Assessment of Heavy Metals Concentration in Agriculture Soil of Kolfe Area, Addis Ababa, Ethiopia

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Abstract- This research evaluated the concentration and distribution of heavy metals (Chromium (Cr), Lead (Pb), & Cadmium (Cd)) in the vegetable field in the Kolfe area, Addis Ababa. Soil samples are tested for pH and heavy metals. Heavy metals in the soil are higher than the earlier report [1]. However, concentrations of heavy metal were observed (Cr > Pb >Cd), mean concentrations of heavy metal Cr, Cd and Pb were 274.83 mg kg^{-1}, 3.09 mg kg^{-1}, and 29.83 mg kg^{-1}, respectively. Overall, some concentrations of heavy metal (Cr & Cd) are higher than the safe limit. Hence, the soils studied indicate that vegetable cultivation in the area of study can lead to health and environmental problems. In terms of health and safety, soil pollution and toxicity, heavy metal sources are discussed.

Index Terms- Soil, Heavy metals, Soil Pollution

I. Introduction

Due to the availability of pollutants in the soil, soil contamination is natural and inorganic [2]. Contaminants from heavy metal soil cannot be biodegraded and would cause harm to the human body through the food chain bioaccumulation [2-8]. Arsenic (As), cadmium (Cd), lead (Pb), copper (Cu), nickel (Ni), chromium (Cr) and zinc (Zn) are heavy metals. An element's available concentration in the soil is an estimate of the fraction of that element that is present either as free ions, soluble complexes or in readily absorbable forms [9]. The maximum heavy metal content in the soil is the estimate of the concentrations of mineral-derived elements in the geological parent material on which the soil has formed and contributions from a wide range of potential sources of contamination. The causes of heavy metal contamination are the airborne absorption of aerosol particles (< 30 mm in diameter), raindrops containing heavy metals or gaseous types of elements, direct applications of agricultural fertilizers, agrichemicals and various organic materials like sewage sludge's, animal manures, food waste and compost [2, 9].

The level of concentration of heavy metals in the soil has an adverse effect on soil quality and biological functions. Heavy metals such as Lead (Pb) are largely insoluble heavy metal soil [10] , which can undergo a complex phosphate and carbonate reaction. When Pb is present in the soil, growth inhibition can affect the plant by inhibiting enzyme activity, changes in membrane permeability, and impaired photosynthesis [11, 12]. Plants and plants eaten by animals and humans will absorb Pb, which is a significant human health problem [13]. Cd occurs in agricultural fields, of course. In addition, the use of phosphate fertilizers and sewage sludge, dumping of mine spills or tailings, and industrial discharge are major causes of soil cadmium dispersion. Cd is a mobile component in soils that can be easily absorbed by roots and transported to shoots of plants [14]. High levels of Cd induce phytotoxicity by decreasing the absorption of nutrients, inhibiting photosynthesis, inducing lipid peroxidation, and altering the antioxidant process and membrane functioning [15]. Cd can be adsorbed from soil and water by plants. Excess consumption of Cd affects human health, can primarily cause kidney damage, and can cause adverse health effects on respiratory, cardiovascular, and musculoskeletal systems [10]. Global cancer research organizations have listed Chromium Cr (VI) as one of the human carcinogens [16]. Chromium (Cr) contamination is primarily caused by industry such as mining and smelting industries [17]. Cr is usually found in the forms of Cr (III) and Cr (VI) in the natural environment. Cr (III) can control insulin and blood glucose levels as one of the important trace elements of a mammal [18]. Cr (III) primarily exists in the form of Cr $(OH)_3$ or Cr_2O, and a complex can be easily produced and stable in the sediment. The toxicity of Cr (VI) is 100 times greater than that of Cr (III). Long-term human skin exposure to Cr (VI) wastewater is confirmed to be the cause of dermatitis and eczema. And Cr (VI) inhalation can cause sneezing, running nose, nosebleeds, ulcers, and even damage to the kidneys and liver. Cr(VI) is detrimental to the human circulatory system or even threatens human life in vital situations [19]. In water and soil, Cr (VI) was highly mobile [20].

Contamination with heavy metals is a major problem worldwide; the problem in a country like China is very serious. One-sixth of China's cultivated land was estimated to have been contaminated by heavy metals [21, 22]. According to the Ethiopian Public Health Institute, over 2,000 factories are based in the capital city of Ethiopia and about 90% of the industries spill untreated effluent into the river network [23]. The two main rivers are used for irrigation of urban farms and contribute about 60% [1, 24]. The present study showed that due to significantly rapid urban expansion, increased industrial activity, lack of sewage treatment, inadequate solid waste management and other economic development, some toxic and potentially toxic elements polluted the Addis Ababa City soil in various degrees [1, 23]. The objective of this research is to evaluate the level of heavy metals in wastewater irrigated agricultural land in Kolfe, Addis Ababa, Ethiopia

II. Materials and Methods

Description of the study area

Kolfe, the research study area is one of the sub-cities of Addis Ababa City. Addis Ababa is the capital city of Ethiopia. It is the country's administrative city and consists of 10 sub-cities [25]. Within the city are two major rivers namely, Tinshu (Little) and Tilku (Big) Akaki River at the eastern and western part of the city respectively. The total catchment area of Tinishu Akaki is about 540km2. It is along the courses of Little Akaki river that most of the manufacturing industries like tanneries, food and beverages, woodworks, textiles, pharmaceutical, wineries, battery and paints, rubber and plastic products, non-metal and metal products, paper and printing products are located. The industries most often discharge untreated wastewater into the river network and unfortunately, the river water is used for irrigation in five different vegetable farm areas including Burayu, Kolfea, Kera, Gofa and Akaki vegetable farms. The major vegetables under irrigation include, Swiss chard, lettuce, red beet, potato, cabbage, Ethiopian kale, salad, tomato, green paper, carrot and onion grow in these farm areas [1].

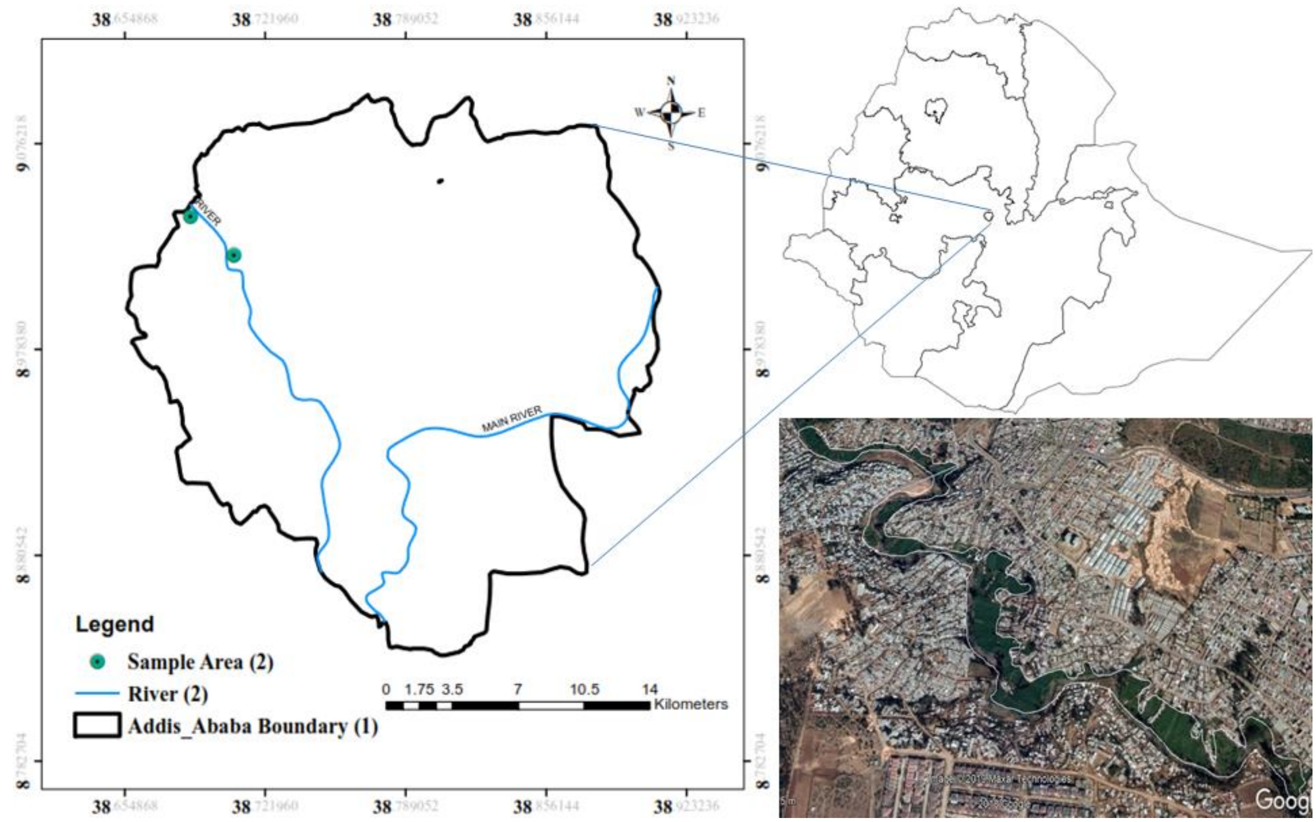

Figure 1Location of study area

Kolfe, is located in the western part of the capital city and has a total land area of 61.25sq.km, its population and population density are 546,219 and 7,448.5 square meters and has 15 Weredas. Kolfe farm is located in the Sub-city of Kolfe Keraneo City Administration, the upstream and south western direction of the Little Akaki River [25].

Sample collection and analysis

A sample site was selected based on wastewater irrigated vegetable farmland. This site was selected because previously report compared to other locations (based on observation and expert view). The selected site was further subdivided into a total of eight (8) sample sites; all which were wastewater irrigated vegetable farmland. The soil sample was collected in July 2019 (Wet season) from eight different vegetable farmlands; the farmland is used for cultivation of garlic, lettuce, carrot, and cabbage. The soil samples were collected from topsoil at the depths of 0–20 cm. The samples were air-dried for five days, ground with mortar and pestle, sieved to < 2 mm and homogenized sieve, sieved through 0.5 mm and then kept in clean polythene bags and coded for further soil characterization.

The soil samples were digested; 0.5 g of sample was mixed with 10 mL of Aqua-regia (3:1 of HCl: HNO_3), heated on a hot plate inside fume cupboard. The digested samples were filtered through Watchman filter paper; the filtrate was diluted with 50 mL of distilled water. The diluted samples were taken for heavy metal determination using Atomic Absorption Spectrophotometer (AAS).

Soil pollution indices

The geo-accumulation index (I-geo) and Contamination factor (CF) were employed to assess the pollution of metals in the soil of Kolfe area.

Geo-accumulation index: The geo-accumulation index (I_{geo}) introduced by Muller [26]. I_{geo} Index is used to assess metal pollution in sediments or soil. I_{geo} Can be calculated by Eq. (1)

$$I_{geo} = \log 2\left(\frac{C_n}{1.5 \times B_n}\right) \quad (1)$$

Where C_n = the concentration of heavy metal (n) in the soil, B_n = is the background value for heavy metal (n) and Factor 1.5 indicates the variation of background values for heavy metal in the environment [27, 28] The classes of soil pollution were identified in terms of I_{geo}, Unpolluted (I_{geo}< 0), unpolluted to moderately polluted (I_{geo}= 0∼1), moderately polluted (I_{geo}= 1∼2), moderately to strongly polluted (I_{geo}= 2∼3), heavily polluted (I_{geo}= 3∼4), strongly to extremely polluted (I_{geo}>5) [28-30].

Average contamination factor (CF): Contamination Factor is the ratio obtained by dividing the concentration of a specific heavy metal in the soil sample by the background value of that metal. It can be calculated by Eq. (2)

$$CF \frac{C_m}{C_b} \quad (2)$$

Where, C_m is the concentration of heavy metals in soils sample, C_b is the reference of background value for heavy metals (permissible limit), the value of C_b can be measured either in precivilization soil or sediments of the study area or taken from the literature and the value of C_b for Cr, Cd and Pb was considered as 100, 0.8 and 80 mg kg^{-1}, respectively [31, 32]. Table 1. Shows different categories of soil contamination class in terms of CF.

Table 1.Classification based on contamination factor (CF) [31]

CFs Value Scale	Classification
≤1	Uncontaminated soil
1-2.0	Suspected
2-3.5	Slight
3.5-8	Moderate
8-27.0	Severe
≥ 27	Extremely

III. Statistical Analysis

The levels of different heavy metals in the soil were measured using a one-way analysis of ANOVA. Furthermore, Pearson correlation was used to determine the heavy metals inter-element relationship in the soil. The mean and standard deviations of metal concentrations, CF and I_{geo} in the soil were calculated. Data and Figure were analysed using OriginPro and SPSS software.

IV. Results and Discussion

Results

The soil heavy metal content in the soil samples is shown in Table 1 and Figure 2. Figure 3 indicates the average heavy metal concentration of the three heavy metals. Results are expressed as a mean and standard sample deviation.

Table 2 Concentration of Heavy Metals at Different Sample Site

Sample Name	Co-ordination		Metal concentration mg kg^{-1}			
	Latitude	Longitude	Cr	Cd	Pb	pH
1	09°02' 40" N	038°41'26" E	329.32	1.11	27.21	7.18
2	09°02' 15" N	038°41'47" E	312.71	3.14	32.12	7.28
3	09°02' 37" N	038°41'39" E	322.51	3.92	39.64	7.29
4	09°02' 08" N	038°42'01" E	271.01	2.99	10.11	7.18
5	09°02' 22" N	038°41'46" E	312.23	1.18	21.34	7.15
6	09°02' 16" N	038°41'46" E	297.45	3.22	34.02	7.23
7	09°02' 11" N	038°41'49" E	189.12	4.18	41.01	6.91
8	09°02' 12" N	038°41'56" E	164.32	5.01	33.23	7.11
Mean ± SD			274.83-63.42	3.09-1.37	29.83-10.16	7.16-0.12
Range			164.32-329.32	1.11-5.01	10.11-41.01	6.91-7.29
Safe limit			100	0.8	80	

The average amounts of the three heavy metals were Cr > Cd > Pb. Figure 2 indicates the distribution of heavy metal in the eight areas.

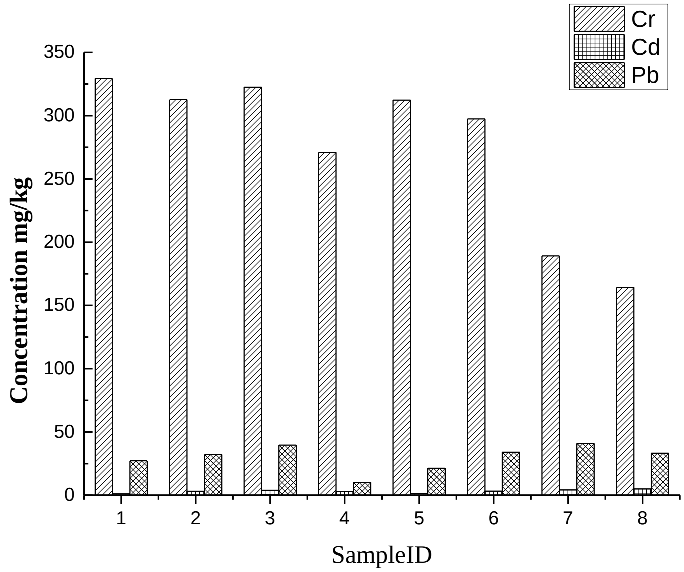

Figure 2.Heavy metals concentration in different sample areas

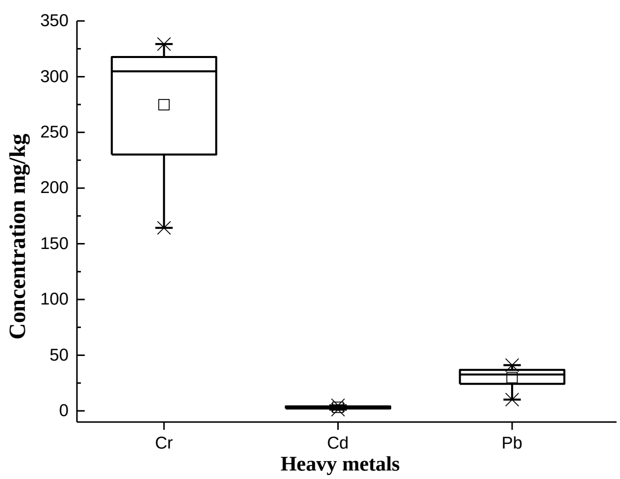

Figure 3 Concentration of the three heavy metals

The findings in Table 2 and Figure 2 indicate that the concentration of the two heavy metals in sample sites 1 and 3 reached the healthy chromium and cadmium limits. Perhaps the highest concentration of Cr is due to wastewater irrigation; waste from Burayu, Winget, and Asko tannery and other industries. The other sample site for heavy metal concentration Cd, Cd, and Pb were lower than FAO / WHO's safe level.

The average contamination factor (CF); shows contamination of soil with heavy metals. Table 3 shows the average values of the soil sample for heavy metal contamination variable. The mean CF values of heavy metal followed the declining order of Pb > Cr > Cd.

Table 3 Average contamination factor (CF) of heavy metals pollution in the soil sample sites

Sample ID	Cr	Cd	Pb
1	3.2932	1.3875	0.340125
2	3.1271	3.925	0.4015
3	3.2251	4.9	0.4955
4	2.7101	3.7375	0.126375
5	3.1223	1.475	0.26675

6	2.9745	4.025	0.42525
7	1.8912	5.225	0.512625
8	1.6432	6.2625	0.415375
Mean±SD	2.748 ± 0.634	3.867 ± 1.713	0.372 ± 0.127

Average geo-accumulation index (I_{geo});

measures the contamination level of soil with different heavy metals[30]. The I_{geo} values of the eight sample sites were shown in Table 4. The mean values of I_{geo} for heavy metals followed the decreasing order of Cd > Cr > Pb

Table 4 Average geo-accumulation index (I_{geo}) of heavy metals pollution in the soil of the eight sites

Sample ID	Cr	Cd	Pb
1	0.66090132	0.27845275	0.068258552
2	0.62756727	0.78769516	0.080575696
3	0.64723456	0.98336465	0.099440242
4	0.54388093	0.75006641	0.025361777
5	0.62660397	0.29601283	0.053533168
6	0.59694248	0.80776382	0.085342004
7	0.37953862	1.04858782	0.102877001
8	0.32976833	1.25680023	0.083360223
Mean ± SD	0.551 ± 0.127	0.776 ± 0.343	0.074 ± 0.025

Table 5 Comparison of heavy metal concentration (mg kg^{-1}) of this study and other authors

Country	Pb	Cr	Cd	Reference
Nigeria	29.67	51.83	1.82	[33]
China	42.89	69.64	0.20	[34]
Colombia	0.071	-	0.040	[35]
Macedonia	17.15	38.21	0.60	[36]
Ethiopia (Kolfe)	18.35	234.23	0.13	[1]
This study	29.83	274.83	3.09	This study
Safe limit	0.8	100	80	[32]

V. Discussions

The contamination factors of metals in all sample sits are shown in Table 4. The contamination factors of Cr were between 1.6432 and 3.2932, indicating slight contamination, cadmium contamination factor were moderate and Pb shows no contamination.

Table 6 Contamination level of all samples site

Sample ID	Cr	CF	Cd	CF	Pb	CF
1	3.2932	Slight	1.3875	Suspected	0.340125	Uncontaminated
2	3.1271	Slight	3.925	Moderate	0.4015	Uncontaminated
3	3.2251	Slight	4.9	Moderate	0.4955	Uncontaminated
4	2.7101	Slight	3.7375	Moderate	0.126375	Uncontaminated
5	3.1223	Slight	1.475	Suspected	0.26675	Uncontaminated
6	2.9745	Slight	4.025	Moderate	0.42525	Uncontaminated
7	1.8912	Suspected	5.225	Moderate	0.512625	Uncontaminated
8	1.6432	Suspected	6.2625	Moderate	0.415375	Uncontaminated

Mean±SD	2.748 ± 0.634	Slight	3.867 ± 1.713	Moderate	0.372 ± 0.127	Uncontaminated

CF-contamination factor

Geo-Accumulation Index in Kolfe farm area, the soil was polluted by Cd and Cr. The geo-accumulation index value of Cr was less than 1; the value shows unpolluted to moderately pollution. Cadmium was also unpolluted to moderately polluted, but in sample site 7 and 8 the pollution was moderate. No pollution by Lead. I_{geo} No pollution to slight pollution of all soil samples. The ANOVA sample analysis presented in Table 7.

Table 7 Pearson correlation and ANOVA analysis of heavy metals in the soil samples

Pearson correlation	*Cr*	*Cd*	*Pb*
Cr	*1*		
Cd	*-0.72296*	*1*	
Pb	*-0.23699*	*0.521556*	1
ANOVA			
P value	*0.1146*	*0.973*	0.902

Heavy Metals

Chromium (Cr): The average chromium concentrations found in the study area were higher than the recommended limit [32]. The high concentration of chromium in the sample site indicated the high availability of Cr in the vegetable farming area for plant uptake.

Cadmium (Cd): The mean Cd concentration results in the study area were between (1.11-5.01 mg kg^{-1}). The concentration of Cd contained in all test sites exceeded the permissible limits (WHO 1996). The high cadmium level may be due to phosphate fertilizers being used. Cadmium concentrations obtained in this sample were higher than the appropriate soil limit of 0.8 mg kg^{-1} [32].

Lead (Pb): Pb levels ranged from 10.11 to 41.01 mg kg^{-1}. In this study site, the average concentration of Pb was generally lower than the safe limits set in soil by [32]. Accumulation of lead may have been due to the use of some chemicals and manufacturing activities.

One-way analysis of variance (ANOVA) was made at 95% confidence level. The results showed that there were significant differences ($p < 0.05$) in the concentrations of the heavy metals Cr, Cd and Pb among the analysed soil samples while there was no significant difference ($p > 0.05$) in the concentrations of Pb. In general, the mean concentration of heavy metals in soils collected from all sampling site decreased in the order of Cr > Pb > Cd.

VI. Conclusion

Following the collected sample analysis the concentrations of heavy metals in soil samples used for cultivation of vegetable including Swiss chard, lettuce, red beet, potato, cabbage, Ethiopian kale, salad, tomato, green paper, carrot and onion Cabbage, Onion, lettuce, Habsha Gomen & carrot area of Kolfe farm were determined. The analysis indicated that the soils serve as the potential source of the heavy metals in the environment and the concentration of the heavy metals Pb in all sample site are far below the maximum tolerable levels set by FAO/WHO however, the values of Cr and Cd were higher than maximum tolerable levels set by the country. In general, the results also show that the level of contamination of the soils by the heavy metals is moderately contaminated at present and the soil is polluted by toxic heavy metals (Cd and Pb). On the other hand however, the increase in concentration of some elemental may be due to long-term wastewater irrigation, application of various types of pesticides and fertilizer in the vegetable farming areas. Further research is needed to analyse the contamination level of heavy metals in the vegetables and recommend proper soil and wastewater remediation method to solve the current situation.

References

[1] M. Aschale, Y. Sileshi, M. Kelly-Quinn, and D. Hailu, "Pollution assessment of toxic and potentially toxic elements in agricultural soils of the city Addis Ababa, Ethiopia," Bulletin of environmental contamination and toxicology, vol. 98, no. 2, pp. 234-243, 2017. [Online]. Available: https://link.springer.com/content/pdf/10.1007%2Fs00128-016-1975-4.pdf.

[2] S. Chaoua, S. Boussaa, A. El Gharmali, and A. Boumezzough, "Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco," Journal of the Saudi Society of Agricultural Sciences, vol. 18, no. 4, pp. 429-436, 2019.

[3] W. Addis and A. Abebaw, "Determination of heavy metal concentration in soils used for cultivation of Allium sativum L.(garlic) in East Gojjam Zone, Amhara Region, Ethiopia," Cogent Chemistry, vol. 3, no. 1, p. 1419422, 2017.

[4] X. Gong et al., "Stabilized nanoscale zerovalent iron mediated cadmium accumulation and oxidative damage of Boehmeria nivea (L.) Gaudich cultivated in cadmium contaminated sediments," Environmental science & technology, vol. 51, no. 19, pp. 11308-11316, 2017.

[5] W. Xue et al., "Nanoscale zero-valent iron coated with rhamnolipid as an effective stabilizer for immobilization of Cd and Pb in river sediments," Journal of hazardous materials, vol. 341, pp. 381-389, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0304389417304491?via%3Dihub.

[6] S. Khan, S. Rehman, A. Z. Khan, M. A. Khan, and M. T. Shah, "Soil and vegetables enrichment with heavy metals from geological sources in Gilgit, northern Pakistan," Ecotoxicology and environmental safety, vol. 73, no. 7, pp. 1820-1827, 2010.

[7] S. Muhammad, M. T. Shah, and S. Khan, "Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan," Microchemical journal, vol. 98, no. 2, pp. 334-343, 2011.

[8] J. Steffan, E. Brevik, L. Burgess, and A. Cerdà, "The effect of soil on human health: an overview," European journal of soil science, vol. 69, no. 1, pp. 159-171, 2018.

[9] B. J. Alloway, "Sources of heavy metals and metalloids in soils," in Heavy metals in soils: Springer, 2013, pp. 11-50.

[10] S. Satarug, "Dietary cadmium intake and its effects on kidneys," Toxics, vol. 6, no. 1, p. 15, 2018.

[11] B. Pourrut, M. Shahid, C. Dumat, P. Winterton, and E. Pinelli, "Lead uptake, toxicity, and detoxification in plants," in Reviews of Environmental Contamination and Toxicology Volume 213: Springer, 2011, pp. 113-136.

[12] J. Meng, M. Tao, L. Wang, X. Liu, and J. Xu, "Changes in heavy metal bioavailability and speciation from a Pb-Zn mining soil amended with biochars from co-pyrolysis of rice straw and swine manure," Science of the Total Environment, vol. 633, pp. 300-307, 2018.

[13] R. A. Wuana and F. E. Okieimen, "Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation," Isrn Ecology, vol. 2011, 2011.

[14] H. Yu et al., "Biochar amendment improves crop production in problem soils: a review," Journal of environmental management, vol. 232, pp. 8-21, 2019.

[15] M. Groppa, E. Rosales, M. Iannone, and M. Benavides, "Nitric oxide, polyamines and Cd-induced phytotoxicity in wheat roots," Phytochemistry, vol. 69, no. 14, pp. 2609-2615, 2008. [Online]. Available: Error! Hyperlink reference not valid..

[16] R. P. Farrell, R. J. Judd, P. A. Lay, N. E. Dixon, R. S. Baker, and A. M. Bonin, "Chromium (V)-induced cleavage of DNA: are chromium (V) complexes the active carcinogens in chromium (VI)-induced cancers?," Chemical research in toxicology, vol. 2, no. 4, pp. 227-229, 1989.

[17] M. Knott, "Toxic tannery sludge made as safe as houses," ed: NEW SCIENTIST PUBL EXPEDITING INC 200 MEACHAM AVE, ELMONT, NY 11003, 1996.

[18] Y. Xu and D. Zhao, "Reductive immobilization of chromate in water and soil using stabilized iron nanoparticles," Water research, vol. 41, no. 10, pp. 2101-2108, 2007. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0043135407001315?via%3Dihub

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