *Science of the Total Environment*, 387, 96 (2007).
15. WHO. Cadmium. Geneva: World Health Organization (1992).
16. WHO. Lead. Geneva: World Health Organization (1995).
17. K. Steenland and P. Boffetta. *American Journal of Industrial Medicine*, 38, 295 (2000).
18. L. Jarup. *British Medical Bulletin*, 68, 167 (2003).
19. ATSDR. Agency for Toxic Substance and Disease Registry. *Toxicological Profile for Cadmium*. Atlanta: US Department of Health and Human Services (1993).
20. S. K. Agrawal. *Pollution Management*,. New Dehli: A P H Pub Co (2002).
21. L. A. Richard. *Diagnosis and Improvements of Saline and Alkali Soils*. Washington DC: US Dept. of Agriculture (1969).
22. AOAC. *Official Methods of Analysis of the Association of Official Analytical Chemists*. 17th ed. USA: Gaithersburg, Maryland (2000).
23. R. G. D. Steel, J. H. Torrie and D. A. Dicky. *Principles and Procedures of Statistics: A Biometrical Approach*. 3rd ed. NY, USA: McGraw Hill Book Co Inc (1997).
24. WHO. *Guidelines for Drinking-Water Quality, Health Criteria and Other Supporting Information*. Geneva: World Health Organization (1996).
25. J. O. Nriagu. *Food contamination with cadmium in the environment*. New York: John Wiley and Sons (1990).
26. N. I. Ward. *Trace elements*. London: Blackie (1995).
27. F. E. Mapanda, N. Mangwayana, J. Nyamangara and K. E. Giller. *Agriculture Ecosystems and Environment*, 107, (2005).
28. S. Singh, S. Sinha, R. Saxena, K. Pandey and K. Bhatt. *Chemosphere*, 57, 91 (2005).
29. R. K. Sharma, M. Agrawal and F. M. Marshall. *Bulletin of Environmental Contamination and Toxicology*, 77, 311 (2006).
30. R. K. Sharma, M. Agrawal and F. M. Marshall. *Ecotoxicology and Environmental Safety*, 66, 258 (2007).
31. M. Muchuweti, J.W. Birkett, E. Chinyanga, R. Zvauya, E. R. Scrimshaw and J. N. Lester. *Agriculture Ecosystems and Environment*, 112, 41 (2006).
32. Z. H. Cao and Z. Y. Hu. *Chemosphere*, 41, 3 (2000).
33. J. Nyamangara and J. Mzezewa. *Agriculture Ecosystems and Environment*, 73, 199 (1999).
34. M. S. Jassir, A. Shaker and M. A. Khaliq. *Bulletin of Environmental Contamination and Toxicology*, 75, 1020 (2005).
35. M. Agrawal. *Enhancing Food Chain Integrity: Quality Assurance Mechanism for Air Pollution Impacts on Food and Vegetable System*. United Kingdom: Department for International Development (2003).