J Bangladesh Agril Univ 17(3): 288–294, 2019 https://doi.org/10.3329/jbau.v17i3.43198

ISSN 1810-3030 (Print) 2408-8684 (Online)

Journal of Bangladesh Agricultural University

Journal home page: http://baures.bau.edu.bd/jbau, www.banglajol.info/index.php/JBAU

Heavy metal accumulation in tomato and cabbage grown in some industrially contaminated soils of Bangladesh

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ARTICLE INFO

Article history:
Received: 09 February 2019
Accepted: 20 July 2019
Published: 30 September 2019

Keywords:
Heavy metal,
Contaminated soil,
Tomato,
Cabbage,
Transfer factor

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ABSTRACT

Heavy metal accumulation in environmental compartments is a potential risk to the living system because of their uptake by plants and subsequent introduction into the food chain. A study was carried out to investigate the heavy metal contents in industrially contaminated soils collected from six different locations of Dhaka and Mymensingh districts and their effects on two important vegetables namely tomato and cabbage. Pot experiment was conducted using contaminated soils at the net house of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh following completely randomized design (CRD) with three replicates. The higher level of heavy metal contents was found in the soil samples of Hajaribag and Dhaka Export Processing Zone (DEPZ). The highest Ni, Cd, Cr, Cu and Fe contents were 59.45, 18.79, 67.57, 40.81 and 1619.61 µg g^{-1} which were much above the recommended level except Cu contents. The highest yield of vegetables was obtained grown in Maskanda soil of Mymensingh district and the lowest from DEPZ soil of Dhaka. The highest Ni, Cr and Fe contents were 8.91, 7.22, 419.65 µg g^{-1}, respectively in tomato fruits grown in the soil of Hajaribag whereas the highest Cu content (3.38 µg g^{-1}) was obtained from Seedstore soil, Mymensingh and highest Cd content (2.88 µg g^{-1}) was from Mitford ghat soil, Dhaka. In cabbage, the highest Ni (17.52 µg g^{-1}) and Fe (411.25 µg g^{-1}) contents were found in the soils of DEPZ whereas the highest Cr (9.17 µg g^{-1}), Cd (3.52 µg g^{-1}) and Cu (8.51 µg g^{-1}) were obtained in the plants grown in the soils of Hajaribag, Mitford ghat and Maskanda, respectively. Concentrations of all the tested heavy metals except Cu in both vegetables were above the maximum allowable limit prescribed by the World Health Organization. Among the metals, the accumulation of Ni was found as higher amount (0.39 and 0.71 for tomato and cabbage, respectively) based on plant concentration factor or transfer factor. The results showed a positive correlation between concentration of the metals present in soils and in vegetables and the highest correlation was found with Cr in tomato and Fe in cabbage. However, both the soils and grown vegetables were consistently observed to pose a risk to human health. So, it can be recommended that government should take necessary action so that heavy metals used in the industries cannot come into the nearby agricultural field to ensure food safety as well as food security.

Introduction

Different contaminants are widely distributed in environmental compartments, and among them heavy metals are of particular concern due to their toxic effects and potentiality to bio-accumulate in the ecosystems (Censi *et al.*, 2006). Heavy metal has drawn much attention to the environmental scientist as it affects different properties of soil and water and even the growth of the plants. The heavy metal contamination risks to human body by the consumption of food plants grown in metal-contaminated soils (Gomes *et al.*, 2016; Cambra *et al.*, 1999). The most important reasons for the elevation of the heavy metals in the developing countries are the rapid and unorganized industrialization and urbanization (Khan *et al.*, 2008). Industrially contaminated soil often contains high concentrations of heavy metals, including cadmium (Cd), copper (Cu), chromium (Cr), zinc (Zn), iron (Fe) arsenic (As), mercury (Hg) and lead (Pb). Accumulation of heavy metals in crop plants depends upon some factors like plant species, soil properties and the efficiency of different plants in absorbing metals which can be studied by either plant uptake or soil−to−plant transfer factors (Rattan *et al.*, 2005). The metals can be deposited on the parts of the plants especially vegetables, exposed to the air, from the

Cite this article

Chowdhury, M.A.H., Chowdhury, T. and Rahman, M.A. 2019. Heavy metal accumulation in tomato and cabbage grown in some industrially contaminated soils of Bangladesh. *Journal of Bangladesh Agricultural University*, 17(3): 288–294. https://doi.org/10.3329/jbau.v17i3.43198

polluted environment as well as from contaminated soils and then absorbed into the leaf tissues because of their non−biodegradable and persistent criteria (Sharma *et al*., 2008; Kachenko and Singh, 2006; Singh and Kumar, 2006; Al-Jassir *et al*., 2005).

Vegetables constitute an important part of the human diet since they contain carbohydrates, proteins, vitamins, minerals and fibers required for human health (Arai, 2002). They also act as neutralizing agents for acidic substances formed during digestion (Thompson and Kelly, 1990). As human activities increase, especially with the application of modern technologies, pollution and contamination of the human food chain has become inevitable. These elements, at concentrations exceeding the physiological demand of vegetables, not only could administer toxic effect in them but also could enter into the food chains by the consumption, get biomagnified and pose a potential threat to human health as well as animals (Sharma *et al*., 2008). Though the consumption of vegetable and fruit is the primary pathway of human exposure to heavy metals, the accumulation of metals in the edible parts of the vegetables is relatively easier and higher than grain or fruit crops (Boamponsem *et al*., 2012; Arora *et al*., 2008; Eslami *et al*., 2007; Mapanda *et al*., 2005; Adamsa *et al*., 2004). Vegetable plants uptake and accumulate higher amount of metals when they are grown in contaminated soils compare to those grown in normal soils (Al-Jassir *et al*., 2005).

Population subgroups living on and consuming vegetables grown on large urban industrial sites might be attacked by a number of diseases, especially cardiovascular, renal, neurological, and bone diseases by causing effects to the liver, kidneys and nervous system, sometimes having carcinogenic and teratogenic effects. Heavy metals uptake by plants grown in polluted soils or polluted areas have been studied to a considerable extent around the world showing the metals as important contaminants (Aktaruzzaman *et al*., 2013; Suruchi and Khanna, 2011; Odai *et al*., 2008; Sinha *et al*., 2006). Heavy metal uptake by vegetables is likely to be higher and recently bioaccumulation of the metals in human body parts created a growing concern by affecting neurological function and mentality (Farahat *et al*., 2017; Arora *et al*., 2008). Information regarding the accumulation of heavy metals in vegetables grown in industrially polluted soils of Bangladesh is very limited. But it is urgent to have some of such information for the production of quality vegetables as well as healthy foodstuffs.

Therefore, the current investigation was designed to provide an idea about the extent of pollution particularly the heavy metals of industrially contaminated soils and their consequences on the yield and contamination of vegetable crops which in turn may threaten the health of the people living inside or outside the industrial areas of Bangladesh.

Materials and Methods

Experimental site

The pot experiment was conducted at the Net House of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. The period of the total experiment including soil collection, preparation, growing of vegetables and post-harvest chemical analysis was performed during September 2015 to June 2016.

Collection and preparation of experimental soils for pot experiment

Contaminated soils from six different industrial sites of Dhaka and Mymensingh districts were collected at a depth of 15cm for the pot experiment (Table 1). The specific global positioning system (GPS) cannot be published due to the privacy of the industries. Soils were collected, cleaned, air dried, ground, sieved using 2mm sieve and labeled carefully. Ten kgs of processed soil was taken in each plastic pot. About 500g of each soil was preserved in polyethylene bag for laboratory analyses.

Table 1. Soil sampling locations

Sampling locations	Type of industrial waste mixed with soil
Maskanda, Mymensingh	Plastic wastes
Bhaluka Sadar, Mymensingh	Washing wastes
Seedstore, Mymensingh	Dying wastes
Mitford ghat, Dhaka	Hospital wastes
Hajaribag, Dhaka	Tannery wastes
DEPZ, Savar, Dhaka	Mixed wastes

DEPZ= Dhaka Export Processing Zone

Test crop and experimental design

The seedlings of tomato (*cv.* BINA Tomato 12) and cabbage (*cv.* Atlas 70) were collected from Horticultural Farm of Bangladesh Agricultural University, Mymensingh, Bangladesh. Total 36 experimental pots were used having six treatments and three replicates of each vegetable. The experiment was designed following completely randomized design (CRD).

Determination of heavy metal of soil samples and vegetables

Soil samples previously stored for laboratory analyses were spread on plastic trays, dried at ambient temperature for 8 days. Then the samples were ground with a ceramic coated grinder and sieved. Approximately 5.0 g samples were taken and were digested with aqua regia (conc. HCl and conc. HNO_3 at a ratio of 3:1) following standard procedure (Page *et al*., 1982). After collection of tomato fruits and cabbage, they were ground following by drying to prepare extract in wet oxidation method. Samples were digested with di-acid mixture (conc. HNO_3 and 60%

$HClO_4$ at a ratio of 2:1) described by Singh *et al*. (1999). Heavy metal contents (Ni, Cr, Cd, Cu and Fe) of soil samples and vegetables were determined by atomic absorption spectrophotometer (SHIMADZU AA-7000) using flame emission in the Soil Science Division, Bangladesh Agricultural Research Institute (BARI), Joydevpur, Gazipur and Soil Resource Development Institute (SRDI), Farmgate, Dhaka.

Determination of plant concentration factors (PCF) or Transfer Factors (TF)

Plant concentration factor (PCF) or Transfer Factor (TF) is the ratio of the heavy metal concentration in the plant to the total heavy metal concentration in the soil at the growing site (Harrison and Chirgawi, 1989; Smith, 1996). It indicates the quantity of heavy metals present in the soil that transferred to the crop and considered as one of the key components of human exposure to heavy metals through the food chain. PCF or TF was calculated as follows (Kachenko and Singh, 2006).

$$\text{PCF or TF} = C_{vegetable}/C_{soil}$$

where, $C_{vegetable}$ is the total concentration of a particular heavy metal in the vegetable (µg g^{-1} dry weight), and C_{soil} is the corresponding heavy metal concentration in the soil habitat of the vegetable (µg g^{-1} soil).

Statistical analysis

The data were statistically analyzed using SPSS 20.0 (SPSS Inc., Chicago 2, USA). The principle of F-statistics was followed for analysis of variance (ANOVA) and the separation of mean values was done by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

Results and Discussion

Heavy metal contents in contaminated soils

Heavy metal contents of different industrially contaminated soils of Dhaka and Mymensingh districts varied significantly (Table 2). The highest Ni content was obtained from the contaminated soils of DEPZ (59.45 µg g^{-1}) followed by Hajaribag (54.17 µg g^{-1}) and the lowest content was from Maskanda soil (15.28 µg g^{-1}). Data revealed that the Ni concentration of most of the soil samples were lower than the standard values proposed by European Union Standards (EU, 2002), Environmental quality standard for soils (SEPA, 1995) and Indian Standard (Awashthi, 2000). The soil samples of Hajaribag and DEPZ were almost near the standard limits which may cross the limit in near future because of their continuous accumulation to the soil system. The Cr contents ranged from 14.62 to 67.57 µg g^{-1}. The highest Cr content was found in the Hajaribag soil followed by DEPZ soil (39.67 µg g^{-1}) and the lowest from Bhaluka Sadar soil (14.62 µg g^{-1}). Previous reports recorded the soil Cr content (4.55−33.46 µg g^{-1}) alongside of Dhaka-Aricha Road (Aktaruzzaman *et al*., 2013), 21.51 µg g^{-1} in Ado Ekiti, Southwestern Nigeria (Aruleba and Ajayi, 2012), 54.88 µg g^{-1} in urban soil of Hongkong (Li *et al*., 2001) and 159.3 µg g^{-1} in urban soils of China (Shi *et al*., 2008). The recorded values of Cr concentration were lower than the standard limits (Table 2). The highest mean concentration of Cd was found in the soil of Hajaribag (18.79 µg g^{-1} soil) which was significantly different from others and the lowest from Maskanda soil (3.22 µg g^{-1} soil). The Cd concentration in collected soils was much higher than the recommended average concentration in normal soil ranges between 0.01 to 2.00 µg g^{-1} (Adriano, 2001). Industrial soils were much polluted containing very high level of Cd concentration.

Table 2. Heavy metal contents of some industrially contaminated soils of Mymensingh and Dhaka districts.

	Heavy metal content (µg g^{-1} soil)				
	Ni	Cr	Cd	Cu	Fe
Study soils					
Maskanda	15.28f	17.34d	3.22e	28.92c	719.61f
Bhaluka sadar	21.19e	14.62e	5.13d	34.93b	911.66be
Seedstore	27.56d	22.41cd	4.77de	40.81a	1108.12d
Mitford ghat	41.57c	25.62c	11.46c	13.11e	1619.61a
Hajaribag	54.17b	67.57a	18.79a	19.21d	1482.21b
DEPZ	59.45a	39.67b	13.21b	12.78e	1237.33c
Reference values					
European Union Standards (EU, 2002)	75	150	3	140	-
Environmental quality standard for soils (SEPA, 1995)	60	250	0.6	100	-
Indian Standard (Awashthi, 2000)	75-150	-	3-6	135-270	-
SE	2.43	3.14	1.87	2.81	32.62
CV (%)	5.51	7.82	2.37	6.56	17.89

Means within the same column followed by the different letter(s) were significantly different according to DMRT, SE= Standard Error of the Mean; CV= Coefficient of variance.

According to the standards of European Union (2002), SEPA (1995) and Awashthi (2000), all the collected industrial soils were much polluted. Almost similar result of Cd content in different soil samples was found by Aktaruzzaman *et al*. (2013) who found the range as 1.01−7.83 µg g^{-1} Cd. Previous reports on Cd contents in soil was found as 0.50−2.90 µg g^{-1} (Mapanda *et al*., 2005), 0.05−0.87 µg g^{-1} (Mohamed *et al*., 2003), and 0.34−0.58 µg g^{-1} (Wong *et al*., 2002), which were lower enough from those obtained in different contaminated soils of Dhaka and Mymensingh districts. The concentrations of Cu and Fe also varied significantly across the sampling locations. The highest Cu (40.81 µg g^{-1}) and Fe (1619.61 µg g^{-1}) contents were found in the soils of Seedstore, Mymensingh and Mitford ghat, Dhaka, respectively. The average Cu content of arable soils contain between 1−50 µg g^{-1} (Alloway, 1990). Barman and Lal (1994) conducted an experiment in industrially polluted field soils and reported that the Cu and Cd concentration of the soil samples were 41.50 and 6.11 µg g^{-1} soils, respectively.

Yield of tomato and cabbage grown in contaminated soils

Yield of tomato and cabbage grown in some industrially contaminated soils of Mymensingh and Dhaka districts varied significantly (Figure 1 and 2). The highest yield of both the vegetables was obtained from Maskanda soil of Mymensingh and the lowest yield was observed in DEPZ soil. The highest yield of tomato fruit (1.07 kg pot^{-1}) was identical with yield obtained from the soil of Bhaluka sadar (0.93 kg pot^{-1}) and the lowest yield from DEPZ (0.37 kg pot^{-1}) followed by Hajaribag soil (0.40 kg pot^{-1}). Almost same trend was found for cabbage yield grown in the soils of Dhaka and Mymensingh districts. The highest cabbage yield was 1.54 kg pot^{-1} obtained from Maskanda soil and the lowest was 0.72 kg pot^{-1} from Hajaribag soil, Dhaka. Dhaka soil consistently produced lower yield of both the vegetables compared to Mymensigh soil. It might be due to the fact that Dhaka soil was more polluted by heavy metals in comparison to Mymensingh soil.

Heavy metal contents in tomato and cabbage

The heavy metal contents in tomato and cabbage grown in different industrially contaminated soils of Dhaka and Mymensingh districts have been presented in Table 3. Soils collected from different locations of both the districts significantly influenced the heavy metal concentrations of tomato. The highest contents of Ni, Cr, and Fe were 8.91, 7.22, 419.65 µg g^{-1}, respectively recorded in the plants grown in the soils of Hajaribag, Dhaka whereas the highest Cu content (3.38 µg g^{-1}) was obtained from Seedstore soil of Mymensingh. The highest Cd content (2.88 µg g^{-1}) was from obtained from the plants grown in Mitford soil. The lowest Ni and Cr content were found from the vegetable grown in Seed store soil. In contrast, the lowest Cd and Fe contents were obtained from the plant of Maskanda soil, Mymensingh. The lowest Cu content was found in the plant grown in Bhaluka sadar soil.

Soils collected from different locations of both districts significantly influenced the heavy metal contents of cabbage. The highest Ni (17.52 µg g^{-1}) and Fe (411.25 µg g^{-1}) contents was found in the plants grown in the soils of DEPZ where as the highest Cr (9.17 µg g^{-1}) content were obtained in the plants grown in Hajaribag soil of Dhaka. The highest Cd (3.52 µg g^{-1}) and Cu (8.51 µg g^{-1}) contents were obtained from the plants grown in the soils of Mitford ghat and Maskanda soils, respectively. The lowest Ni, Cr, Cd and Fe contents were observed in the plants grown in Maskanda soil.

Table 3. Heavy metal contents of tomato and cabbage grown in industrially contaminated soils of Mymensingh and Dhaka area

Sample location	Heavy metal content (µg g^{-1} dry weight) in vegetables									
	Tomato					Cabbage				
	Ni	Cr	Cd	Cu	Fe	Ni	Cr	Cd	Cu	Fe
Maskanda	5.89d	2.63d	0.62c	3.26a	110.33e	10.89d	3.59d	0.91d	8.51a	118.42e
Bhaluka sadar	4.56e	3.43c	1.39bc	1.77b	214.82d	12.56c	4.92cd	1.79c	5.42b	193.47d
Seedstore	4.11e	2.14d	0.80 c	3.38a	319.69cd	14.11b	5.56c	1.12cd	3.23cd	248.52c
Mitford ghat	6.72c	4.99bc	2.88a	2.67ab	333.45c	16.72ab	5.49c	3.52a	2.89d	381.72b
Hajaribag	8.91a	7.22a	1.56b	1.78b	419.65a	13.91bc	9.17a	2.33b	3.39c	399.83a
DEPZ	7.52b	5.79b	0.94c	2.91a	381.56b	17.52a	7.52b	2.48ab	4.77bc	411.25a
MAL*	0.3	2.3	0.2	10.0	5.0	0.3	2.3	0.2	10.0	5.0
SE	1.14	1.37	0.71	0.57	35.32	2.11	1.26	0.82	1.09	27.53
CV (%)	2.45	3.23	2.62	1.42	16.26	3.32	2.46	1.97	2.11	14.12

*Maximum Allowable limit by WHO (Lone *et al*., 2003); Means within the same column followed by the different letter(s) were significantly different according to DMRT, SE= Standard Error of the Mean; CV= Coefficient of variance.

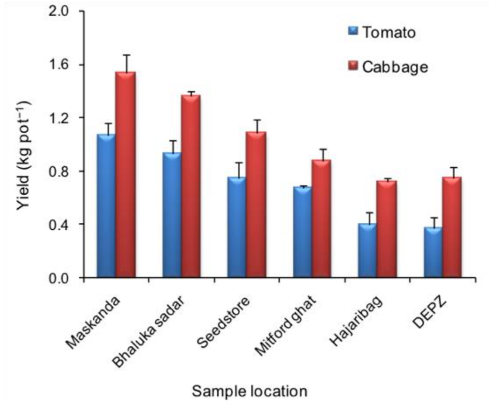

Fig. 1 Yield of tomato and cabbage grown in some industrially contaminated soils of Mymensingh and Dhaka districts. The error bars indicate the standard error of means

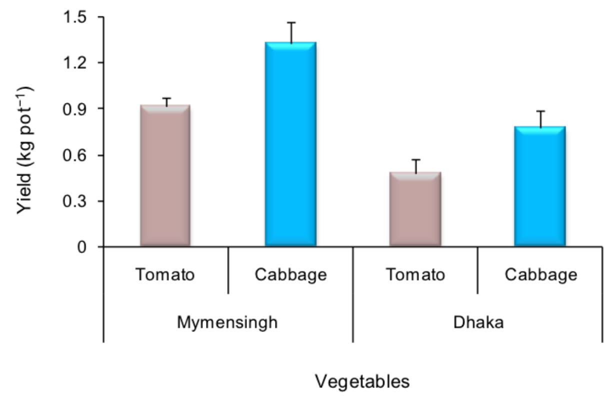

Fig. 2 Comparative yield of tomato and cabbage grown in contaminated soils of Mymensingh and Dhaka districts. The error bars indicate the standard error of means

Table 4. Plant concentration factor (PCF) of heavy metals from soil to tomato and cabbage.

Sample location	PCF or TF									
	Tomato					Cabbage				
	Ni	Cr	Cd	Cu	Fe	Ni	Cr	Cd	Cu	Fe
Maskanda	0.39	0.15	0.19	0.11	0.15	0.71	0.21	0.28	0.29	0.16
Bhaluka sadar	0.22	0.23	0.27	0.05	0.24	0.59	0.34	0.35	0.16	0.21
Seedstore	0.15	0.10	0.17	0.08	0.29	0.51	0.25	0.23	0.08	0.22
Mitford ghat	0.16	0.19	0.25	0.20	0.21	0.40	0.21	0.31	0.22	0.24
Hajaribag	0.16	0.11	0.08	0.09	0.28	0.26	0.14	0.12	0.18	0.27
DEPZ	0.13	0.15	0.07	0.23	0.31	0.29	0.19	0.19	0.37	0.33
Mean	0.20	0.15	0.17	0.13	0.25	0.46	0.22	0.25	0.22	0.24

Table 5. Correlations between heavy metal contents in soils and vegetables

Vegetables	Heavy metals				
	Ni	Cr	Cd	Cu	Fe
Tomato	0.827*	0.913**	0.582ns	0.694ns	0.819*
Cabbage	0.892*	0.876*	0.715ns	0.681ns	0.902**

* and **= Significant at 5% and 1% level of probability, ns= non significant

On the other hand, the lowest Cu content was found in the plants grown in Mitford soil. Except Cu, all the heavy metals were above the maximum allowable limit prescribed by World Health Organization (Lone *et al*., 2003). In another study of Ndibukke and Egbe (2018), the concentration of Ni was found as 0.102 mg kg^{-1} in cabbage which was lower than the present study. Aktaruzzaman *et al*. (2013) found the contents of Cr, Cd, Cu ranging between 1.17−3.83; 0.180−2.305; 0.26−3.53 mg kg^{-1}; and order were: Cr>Cu>Cd. The concentrations of heavy metals in tomatoes in Saudi Arabia were 0.77 mg kg^{-1} for Cd, 4.47 mg kg^{-1} for Cu (Mohamed *et al*., 2003). Numerous studies have also suggested that plants grown in polluted areas have higher concentrations of heavy metals than those grown in non−polluted soils (Arora *et al*., 2008; Alam *et al*., 2003).

Plant concentration factor (PCF) or Transfer Factor (TF)

Plant Concentration Factor (PCF) or Transfer Factor (TF) is a parameter used to describe the transfer of trace elements from soil to plant body. In this study, PCF of TF of different heavy metals from soil to vegetables was calculated as the ratio between the concentrations of heavy metals in vegetables with their respective concentrations in soils which has been presented in Table 4. The highest PCF values of 0.39, 0.27, 0.23, 0.23 and 0.31 were found for Ni, Cd, Cr, Cu and Fe, respectively in tomato grown in different soils of Dhaka and Mymensingh. In contrast, the highest PCF values of Ni, Cd, Cr, Cu and Fe were 0.71, 0.35, 0.34, 0.37 and 0.33, respectively in cabbage. Higher TF was obtained for those metals *i.e.*, having higher mobility and low retention in the soil supported by previous reports (Alam *et al*., 2003; Lokeshwari and Chandrappa, 2006).

This finding was in line with Aktaruzzaman *et al*. (2013) who found TF or PCF value in vegetables samples ranging between Cd 0.03−1.1, Cr 0.06−0.32 and Cu 0.03−0.53 having the order: Cd>Cu>Cr. The properties of the soil and of vegetable species are influenced by the mobility of metals from soil to plants and are altered by different environmental factors (Zurera *et al*., 1987). However, the higher TF of heavy metals indicates the industrial activities, such as textile, paint, battery and chemical industries which contaminate the soil. This statement is supported by with Aktaruzzaman *et al*. (2013).

Correlation studies

In order to ascertain probable relationship between heavy metal (Ni, Cr, Cd, Cu and Fe) contents of soils and vegetables, correlations were calculated. The results showed (Table 5) positive correlation between concentration of the metals in soils and vegetables, and the correlation varied widely. The highest correlation between soil-vegetable was found with Cr (r= 0.913**) in tomato where as it was highest with Fe (r = 0.902**) in cabbage.

Conclusion

The contents of heavy metals varied considerably in different soils showing the trend: Fe>Cu>Ni>Cr>Cd. Tomato and cabbage yield were significantly affected by different contaminated soils. Yield of both vegetables were higher in Mymensingh soil than Dhaka soil. Heavy metal contents in vegetables were related to their concentrations in the corresponding soils with few exceptions. The Ni, Cr, Cd and Fe contents in the studied vegetables were higher than the maximum level suggested by WHO. Metal transfer factors from soil to vegetables were found to be significant for Ni, Cr and Cd. Considering the plant concentration factor or transfer factor of the metals, it can be suggested that vegetables like tomato and cabbage grown in the contaminated soils of the study areas should not be used as food or even feed. It is of prime importance to the researchers for protecting the soil health from industrial pollution by taking different pragmatic actions for healthy vegetable production.

Acknowledgement

We are thankful to the Ministry of Science and technology, Government of the Peoples Republic of Bangladesh for financial support in the present piece of research work.

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