Toxicology International, *Vol 28(1), 67-80, 2021, DOI: 10.18311/ti/2021/v28i1/26340*

Original Research
ISSN (Print): 0971-6580
ISSN (Online): 0976-5131

Investigation of Human Health Risks Influenced by Trace Metals (TMs) in Chili Plant (*Capsicum annuum* L.) Grown on Tannery Effluents Contaminated Soil

F. Ahmed[1,2*], A. N. M. Fakhruddin[1], Z. Fardous[3], M. A. Z. Chowdhury[3] and M. M. Kabir[4,5]

[1]Department of Environmental Sciences, Jahangirnagar University, P. O. Box 1342, Savar, Dhaka, Bangladesh; fowzia.ju@gmail.com
[2]Department of Environmental Science, Bangladesh University of Professionals, Mirpur Cantonment, P. O Box 1216, Dhaka, Bangladesh
[3]Agrochemical and Environmental Research Division, Institute of Food and Radiation Biology, Atomic Energy Research Establishment, P. O. Box 1349, Savar, Dhaka, Bangladesh
[4]Department of Environmental Science and Disaster Management, Noakhali Science and Technology University, P. O. Box 3814, Noakhali, Bangladesh
[5]Research Cell, Noakhali Science and Technology University, P. O. Box 3814 Noakhali, Bangladesh

History: Received 2020-11-07; Accepted 2021-01-25; Published 2021-05-24

Abstract

This study investigated the characteristics of tannery effluents of Hazaribagh area, Dhaka, Bangladesh, as well as assess the human health risks due to the accumulation and translocation of trace metals (TMs) in different parts of the chili plant (*Capsicum annuum* L.) grown on tannery effluents contaminated soil at three levels of contamination. The mean values of pH, TDS, EC, DO, turbidity, BOD, and TOC were 5.98, 4195 mg/L, 7950 µS/cm, 3.20 mg/L, 358 FTU, 660 mg/L and 3368.74 mg/L, respectively whereas the mean concentration of Cr, Pb, Fe, Zn, Cd, Mn and Cu was 374.40, 27.70, 26.06, 1.80, 1.27, 1.26 and 1.24 mg/L, correspondingly. The TMs constituents and water quality parameters in the tannery effluents exceeded both the national and international standards. A significant amount of Cr and Pb was traced in fruits of the medium and low level of contamination that exceeded the standard limit set by FAO/WHO. The highest transfer factor was found on Pb and it was mostly accumulated in the leaves. Cr and Pb concentrations in fruits of medium level exceeded the standard given by WHO/FAO/ SEPA. Although the daily intake of metals in combination with health and carcinogenic risk indexes indicated that the edible parts of Chili plants are within the safe limit, the potential human health risks cannot be abandoned for the consistent/long term consumption of TMs contained Chili plants (*Capsicum annuum* L.).

Keywords: Bangladesh, Carcinogenic Risks, Tannery Wastewater, BCF, DIM, HRI

1. Introduction

Tannery industries are one of the most dreadful industries due to its intense level of pollution. The pollution created an enormous effect on the environment (soil, air, water, etc.) as well as human health. Every year about 300 million pieces of cowhide are processed throughout the world, which produces 300 million of tons wastewater[1]. In Bangladesh, from small and medium scaled tannery industries around 18 m^3d^{-1} of liquid waste are generated and these effluents are discharged into the rivers without any treatment[2]. Therefore, it causes a serious impact on the water quality of the river, ecological health of the river is deteriorated[3]. Hazaribagh area of the Dhaka, Bangladesh is one of the most polluted areas of Bangladesh, most of the tannery industries are situated in this area. Due to the

*Author for correspondence

untreated discharge of the tannery wastewater, the adjacent river Buringanga is threatened by pollution. The Buriganga River contains a huge amount of heavy metals[4]. Tannery industry waste poses a serious environmental impact on soil, water and air as it contains toxic chemical constituents[5]. Heavy metal pollution from tannery industries represents a significant environmental problem. Different types of metallic constituents like Cr, Fe, Pb, Mn, Zn, Cd, Cu, Ni, etc. are found in high concentration in the effluent. Among them, chromium has been found in high concentrations[6]. Chromium and its compounds have been used extensively in leather tanning and electroplating. Chromium-based wastes such as chromium sludge, chrome-tanned leather shavings, chrome leather trimmings, etc. are generated from the tannery industry[7]. Heavy metals accumulated in the soil adjacent to the tannery industry. Plants grown on the contaminated soil can accumulate heavy metals in the edible part of the plants, which can enter the human body. A wide variety of vegetables accumulate toxic heavy metals that have carcinogenic, neurotoxic, and genotoxic effects[8].

Chili (*Capsicum annuum* L.) is one of the significant spice crops of Bangladesh. It is widely grown both in winter and summer seasons. Chili is an indispensable ingredient for the preparation of dishes ranging from green salad to brick red curries. It is a part of the daily human diet in Bangladesh and it is one of the most popular spices. Around 93.55 thousand hectares were used for the chili cultivation where the production was about 102.25 thousand tons in the year 2012-13. Chili production covers 10.54% of the production of the total spice of the country[9]. Chilies are a good source of vitamin A and C. In particular, a significant amount of vitamin-B and vitamin-B6 is found in chili. They are also packed with potassium, magnesium, and iron. Capsicum is a genus of plants from the Solanaceae family that have a variety of names depending on location and type. Chilies are well known for their sharp acidic flavor and color. The presence of capsaicin gives strong spicy pungent character, contain health benefiting an alkaloid compound. Currently, chili is used throughout the world as a spice and also to making beverages and medicine. Like other vegetables of Solanaceae family, such as tomato (*Licopersicon esculentum* L.), eggplant (*Solanum melongena* L.), potato (*Solanum tuberosum* L.); chili plant (*Capsicum annuum* L.) accumulate and translocate heavy metals from the contaminated soil to its fruits. Cultivation of vegetables in the adjacent area of high density industries results heavy metal contamination in plants[10]. Hazaribagh tannery effluent contains a wide variety of heavy metals, plant grown on this contaminated soil can translocate metals to the edible parts of plants.

In Bangladesh, chilies are regularly used as condiments and spices. However, it is a matter of great concern that the agricultural land is contaminated by industrial effluent, especially from textile and tannery industries. Therefore, it is necessary to monitor and assess the trace metals in Chili plants for the human health risk assessment. However, according to the scientific literature and to the best of our knowledge, there is no structured scientific study regarding contaminants risk assessment, characterization and bioaccumulation potentials of Chili pants. The present study deals with the analysis of water quality parameters of Hazaribagh tannery effluents, also aims to study translocation and accumulation of heavy metals (Cr, Pb, Cd, and Cu) in different parts of chili plant (*Capsicum annuum* L.) grown on tannery effluent contaminated soil.

2. Material and Methods

2.1 Effluent Sample Collection

Tannery effluent samples were collected randomly from different sites of Hazaribagh tannery area in Dhaka city, situated in the south-western part of Dhaka. Total grab 10 samples were collected in 500 ml plastic containers. After collecting the water samples, one ml of concentrated HNO_3 (65%) was added instantly to determine trace metallic concentration. The samples were mixed accurately to bring the pH below 2[11]. The samples were preserved at -20°C in a refrigerator to prevent hydrolysis and oxidation.

2.2 Water Quality Parameters

Water quality parameters, i.e. pH, Dissolved Oxygen (DO), Total Dissolved Solid (TDS), Electrical Conductivity (EC), Turbidity, Total Organic Carbon (TOC) were determined by pH-meter (Model- HI 211, HANNA), DO-meter (Model- DO 110, ECOSCEN), TDS-meter (Model-HI 8734, HANNA), EC-meter (Model-HI 8033, HANNA), Turbidity-meter (Model- HI 93703, HANNA), and TOC analyzer (TOC-L CPN, Shimadzu), respectively. Biological Oxygen Demand was determined by BOD5 method. All the instruments were calibrated with standard solution prior to use and the utilized chemicals were of analytical grade.

2.3 Determination of Trace Metallic Constituents

To determine the concentration of trace metallic constituents in the effluent samples, acid digestion was done according to[12]. Whatman No. 41 (0.45 µm pore size) filter papers were used to filter the samples.100 ml of sample was transferred into a clean beaker and 5 ml 65% concentrated HNO_3 acid was added to it for digestion. Then the solution was slowly boiled and evaporated on the hotplate until it got dry. After cooling, the samples were diluted to 50 ml by distilled water. Finally, the samples were taken for analysis by Atomic Absorption Spectrophotometer (AAS -6300, SHIMADJU, Japan).

2.4 Soil Preparation

The soil was collected from the arable horizon (0-30 cm depth) of the Botanical garden of Jahangirnagar University, Dhaka. The soil was also mixed with cow dung as amendments. The soil was air-dried under room temperature, grass and dirt was removed and also grinded. Every 4L of plastic pot was filled with 3 kg of soil. Four levels of tannery effluent (0, 4 times diluted, 2 times diluted, without dilution) as unadulterated, low, medium and high levels were sprayed in soil with two replicates. Another same four levels of effluent were sprayed in soil with two replicates as blank sample and they remained without the plant. The spiked soils were allowed to be air-dried and mixed periodically for two weeks.

2.5 Chili (*Capsicum annuum* L.) Plant Growth on Artificially Contaminated Soil

Chili (black cobra peepers) plant saplings were collected from a nursery nearby Jahangirnagar University. They were about 4–5 inch height and planted in artificially contaminated soil. Plants were allowed to grow in normal temperature and light and were prevented from the contact of external rainwater and dew. Plants were irrigated with tap water and allowed to grow until fruits came out.

2.6 Soil Sample Preparation and Digestion

With the addition of concentrated HNO_3 acid and concentrated $HClO_4$ acid, soil samples were digested for the determination of heavy metals[13]. 1 gm of homogenized composite soil sample was taken into the clean beaker, and 10 ml of 65% concentrated HNO3 acid and 5 ml of 70% concentrated $HClO_4$ acid were poured on it. Then the mixture was heated in a hotplate at different temperatures up to dryness in a fume chamber. After cooling it down, the beaker was washed with distilled water, and the mixture was transferred into a volumetric flask to determine the volume into 50 ml. Then the solution was filtered into a plastic bottle using Whatman No. 1 (Qualitative, Circles, 125 mm dia, cat no 1001, 125) and finally taken the sample for analysis by Atomic Absorption Spectroscopy (AAS).

2.7 Plant Material Digestion

Different parts of chili were washed with distilled water and were oven dried. Then they were crushed with morter and were stored in the plastic container. The powdered samples were transferred to the crucible and then 10 ml of acid 65% HNO_3 and 5 ml 70% concentrated $HClO_4$ acid were added. Then the mixture was heated in a hotplate at different temperatures up to dryness in a fume chamber. After that, the samples were cooled and filtered by Whatman no 1 filter paper. The volume of the residues was made up to 50ml. Finally, the solution was taken for the analysis in Atomic Absorption Spectroscopy for the quantitative determination of heavy metal.

2.8 Transfer Factor

The transfer factor of heavy metals was evaluated to determine the translocation of heavy metals from soil to different parts of the chili plants[14]. To determine the transfer factor from soil to root, the concentration of heavy metals in the root of *Capsicum annuum* L. was divided by the total heavy metal concentrations in soil. The Transfer factor of heavy metals from root to shoot, shoot to leaves, and leaves to fruit was also determined by using the following equation.

$$TF = \frac{Concentration\ of\ metal\ in\ root}{Concentration\ of\ metal\ in\ soil}$$

2.9 Bioconcentration Factor

The Bioconcentration Factor (BCF) of metal is an index that determines a plant's capacity to assemble a specific metal regarding its concentration in the soil. It is a valuable indicator of the bioaccumulation potential of a substance. BCF was calculated by determining the ratio of the concentration of a metal in a plant to the concentration in the soil. The equation is given below:

$$\mathbf{BCF} = \frac{Metal\ concentration\ in\ plant\ tissue\ (whole\ plant)}{Initial\ concentration\ of\ metal\ in\ substrate\ (soil)}$$

The high BCF value indicates the more suitability of plant for phytoextraction[15].

2.10 Daily Intake of Heavy Metals (DIM)

The daily intake of heavy metals was calculated by the multiplication of the concentration of heavy metals in vegetables with conversion factors and daily intake of vegetables. Then, this value was divided by the average body weight. The determination of DIM value was determined according to the following equation[16]:

$$DIM = C_{metal} \times C_{factor} \times F_{ood\ intake} / B_{average\ weight}$$

Where, M_{etal} = heavy metals concentration in vegetables (mg/kg), C_{factor} = conversion factor of 0.085, $F_{ood\ intake}$ = daily intake of vegetables (kg/day) and $B_{average\ weight}$ = average body weight, kg. An estimated value of daily intake of chili is 15 gm per day per person, and the average weight is 60 kg.

2.11 The Health Risk Index

The health risk index of heavy metals by consumption of chili grown on the contaminated soil was calculated by dividing the DIM to oral reference dose RfD values.

HRI =DIM/RfD

RfD is the USEPA's highest tolerable oral dose of a lethal substance.

In this study, the oral reference dose values for Cr (0.003 mg kg-1 per day), Pb (0.0035 mg kg-1 per day), Cu (0.040 mg kg^{-1} per day), and Cd (0.001 mg kg^{-1} per day) were considered as described by WHO (1993). The safe value of health risk index for the exposed population is not more than 1[17,18].

2.12 Carcinogenic Risk (CR)

Carcinogenic risk (CR) is the index of determining the risk of cancer. The CR was estimated by using the following equation, which was proposed by[8]:

CR= DIM/CSFo

Here, CSFo is the oral carcinogenic slope factor, which was 0.5 mg/kg/day for Cr, 0.0085 mg/kg/day for Pb and 15 mg/kg/day for Cd[19].

2.13 Quality Control and Quality Assurance

Quality control and quality assurance were incorporated into the analysis. The analytical method was standardized by processing spiked samples. The accuracy and precision were also validated in accordance with the European Commission guidelines. The precision was expressed as the Relative Standard Deviation (RSD). Accuracy was measured by analyzing samples with known concentrations and comparing the measured values with the actual spiked values. For the recovery experiments, metal free samples were spiked, in three replicates, after homogenization by the addition of the appropriate volumes of standards of Cr, Fe, Pb, Mn, Zn, Cd and Cu at three different levels (0.125, 0.50 and 1.0 and 5.0 mg/L). Control samples were processed along with spiked ones. Average percent recoveries were ranged from 87.43-103.78 for Chromium (Cr) with precisions ranging from 1.67 to 4.50%, 94.74-98.61 for Iron (Fe) with precisions ranging from 1.98 to 4.52%, 88.90-98.92 for Lead (Pb) with precisions ranging from 3.71 to 6.12%, 89.52-99.72 for Manganese (Mn) with precisions ranging from 2.56 to 3.87%, 92.79-107.73 for Zinc (Zn) with precisions ranging from 2.91 to 3.63%, 91.45-102.29 for Cadmium (Cd) with precisions ranging from 0.24 to 5.20% and 90.34-107.51 for Copper (Cu) with precisions ranging from 0.29 to 6.03%. The QC and QA data are provided in Table 1.

Table 1. Performance characteristics of the analytical methods employed for metallic residues analysis at three spiking levels.

Spiked Levels (mg/L)	% Recovery (n=3) (Repeatability / % RSD) of trace metals						
	Cr	Fe	Pb	Mn	Zn	Cd	Cu
0.5000	87.4326 (1.67)	94.74 (4.52)	92.32 (3.71)	89.52 (2.56)	92.79 (3.63)	102.29 (0.24)	90.34 (6.03)
1.0000	97.52 (2.82)	98.61 (1.98)	88.90 (4.56)	96.73 (3.87)	97.91 (2.91)	95.30 (5.20)	107.51 (2.73)
5.0000	1O3.78 (4.50)	95.51 (5.62)	98.92 (6.12)	99.72 (2.91)	107.73 (3.54)	91.45 (0.41)	98.67 (0.29)

n*= number of replicates, values are average of triplicate analysis

3. Results and Discussion

3.1 Water Quality Parameters of Effluents

Table 2 represents the water quality parameters of Hazaribagh tannery effluent. In this study, among the ten samples, only four samples were within the standard range, others were highly acidic or highly basic. Parallel to heavy metals, the Hazaribagh tannery industry use a wide variety of chemicals that caused highly acidic and basic effluent[20]. The TDS values were found in between 1360 to 7540 mg/l and the mean value was 4349 mg/l. According to waste discharge quality standards for Industrial unit (DoE 2008) and ECR (1997), standard TDS is 2100 mg/l. Except for DHTW-2 and DHTW-10, all the samples exceeded the

standard values of TDS. Five samples did not exceed the standard limit of TDS given by NEQS (2000) (3500 mg/l). These values indicate that effluent contain an excess amount of dissolved chemicals.

The EC values of the effluent were found in this study between 3900 to 18800 µS/cm. The mean EC value is 9490 µS/cm. All the samples represent higher conductivity compared to the limits of the prescribed standards (DoE 2008, ECR, 1997; 1200 mg/l and NEQS, 2000; 288 mg/l). The DO values ranged from 0.48 to 4.88 mg/l and the mean value was 2.55 mg/l. According to waste discharge quality standards for the Industrial unit (DoE 2008), standard DO is 4.5-8 mg/l. Except for DHTW-2 and DHTW-6, DO level of all the samples was below the standard level which indicates low oxygen availability in water. Hazaribagh tannery effluent contain excess amount of organic matter, which reduces the dissolved oxygen level[6].

The turbidity values of the tested samples were found between 92 FTU to 706 FTU. The mean turbidity value was 368.30 FTU. To produce polished and refined leather, several processes were performed in the tannery industries which emit several chemicals such as salt, lime, organic solvents, fats sludge etc. These emitted chemicals increase the turbidity of tannery effluent[21].

In the current study, the highest value of Biological Oxygen Demand (BOD) was 926 mg/l and the lowest value was 530 mg/l. The mean value of BOD of Hazaribagh tannery effluent was 707.4 mg/l. The standard value of BOD for discharging wastewater is 50-250 mg/l (DoE, 2008). All the samples exceeded the standard of BOD value. The presence of organic matter in tannery effluent results higher Biological Oxygen Demand (BOD). The discharge of organic matter in the water cause oxygen depletion which is harmful for the aquatic life. Several studies found on the characterization of tannery effluent where results showed high amount of BOD22–24. The TOC values of five samples ranges from 0.095 mg/l to 0.215 mg/l. The mean value of those samples was 4254.03 mg/l. The maximum value of TOC found in DHTW -10 and minimum value in DHTW -9.

3.2 Determination of Some Metallic Const ituents in the Tannery Effluent

The concentration of heavy metals in the water samples collected from the tannery industries are presented in Table 3. Concentrations (mg/l) of metallic constituent ranges were: Cr:760.81±0.395 to 21.13±0.025; Pb: 42.67±0.015 to 6.67±0.015; Cd: 1.46±0.065 to 0.76±0.04; Cu: 1.52±0.01 to 0.97±0.15; Mn: 2.41±0.015 to 0.59±0.02; Zn: 6.62±0.05 to 0.36±0.01; Fe: 45.85±0.02 to 9.21±0.02. The concentrations of heavy metals in the tannery effluent found in the following order: Cr > Pb> Fe > Zn > Cd > Mn > Cu. The average concentration of total chromium (Cr) in the effluent samples was 374.402 mg/l, which was approximately 750 times higher than the standard value. The highest concentration of Cr was found in DHTW-3 (760.81±0.395 mg/l), DHTW-6 (749.11±0.07 mg/l), DHTW-1 (735.89±0.335 mg/l), and DHTW-8 (697.94±0.46 mg/l) which were collected from the equalizer tanks of four tanneries in the Hazaribagh tannery area. The other six samples were collected from different drain water and the concentration ranges from 363.55±0.305 to 21.13±0.025 mg/l, which were relatively low compared to the other samples as they were diluted by mixing with drain water. All the samples exceeded the permissible limit set by DoE (0.5 mg/l), NEQS (1.0 mg/l) and ECR (0.5 mg/l). Chromium is extensively used for chrome tanning in Hazaribagh tannery industry. All the Cr(III) may sometimes converted to more toxic hexavalent chromium [Cr(VI)]. Chromium is not easily degraded in the environment and it caused a negative impact on soil, water as well as life[25,26].

The average concentration of Pb in the tested samples was 27.70 mg/l that was more than 270 times higher than the standard value permitted by the DoE (0.1 mg/l), NEQS and ECR (0.5 mg/l). Discharge of untreated tannery effluent in the water and soil may poses a serious effect to the living organisms. High lead concentration is a matter of concern because it has harmful effects on the human neurological system[27]. The mean concentration of Fe (26.06 mg/l) was close to Pb (27.70 mg/l). The standard value for discharging Fe into inland surface water is only 2 mg/l permitted by DoE which was almost 13 times higher than the measured value. The mean concentration of Cd was 1.27 mg/l which also exceeded the permitted value 0.05 mg/l which indicated high metallic pollution in Hazaribagh tannery effluent. Cd has also phytotoxic effects on the growth of the plants. Cd accumulation causes morphological, physiological, and biochemical toxic effects to plants grown on contaminated soil[28]. The mean concentration of Cu was1.24 mg/l. The analyzed concentration of Cu also exceeded the permitted value DoE (0.5 mg/l), NEQS (1 mg/l) and ECR (0.5 mg/l). The mean concentration of Zn and Mn were 1.80 mg/l and 1.26 mg/l, respectively. Though the mean concentration of Zn and Mn did not exceed the permitted value 5 mg/l, some of the individual samples exceeded this standard. The highest value of Zn found in DHTW-9 (6.62±0.05 mg/l) which cross the standard established by DoE (5 mg/l). Hazaribagh tannery effluents were also characterized by [24] where they found high concentrations of metallic constituents (Cr, Cd, Pb and As) at different stages of leather production. From the above discussion, it can be concluded that the Hazaribagh tannery area is polluted severely by metallic constituents, the concentration of all the heavy metals was several times higher than the standard value, which may pose a horrendous threat to adjacent environmental condition, human health of the local exposed people, aquatic communities of the area and plant life.

Table 2. Physico-chemical parameters of Hazaribagh tannery effluents (n=10)

Sample ID		pH	TDS (mg/l)	EC (µS/cm)	DO (mg/l)	Turbidity (FTU)	BOD (mg/l)	TOC (mg/l)
DHTW- 1		10.06	6430	5600	3.10	178	662	2954. 32
DHTW - 2		5.62	1360	3900	4.88	215	530	3051.23
DHTW - 3		5.50	5500	6600	3.31	92	658	2579.81
DHTW - 4		8.75	3150	14400	0.62	572	825	5561.65
DHTW - 5		6.35	6560	18800	3.74	706	627	4152. 56
DHTW - 6		4.86	7540	9300	4.01	408	556	4928.16
DHTW - 7		6.37	3390	15500	0.48	308	926	5276. 75
DHTW - 8		5.42	5000	4700	3.74	126	610	3368.74
DHTW - 9		7.06	2890	9900	1.10	484	765	2435.27
DHTW - 10		4.81	1670	6200	0.51	594	915	6451.25
Maximum		10.6	7540	18800	4.88	706	926	6451.25
Minimum		4.81	1360	3900	0.48	92	530	2435.27
Mean		6.48	4349	9490	2.55	368.30	707.4	4053.73
Median		5.98	4195	7950	3.205	358	660	3368.74
SD		1.72	2153.74	5116.52	1.685	215.98	142.55	1583.91
Guideline values for discharging in surface water	(DoE, 2008)	6-9	2100	1200	4.5-8	-	50-250	-
	NEQS (2000)	6-9	3500	288	4-6	-	-	-
	ECR (1997)	6-9	2100	1200	4.5-8	-	-	-

DoE*= Department of Environment, Bangladesh, NEQS*= National of Environmental Quality Standards, ISW-BDS-ECR*= Inland Surface Water in Bangladesh.

Table 3. Concentrations of heavy metals in the Hazaribagh tannery effluent.

Sample ID	Concentration of metallic constituents (mg/l or ppm) (n=10)						
	Cr	Pb	Cd	Cu	Mn	Zn	Fe
DHTW- 1	735.89±0.335	14.76±0.01	0.76±0.04	0.97±0.15	0.97±0.005	0.93±0.005	17.84±0.1
DHTW– 2	52.93±0.21	10.77±0.025	1.28±0.05	1.15±0.005	0.59±0.02	0.51±0.05	9.21±0.02
DHTW - 3	760.81±0.395	26.72±0.025	1.30±0.035	1.03±0.005	1.76±0.02	1.08±0.045	33.75±0.055
DHTW - 4	39.27±0.18	28.71±0.015	1.39±0.06	1.09±0.005	0.71±0.025	0.36±0.01	16.49±0.08
DHTW - 5	244.16±0.215	36.69±0.1	1.37±0.03	1.18±0.015	1.35±0.035	1.08±0.085	16.72±0.04
DHTW - 6	749.11±0.07	42.67±0.015	1.41±0.06	1.33±0.01	2.41±0.015	1.29±0.03	29.60±0.09
DHTW - 7	363.55±0.305	38.68±0.015	1.46±0.065	1.37±0.005	1.39±0.02	1.24±0.05	45.85±0.02
DHTW - 8	697.94±0.46	40.64±0.025	1.17±0.065	1.24±0.005	1.78±0.045	3.61±0.095	44.84±0.115
DHTW - 9	79.23±0.36	6.67±0.015	1.32±0.005	1.47±0.01	0.69±0.06	6.62±0.05	23.33±0.05
DHTW - 10	21.13±0.025	30.71±0.015	1.25±0.045	1.52±0.01	1.01±0.03	1.27±0.04	22.99±0.065
Mean	374.402	27.70	1.27	1.24	1.26	1.80	26.06
Maximum	760.81±0.395	42.67±0.015	1.46±0.065	1.52±0.01	2.41±0.015	6.62±0.05	45.85±0.02
Minimum	21.13±0.025	6.67±0.015	0.76±0.04	0.97±0.15	0.59±0.02	0.36±0.01	9.21±0.02
DoE, 2008	0.5	0.1	0.05	0.5	5.0	5.0	2.0
NEQS (2000)	1.00	0.5	0.1	1.0	1.5	5.0	8.0
ECR (1997)	0.5	0.5	0.1	0.5	5.0	0.5	2.0

DoE*= Department of Environment, Bangladesh, NEQS*= National of Environmental Quality Standards, ISW-BDS-ECR*= Inland Surface Water in Bangladesh.

3.3 Accumulation of Heavy Metals (Cr, Pb, Cd and Cu) in Different Parts of Chili Plant (*Capsicum annuum* L.)

Three levels of tannery effluents (high, medium and low levels) were sprayed in soil with two replicates. At high level of contamination, plants did not survive and died after 20 days of planting. Because of the direct input of tannery effluent, the contaminated soil became toxic for plant growth. The effluents might contain a wide variety of substances, not only heavy metals. The plant growth was considerably hampered because of the high concentration of Cr. Growth reduction and biomass accumulation had been caused due to the high toxicity of Cr[29].

The uptake and distribution of heavy metals (Cr, Pb, Cd and Cu) in different parts of the chili plant (*Capsicum annuum* L.) is illustrated in Table 4. The order of accumulation of trace metallic constituents in the soil and different parts of the chili plant were: Cr > Pb> Cd > Cu which is similar to the order of heavy metal concentration found in Hazaribagh tannery effluent (Table 3). In considering the three heavy metals Cr, Cd, and Cu, similar patterns were observed. The elemental distribution of these three heavy metals appeared in the decreasing order from roots > shoots > leaves > fruits reflecting the heavy metal assembly in the plants. Chromium recorded the highest accumulation in all parts of the chili plant among other heavy metals because the mean concentration of total chromium (374.402 mg/l) in Hazaribagh tannery effluent was higher than rest of the heavy metals. The highest values of Cr were found in the roots of the chili plant which was 35.921±0.02 mg/kg, 30.461±0.04 mg/kg and 13.979±0.045 mg/kg at high, medium and low level of contamination, respectively. The fruits obtained the lowest Cr concentration among the plant organs with 3.672±0.05 mg/kg and 1.575±0.08 mg/kg both in medium and low level of contamination as compared to the control with 0.2±0.01 mg/kg. Table 4 represents the safe limit of heavy metal concentration in vegetables which indicated that the Cr concentrations in fruits of medium level (3.672±0.0 5mg/kg) exceeded the standard given by WHO/FAO and SEPA. Fruits of low contamination (1.575±0.08 mg/kg) exceeded the standard value given by SEPA 2005. However, it is in the safe limit according to FAO/WHO 1985 which is 5 mg/kg given. Budak et al. (2011), studied ornamental plants grown on peat medium and exposed to irrigation water with Cr (VI) and found a proportionate relation between the increasing concentration of irrigation water and accumulation and translocation of Cr of the plants.

Pb accumulation in roots, shoots, leaves and fruits were not in a similar order as Cr. The order of Pb accumulation is roots>shoots>leaves>fruits. Pb concentration in fruits did not exceed the standard value given by FAO/WHO 1985 (5 mg/kg) and SEPA 2005 (9 mg/kg). However, fruits of both medium and low level of contamination exceeded the safe limit of Pb accumulation given by FAO/WHO 2001. At the medium and low level of contamination, Pb concentration was 0.839±0.02 mg/kg and 0.317±0.05 mg/kg, respectively[30]. studied on Oryza sativa grown near the e-waste dumping site and found that rice grains accumulated high concentration of Pb which was beyond the safe limit given by FAO/WHO (1972).

Cd also accumulated at the highest concentration in roots ranged from 0.133±0.003 mg/kg and 0.152±0.05 mg/kg. Cd accumulation in fruits did not exceed the safe limit and it ranged from 0.073±0.025 mg/kg to 0.122±0.021 mg/kg. The accumulation trend of Cu was roots> shoots>leaves>fruits, which similar to this Cr and Cd. Parallel to the Cr, Pb and Cd, root is the organ that accumulated the highest level of Cu and it ranged from 0.63±0.03 mg/kg to 0.958±0.037 mg/kg. Cd accumulation in fruits is far below the standard limit as Cd concentration was much lower in the tannery effluent.

A comparable study was conducted by Tom et al., 2014 where they created an artificially contaminated garden irrigated urban stormwater. They cultivated bean (*Phaseolus vulgaris*), kale (*Brassica oleracea*), and beetroot (*Beta vulgaris*) and found the highest accumulation of Pb in the plants[31]. Crops members of the family Solanaceae, tomato (*Licopersicon esculentum* L.), eggplant (*Solanum melongena* L.) and peeper (*Capsicum annum* L.) which were grown in the industrially polluted region and found Pb, Cd, Cu and Zn accumulation at a significant concentration[32].

3.4 Heavy Metal Transfer from Tannery Effluent Contaminated Soil to Different Parts of Chili Plant (*Capsicum annuum* L.)

The transfer factors (TF) of heavy metals from soil to different parts of chili (roots, shoot and leaves) on tannery effluent contaminated soil are illustrated in Figure 1. At high level of contamination, no plants survived, only roots were available for study. At this level, the translocation of Cr was the lowest (0.19) among other heavy metals. The transfer factor of Pb from soil to root was 0.26. TF value of Cu was the highest (0.47) which was very close to Cd (0.46). The safe limit values of heavy metal concentration in vegetable (mg/kg) have been given in Table 5.

At the medium level of contamination, it showed a large variability among different parts of the plants. The highest translocation found for Pb from shoot to leaves which was 1.41 and the lowest TF value was 0.33 for Cd from root to shoot. At this level of contamination, the translocation of heavy metals from shoot to leaves exhibits the highest value for Pb (1.41) and Cd (0.98). However, Cr and Cu showed

the highest TF value from leaves to fruits. The lowest translocation was found in root to shoot for all heavy metals (Cr, Pb, Cd and Cu), which means root accumulated more heavy metals than other parts of plants.

At the low level of contamination, the highest translocation was found for Pb and Cd from shoot to leaves which was 1.09 and 0.86, respectively. On the other hand, the lowest TF value was 0.27 for Cd from soil to root. For all the heavy metals, the highest TF values found in shoot to leaves and the order was Pb <Cd< Cr < Cu [33] studied on the translocation of heavy metals grown on contaminated soil and found that the edible parts of plants accumulated a high amount of toxic heavy metals. The translocation factor (TF) varied among plant species, and among heavy metals. In the current study, it was found that TF from shoot to leaves was more than 1 for Pb which is similar to Eid and Shaltout 2016 [34].

Table 4. Concentrations of heavy metals in the Hazaribagh tannery effluent.

Heavy metal	Contamination level	Soil	Average concentration in mg/kg			
			Roots	Shoots	Leaves	Fruits
Cr	Control	1.489±0.05	0.165±0.02	0.087±0.01	0.094±0.02	0.2±0.01
	High	191.005±0.04	35.921±0.02	NA	NA	NA
	Medium	77.302±0.03	30.461±0.04	14.908±0.04	6.964±0.03	3.672±0.05
	Low	32.031±0.02	13.979±0.045	7.745±0.025	4.844±0.06	1.575±0.08
Pb	Control	0.161±0.05	0.303±0.05	0.09±0.025	0.283±0.015	0.062±0.06
	High	12.121±0.02	3.161±0.011	NA	NA	NA
	Medium	8.201±0.02	2.961±0.015	1.503±0.03	2.122±0.04	0.839±0.02
	Low	4.941±0.015	2.222±0.035	0.872±0.01	0.951±0.005	0.317±0.05
Cd	Control	0.337±0.04	0.099±0.03	0.07±0.065	0.263±0.01	0.03±0.02
	High	1.293±0.005	0.584±0.003	NA	NA	NA
	Medium	0.952±0.055	0.315±0.051	0.152±0.05	0.149±0.03	0.122±0.021
	Low	0.491±0.005	0.133±0.003	0.111±0.02	0.096±0.01	0.073±0.025
Cu	Control	0.839±0.025	0.712±0.015	0.676±0.02	0.557±0.03	0.376±0.025
	High	0.958±0.037	0.45±0.001	NA	NA	NA
	Medium	0.885±0.035	0.301±0.02	0.271±0.015	0.131±0.03	0.099±0.03
		0.635±0.03	0.231±0.015	0.156±0.02	0.088±0.03	0.028±0.05

*NA= Not available

Table 5. Safe limit of heavy metal concentration in vegetable (mg/kg)

Metal	Safe limit[a]	Safe limit[b]	Safe limit[c]
Cr	2.3	5	0.5
Pb	0.3	5	9
Cd	0.2	0.3	0.2
Cu	73.5	40	20

[a]FAO/ WHO standard (Codex Alimentarious Commission, 2001); [b]FAO/WHO standard (Codex Alimentarious Commission, 1985); [c]SEPA (2005)

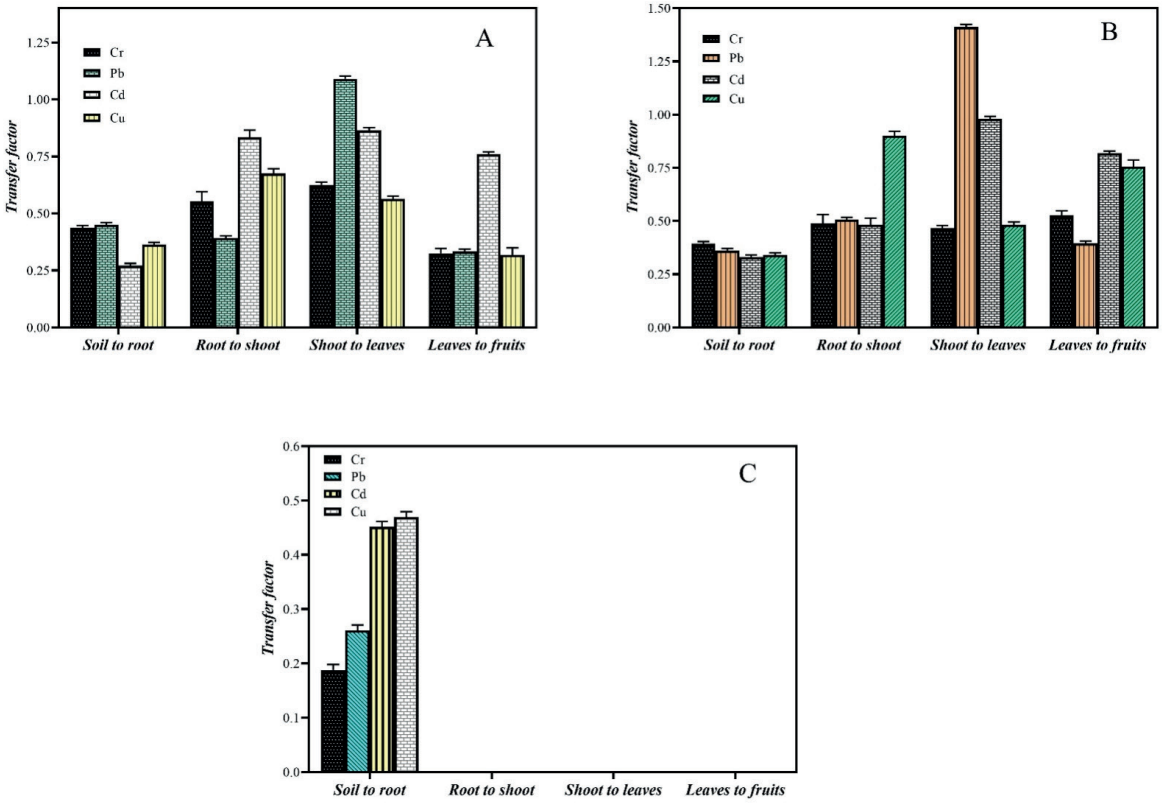


Figure 2. Transfer factors of heavy metals from tannery effluent contaminated soil to different parts of chili plant (*Capsicum annuum* L.); **A.** Low contamination level, **B**. Low contamination level,**C.** High contamination level.

3.5 Bioconcentration Factor (BCF)

The Bioconcentration Factor (BCF) symbolizes the capability of the chili plant (*Capsicum annuum* L.) to uptake heavy metals from the soil. Table 6 illustrates the BCF of Cr, Pb, Cd and Cu from the soil to the whole chili plant. Cr exhibited the highest BCF value at the medium level of contamination. Pb and Cd showed an increasing order of BCF value with the increase of the contamination. The trend of the average Bioconcentration factor of the heavy metal was found in the following sequence: Cr>Cu> Pb>Cd. When a BCF ≤ 1, the plant cannot accumulate heavy metals, just can only absorb. When a BCF> 1, the plant can accumulate metals[35]. According to this, all the heavy metals were absorbed by the Chili plant not accumulated accept Cr in the medium level of contamination. Chang et al., 2014 worked on six kinds of vegetables and found that Cd had higher BCF value than the other heavy metals like Hg, Pb, Cr and As[36]. The BCF for heavy metals indifferent vegetables were studied by Ahmad and Goni, 2009 and found the order Cu> Pb > Zn > Cd > Ni > Fe > Cr, where Cr had lowest BCF[37]. In the current study, high Cr BCF value was found due to the extremely high concentration of Cr in the tannery wastewater.

Table 6. Bioconcentration factor (BCF) of Cr, Pb, Cd and Cu from the soil to the whole chili plant (*Capsicum annuum* L.)

Level of contamination	Bioconcentration factor (BCF)			
	Cr	Pb	Cd	Cu
High	0.188063	0.260787	0.451663	0.469729
Medium	1.724496	0.905377	0.77521	0.906215
Low	0.878618	0.923295	0.841141	0.792126
Average	0.930392	0.696486	0.689338	0.72269

3.6 Daily Intake of Metals (DIM)

The daily intake of Cr, Pb, Cd and Cu were estimated for the chili plants grown in artificially contaminated soils are presented in Table 7. DIM value for Cr, Pb, Cd and Cu was very low in all levels of contamination. Although chili is needed in the daily diet in Bangladesh, usually used as a spice and condiment and taken in low quantity. The trend of DIM found in the order of Cr> Pb> Cd> Cu at the medium level of contamination which showed a correlation with the concentration of the tannery wastewater. Cr exhibited the highest DIM among all the metals due to its high concentration in the tannery effluent. The DIM values for studied heavy metals did not exceed the standard value set by WHO/FAO. Therefore, chili grown on this soil can be considered completely safe to eat. In comparison with the vegetables of the clean water-irrigated area, DIM values were high when food crops grown with contaminated water[38].

Table 7. Daily intake of metals (DIM) of Cr, Pb, Cd and Cu from the soil to the whole chili plant (*Capsicum annuum* L.)

Level of contamination	Daily intake of metals (DIM)(mg/day)			
	Cr	Pb	Cd	Cu
High	NA	NA	NA	NA
Medium	1.3005×10^{-4}	2.97146×10^{-5}	4.32083×10^{-6}	3.50625×10^{-6}
Low	5.57813×10^{-5}	1.83104×0^{-5}	2.58542×10^{-6}	9.91667×10^{-6}
WHO/FAO*	0.05-0.2	0.214		1.2 - 3

*NA=Not Available *WHO/FAO values in mg/day are based on a 60 kg body weight adult

3.7 Health Risk Index and Carcinogenic Risks

The health risk index (HRI) and Carcinogenic Risks of Cr, Pb, Cd and Cu were estimated for the chili plants (*Capsicum annuum* L.) grown in artificially contaminated soils by tannery effluent are presented in Table 8. HRI value of the heavy metals found in the order of Cr>Pb>Cd>Cu in both medium and low level of contamination. HRI of Cr is 0.004 at the medium level of contamination which was the highest. The lowest HRI was found on Cu (0.00002) at the low level of contamination. In this study, the HRI value was less than 1, which indicates the consumers were safe. A similar study conducted by Mahmood, and Malik 2015, vegetables grown in industrial wastewater contaminated soil and found HRI value of Cr and Pb was 0.0009–0.0029 and 0.10–0.76, respectively.[39] Based on the results of Carcinogenic risks (CR) values in the present study (Table 8), contamination by Cr, Pb, Cd and Cu in Chili Plant (*Capsicum annuum* L.) can be said safe in terms of carcinogenic risks. According to USEPA 2014, a CR values exceeding 1×10^{-4} cause significant cancer risks.[40] However, the CR values in this study for Cr ranged from 2.79×10^{-5} to 6.50×10^{-5} which is very close to carcinogenic risk. However, carcinogenic risk was found on vegetables which grown in the vicinity of the highly urbanized city, China.[41]

Table 8. Health risk index and Carcinogenic Risks of Cr, Pb, Cd and Cu from the soil to the whole chili plant (*Capsicum annuum* L.)

Level of contamination	Health risk index				Carcinogenic Risks			
	Cr	Pb	Cd	Cu	Cr	Pb	Cd	Cu
High	NA	NA	NA	NA	NA	NA	NA	NA
Medium	0.004	0.0008	0.0004	0.00005	6.50×10^{-5}	2.53×10^{-6}	6.48×10^{-5}	NA
Low	0.001	0.0005	0.0002	0.00002	2.79×10^{-5}	1.56×10^{-6}	3.88×10^{-5}	NA

*NA= Not available

4. Conclusions

Hazaribagh tannery effluent is extremely contaminated with high concentrations of heavy metals. Plants grown on this type of soil can accumulate and translocate heavy metals to the edible parts of plants. Consumption of heavy metals through plants has caused severe damage to human health. Hazaribagh tannery effluent contains high concentration of heavy metals especially Cr, Pb, Cd and Cu. Chili plants (*Capsicum annuum* L.) grown on the contaminated transfer heavy metals from root to fruits. Cr concentrations in the fruits of both medium (3.672±0.05 mg/kg) and low (1.575±0.08mg/kg) contaminated soil exceeded the permissible limit given by SEPA/WHO/FAO. Fruits of chili plants were also accumulated Pb which exceeded the threshold limit. However, Cd and Cu concentrations in fruits of the chili plant did not exceed the permissible limit. The highest transfer factor was found on Pb at both level of contamination and it was mostly accumulated in the leaves. For all the heavy metals, the highest TF values were found in shoot to leaves and the order was Pb <Cd< Cr < Cu. Daily Intake of Metals (DIM) for Cr, Pb, Cd and Cu was deficient in all levels of contamination. Therefore, industrial wastewater containing heavy metals needs treatment before discharging into the environment. Consumption of plants grown in the contaminated area also requires proper pretreatment.

5. Acknowledgement

The authors are thankful to the Bangladesh Atomic Energy Commission (BAEC) for providing support and necessary facilities to carry out the research work.

6. References

1. Zhao C, Chen W. A review for tannery wastewater treatment: some thoughts under stricter discharge requirements. Environ Sci Pollut Res. 2019;26:26102–11. https://doi.org/10.1007/s11356-019-05699-6. PMid:31280442
2. SHED, 2002. Industrialization and industrial pollution. In: Gain, P. (Ed.), Bangladesh: Environment Facing the 21st Century. Society for Environment, Human and Development (SEHD), Bangladesh.
3. Saeed T, Afrin R, Muyeed AA, Sun G. Treatment of tannery wastewater in a pilot-scale hybrid constructed wetland system in Bangladesh. Chemosphere. 2012; 88(9):1065–73. https://doi.org/10.1016/j.chemosphere.2012.04.055. PMid:22673399

4. Tamim U, Khan R, Jolly YN, Fatema K, Das S, Naher K, Islam MA, Islam SMA, Hossain SM. Elemental distribution of metals in urban river sediments near an industrial effluent source. Chemosphere. 2016; 155:509–18. https://doi.org/10.1016/j.chemosphere.2012.04.055. PMid:22673399
5. Mwinyihija M. Main pollutants and environmental impacts of the tanning industry. Ecotoxicological Diagnosis in the Tanning Industry. Springer Science and Business Media; 2010. https://doi.org/10.1007/978-1-4419-6266-9
6. Kabir MM, Fakhruddin ANM, Chowdhury MAZ, Fardous Z, Islam R. Characterization of tannery effluents of Hazaribagh area, Dhaka, Bangladesh. Pollut. 2017; 3:395–406, https://doi.org/10.7508/pj.2017.03. 005
7. Pati A, Chaudhary R, Subramani S. A review on management of chrome-tanned leather shavings: a holistic paradigm to combat the environmental issue. Environ Sci Pollut Res. 2014; 21(19):11266–82. https://doi.org/10.1007/s11356-014-3055-9. PMid:24906828
8. Shaheen N. Irfan NM, Khan IN, Islam S, Islam MS, Ahmed MK. Presence of heavy metals in fruits and vegetables: Health risk implications in Bangladesh. Chemosphere. 2016. 152:431–8. https://doi.org/10.1016/j.chemosphere.2016.02.060. PMid:27003365
9. BBS. Statistical Yearbook of Bangladesh. Bangladesh Bureau of Statistics, Planning Division, Ministry of Planning, Dhaka; 2015.
10. Zwolak A, Sarzyńska M, Szpyrka E, Stawarczyk K. Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. Water Air Soil Pollut. 2019; 230(164). https://doi.org/10.1007/s11270-019-4221-y
11. APHA (American Public Health Association) Standard Methods for Examination of Water and Wastewater, 21st ed. Washington D. C.; 1995. 15–36
12. Baker DE, Amacher MC. Nickel, copper, zinc and cadmium. In: Page, Miller, AR, Keeney DR. (eds.) Methods of soil analysis, American Society of Agronomy; Madison, Wisconsin, USA; 1982. 323–36. https://doi.org/10.2134/agronmonogr9.2.2ed.c19. PMCid:PMC4668747
13. Allen SE, Grimshaw HM, Rowland AP. Chemical Analysis in: Methods in Plant Ecology, Moore PD and SB Chapman (Eds). Blackwell scientific publication, Oxford, London; 1986. 285–44.
14. Lawrence HS, Borkowsky W. A new basis for the immuno regulatory activities of transfer factor–An Arcane Dialect in the Language of Cells. Cell. Immunol. 1983; 82(1):102–16. https://doi.org/10.1016/0008-8749(83)90145-4
15. Mackay D. Correlation of Bioconcentration factors. Environ Sci. Technol. 1982; 16:274–8. https://doi.org/10.1021/es00099a008. PMid:22257252
16. Khan S, Farooq R, Shahbaz S, Khan MA, Sadique M. Health risk assessment of heavy metals for population via consumption of vegetables. World Appl Sci J. 2009; 6(12):1602–6.
17. Tsafe AI, Hassan LG, Sahabi DM, Alhassan Y, Bala BM. Evaluation of Heavy Metals Uptake and Risk Assessment of Vegetables Grown in Yargalma of Northern Nigeria. J Basic Appl Sci Res. 2012; 2(7):6708–14.
18. Harmanescu M, Alda L, Bordean D, Gogoasa I, Gergen I. Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. Chem Cent J. 2011; 5(1):64. https://doi.org/10.1186/1752-153X-5-64. PMid:22017878 PMCid:PMC3212802
19. USEPA (US Environmental Protection Agency). Regional Screening Level (RSL) Summary Table (TR=1E-06, HQ=1) [Internet]. 2017 Jun. Available from: https://semspub.epa.gov/work/03/2245059.pdf.
20. Hashem MA, Islam A, Mohsin S, Nur-A-Tomal M.S. Green environment suffers by discharging of high-chromium-containing wastewater from the tanneries at Hazaribagh, Bangladesh. Sustain. Water Resour Manag. 2015; 1:343–7. https://doi.org/10.1007/s40899-015-0033-4
21. Rouf MA, Islam MS, Haq MZ, Ahmed N, Rabeya T. Characterization of effluents and leather industries in Hazaribagh area of Dhaka city. Bangladesh J Sci Ind Res. 2013; 48(3):155–66. https://doi.org/10.3329/bjsir.v48i3.17324
22. Famielec S, Ciurowa K. Wastes from leather industry, threats to the environment. Chemia chemistry. 2011; 108(8):43–8.
23. Jahan MAA, Akhtar N, Khan NMS, Roy CK, Islam R, Nurunnabi M. Characterization of tannery wastewater and its treatment by aquatic macrophytes and algae. Bangladesh J. Sci. Ind. Res. 2014; 49(4):233–42. https://doi.org/10.3329/bjsir.v49i4.22626
24. Chowdhury M, Mostafa MG, Biswas TK, Mandal A, Saha AK. Characterization of the Effluents from leather processing industries. Environ. Process. 2015. 2(1):173–87. https://doi.org/10.1007/s40710-015-0065-7
25. Saxena G, Chandra R, Bharagava RN. Environmental pollution, toxicity profile and treatment approaches for tannery wastewater and its chemical pollutants.

Rev Environ Contam T. 2016; 31–69. https://doi.org/10.1007/398_2015_5009. PMid:26795766

26. Shakir L, Ejaz S, Ashraf M, Aziz QN, Ahmad AA, Iltaf I, Javeed A. Ecotoxicological risks associated with tannery effluent wastewater. Environ Toxicol Pharmacol. 2012; 34(2):180–91. https://doi.org/10.1016/j.etap.2012.03.002. PMid:22522427
27. Hardison DW, Ma LQ, Luongo T, Harris WG. Lead contamination in shooting range soils from abrasion of lead bullets and subsequent weathering. Sci. Total Environ. 2004; 328(1–3):175–83. https://doi.org/10.1016/j.scitotenv.2003.12.013. PMid:15207582
28. Shahid M, Dumat C, Khalid S, Niazi NK, Antunes PMC. Cadmium bioavailability, uptake, toxicity and detoxification in soil-plant system. Rev Environ Contam T. 2016; 241:73–137. https://doi.org/10.1007/398_2016_8. PMid:27300014
29. Iqbal MZ, Saeeda S, Muhammad S. Effects of chromium on an important Arid Tree (Caesalpinia pulcherrima) of Karachi city, Pakistan, Ekologia Bratislava. 2001; 20:414–22.
30. Neeratanaphan L, Khamma S, Benchawattananon R, Ruchuwararak P, Appamaraka S, Intamat S. Heavy metal accumulation in rice (Oryza sativa) near electronic waste dumps and related human health risk assessment. Hum Ecol Risk Assess. 2017; 23(5):1086–98. https://doi.org/10.1080/10807039.2017.1300856
31. Tom M, Fletcher TD, McCarthy DT. Heavy metal contamination of vegetables irrigated by urban stormwater: A matter of time? PLoS ONE. 2014; 9(11). https://doi.org/10.1371/journal.pone.0112441. PMid:25426946 PMCid:PMC4245087
32. Shilev S, Babrikov T. Heavy metal accumulation in solanacea-plants grown at contaminated area. Proceedings of the Balkan Scientific Conference of Biology in Plovdiv (Bulgaria). 2005; 452–60.
33. Tiwari KK, Singh NK, Patel MP, Tiwari MR, Rai UN. Metal contamination of soil and translocation in vegetables growing under industrial wastewater irrigated agricultural field of Vadodara, Gujarat, India. Ecotoxicol Environ Saf. 2011; 74:1670–7. https://doi.org/10.1016/j.ecoenv.2011.04.029. PMid:21555153
34. Eid EM, Shaltout KH. Bioaccumulation and translocation of heavy metals by nine native plant species grown at a sewage sludge dump site. Int J Phytoremediat. 2016; 18(11):1075–85. https://doi.org/10.1080/15226514.2016.1183578. PMid:27184987
35. Liu WX, Shen LF, Liu J.-W, Wang Y.-W, Li S.-R. Uptake of Toxic Heavy Metals by Rice (Oryza sativa L.) Cultivated in the agricultural soil near Zhengzhou City, People's Republic of China. Bull Environ Contam Toxicol. 2007. 79:209–13. https://doi.org/10.1007/s00128-007-9164-0. PMid:17639323
36. Chang CY, Yu HY, Chen JJ, Li FB, Zhang HH, Liu CP. Accumulation of heavy metals in leaf vegetables from agricultural soils and associated potential health risks in the Pearl River Delta, South China. Environ Monit Assess. 2013; 186(3):1547–60. https://doi.org/10.1007/s10661-013-3472-0. PMid:24185814 PMCid:PMC3902199
37. Ahmad JU, Goni MA. Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh. Environ Monit Assess. 2009; 166(1–4):347–57. https://doi.org/10.1007/s10661-009-1006-6. PMid:19521788
38. Gupta N, Khan DK, Santra SC. Heavy metal accumulation in vegetables grown in a long-term wastewater-irrigated agricultural land of tropical India. Environ Monit Assess. 2012. 184:6673–82. https://doi.org/10.1007/s10661-011-2450-7. PMid:22131014
39. Mahmood A, Malik RN. Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arab. J. Chem. 2014. 7(1):91–9. https://doi.org/10.1016/j.arabjc.2013.07.002
40. USEPA (US Environmental Protection Agency). 2015. Risk based screening table. Composite Table: Summary Tab 0615.
41. Sawut R, Kasim N, Maihemuti B, Hu L, Abliz A, Abdujappar A, Kurban M. Pollution characteristics and health risk assessment of heavy metals in the vegetable bases of northwest China. Sci Total Environ. 2018; 642: 864–78. https://doi.org/10.1016/j.scitotenv.2018.06.034. PMid:29925057