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https://doi.org/10.5109/7340475

出版情報：九州大学大学院農学研究院紀要. 70 (1), pp.1-12, 2025. 九州大学大学院農学研究院
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **70** (1), 1–12 (2025)

Ecological and Human Health Risk Assessment of Heavy Metal Contaminated Water, Soil and Vegetables in Narayanganj Industrial Area of Bangladesh

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(*Received November 4, 2024 and accepted November 6, 2024*)

The study focused on examining heavy metal contamination (chromium, copper, nickel, cadmium, and lead) in the irrigation water, soil and vegetables of Narayanganj industrial area, Bangladesh. This region faces potential environmental pollution due to various industries discharging wastewater into nearby irrigation canals, which could contaminate the soil. This study was to assess the heavy metal concentration in water, soil and vegetables and to enhance the ecological and health risk assessment by exploring various methodologies. Soil and vegetable samples were collected from various sites that received wastewater from different disposal systems. In most cases, the prevalent contaminants were found to be Cr, Cu, and Ni, followed by Pb and Cd in irrigation water, soil and vegetables. The assessment using the geoaccumulation index (Igeo) indicated that the area ranged from moderately to heavily contaminated, particularly concerning Cd and Ni concentration. The pollution load index (PLI) results suggested slight to moderate contamination. Moreover, the potential ecological risk index (RI) posed a very high risk to the environment signifying the need for monitoring and remedial measures to mitigate any adverse impacts. For the high heavy metal concentrations in vegetables, a high bio–concentration factor of vegetables (mostly >20 %) might be responsible. Despite that the soil's concentrations were in permissible level, the higher vegetable's concentrations such as Cr, Cd and Pb in Narayanganj than the standard level were observed causing serious health effect. Furthermore, the health risk index was calculated to assess the potential health risk by consuming vegetables. The results showed that the vegetables grown in the study areas were assessed unsafe for human consumption due to high heavy metals concentrations.

Key words: heavy metal, geo–accumulation index, potential ecological risk index, pollution load index, bioconcentration factor and health risk

INTRODUCTION

Heavy metals and metalloids are typically present in the environment at low levels, supporting ecological balance. However, the rise in heavy metal contamination of agricultural soils has become a critical issue in developing countries due to the high toxicity involved (Ağca and Özdel, 2014). Human activities, especially those linked to industrialization and urban expansion, have significantly raised heavy metal levels in soil, water, and crops (Islam *et al.,* 2017). Agricultural soil is especially impacted by contaminants from sources like mining, smelting, and the extensive use of fertilizers and pesticides, which deteriorate soil and water quality and harm ecosystems (Jiang *et al.,* 2017). When heavy metals enter the food chain, they create serious health hazards for both humans and animals (He *et al.,* 2015). In Bangladesh, industrial areas are concentrated in heavily populated zones, leading to unregulated waste disposal and high pollution levels. (Aktaruzzaman *et al.,* 2014).

Research indicates that wastewater from multiple sources, including industrial processes, significantly contributes to heavy metal contamination in agricultural soils (Mapanda *et al.,* 2005; Nan *et al.,* 2002). This influx of heavy metals not only harms soil quality but also results in the contamination of crops, especially vegetables, grown in these soils. Thus, the primary route of human exposure to heavy metals is through the soil–to–crop–to–food pathway. Moreover, leftover plant materials, such as roots, are often returned to the soil or used as livestock feed, presenting an additional route for heavy metals to reach humans through the consumption of contaminated animal products.

Crops grown in polluted soils tend to accumulate high levels of heavy metals, which can lead to serious health issues when consumed. Heavy metals are found on the surfaces and within the tissues of these crops, particularly vegetables. Although some trace elements are necessary for plant nutrition, crops in contaminated environments absorb excessive amounts, which has been linked to a higher rate of upper gastrointestinal cancers (Turkdogan *et al.,* 2002). Due to their non–biodegradable nature and ability to accumulate within the body, trace elements are highly toxic. Vegetables grown in contaminated soils absorb and store these metals in their

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tissues, leading to health problems for both humans and animals, as there is no effective mechanism for their elimination from the body (Arora *et al.,* 2008; Alam *et al.,* 2003).

Narayanganj district, located about 32 km from Dhaka, is a suburban industrial area experiencing rapid growth in the garments, textile, and dye industries. Unfortunately, many of these industries release untreated waste directly into nearby rivers, canals, and lakes, causing severe harm to the environment and aquatic ecosystems. Alarmingly, the final industrial effluents are often used to irrigate nearby agricultural lands. Additional pollution sources in the area include traffic congestion, emissions from brick kilns, and industrial waste, all of which significantly impact human health. As a result, water, soil, and crops in Narayanganj may contain elevated levels of heavy metals. Therefore, it is essential to perform a thorough risk assessment to examine heavy metal accumulation.

Although some research has examined heavy metal buildup in water–soil–crop systems near industrial zones in Bangladesh, there is an important gap in published data specifically addressing heavy metal contamination in Narayanganj district. Therefore, the primary objective of this study was to assess the toxic heavy metal contamination in water, soil and vegetables with a view to enhancing the ecological risk and health risk assessment by various methodologies to better understand the extent of heavy metal contamination and its potential implications on the environment.

MATERIALS AND METHODS

Selection of study area:

The research was carried out in the urban soils of Narayanganj Sadar Upazila, situated in the central region of Bangladesh (Fig. 1). This area receives various types of waste, including household waste, industrial waste, and domestic raw sewage, originating from the nearby human settlements. The topography of Narayanganj is characterized by flat Ganges–Brahmaputra–Meghna alluvial plain (Banglapedia, 2014). Soils of the area are predominantly silt loams to silty clay loams on the ridges and clay in the basins. Organic matter content is low on the ridges and moderate in the basins, top soils moderately acidic but subsoils neutral in reaction and general fertility level is low, as reported by UNDP/FAO in 1988. In Narayanganj the climate features an average annual rainfall of 2,550 mm, 80 to 90% of which occurs between May and October. (Banglapedia, 2014).

Water, Soil and vegetables sampling:

The irrigation water was sampled from irrigation canals at 30 points of Naryanganj industrial area as described in Fig. 1. Sampling of irrigation water, soil, and vegetables were carried out in two different times of wet and dry season. The first sampling was done in July–August, 2022 (wet season) and the second one was done in December 2023 to February, 2024 (dry season).

The sampling points were selected carefully to represent the situation of industrial location. Five hundred ml of irrigation water was taken in an airtight sterilized plastic bottle and carried to the Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) laboratory. In BSMRAU laboratory, the water samples were carefully filtered through a paper filter (Whatman No. 42). After filtering, each water sample was stored in a 20 ml plastic bottle, where a drop of concentrated HNO_3 (65%) was added to make the pH <2 for preservation.

Similar sampling method to the irrigation water, soil

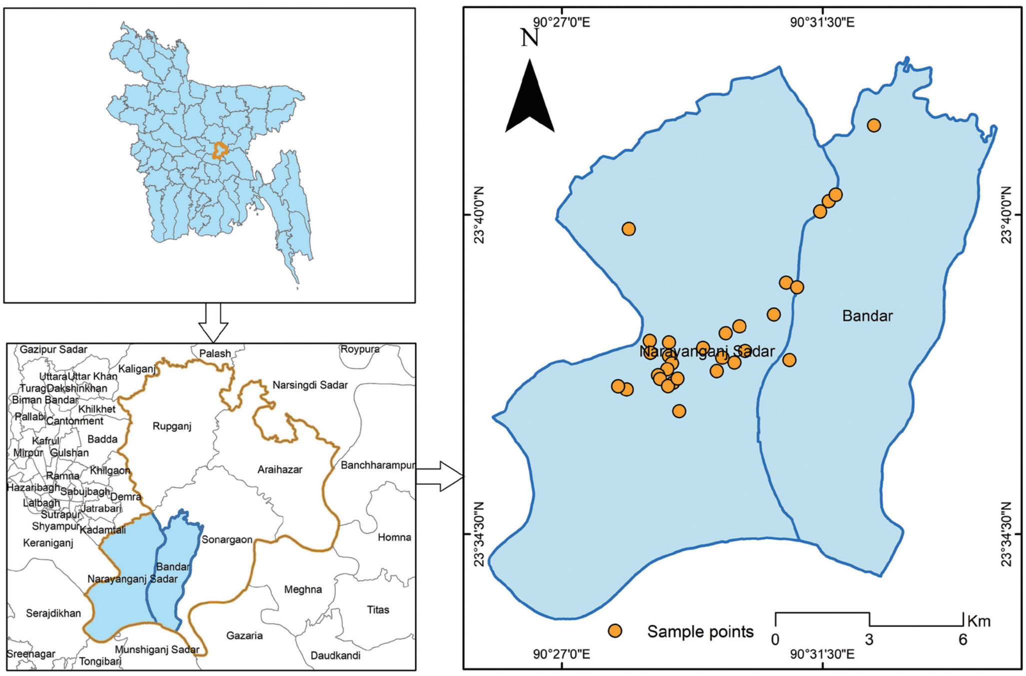

Fig. 1. Sampling locations of the Narayanganj District, Bangladesh.

was sampled from the study area. Soil samples were collected from various sites that received wastewater from different disposal systems. Five sample was collected, and these individual samples were mixed together to create a bulk sample for analysis. The sampling was done at a depth of 0–15 cm from the soil surface.

Different types of vegetables were selected from each of leaf, root and fruit vegetables for sampling, which are grown in the areas. These vegetables were consumed by the surrounding residents and supplied to the wholesale market of Dhaka capital as well. Eleven different types of commonly grown summer vegetables like taro (*Colocasia esculenta*), water spinach (*Ipomoea reptans*), jute (*Corchorus olitorius*), okra (*Abelmoschus esculentus*), *sponge gourd* (*Luffa acutangular*), amaranth (*Amaranthus lividus*), papaya (*Carica papaya*), teasle gourd (*Momordica dioica*), bottle gourd (*Lagenaria siceraria*), Indian spinach (*Basella alba*) *and* banana (*Musa sapientum*) were collected. Vegetables samples were taken from the places where the soil sampling was carried out. As similar to the soil samples mixing, five vegetable samples were mixed together to create a single composite sample for each vegetable species. After making composite samples, vegetables were packed in bags and brought to the BSMRAU laboratory.

Analytical procedure:

The sampling depth of 0–15 cm was chosen based on factors such as root depth, the most active zone with the highest root concentration, and the area's most susceptible to erosion and atmospheric deposition, as suggested by previous studies (Malan *et al.,* 2015; Neagoe *et al.,* 2005). The composite soil samples were then air–dried and ground into a fine powder using a stainless–steel grinder for further analysis.

The vegetable samples were shaken gently by hand to remove soil and washed it with tap water followed by deionized water. The samples were then separated into root, stem, leaf and fruit parts. After that, the samples were air dried to remove the moisture and again packed in transparent Ziploc polyethylene bags for preservation in desiccator. In the analysis, the samples were dried again in a hot air oven at 60°C for 48 hours until the constant weight was achieved. Finally, the dried samples were uniformly ground with a grinder and stored in desiccator.

Heavy metals analysis in water, soils and vegetables:

For the soil analysis, 1 g of each soil sample was subjected to a digestion process using concentrated HNO_3 and 30% H_2O_2 at a temperature of 95°C ± 5°C, following the USEPA 3050B method (USEPA, 1996). The digestion process continued until a clear digested solution was obtained. For the pre–treatment/digestion of vegetable samples, the UWLAB method (UWLAB, 2005) was applied.

After digestion, the resulting digested solutions, approximately 5 mL in volume, were filtered through a paper filter and then diluted to a final volume of 100 mL for soil samples and 50 ml for vegetables samples using pure water. The concentrations of the heavy metals (chromium, copper, nickel, cadmium, and lead) in the water, soils and vegetables were then analyzed using an Atomic Absorption Spectrophotometer (AAS) at Bangabandhu Sheikh Mujibur Rahman Agricultural University.

Soil quality assessment:

Geoaccumulation index (I_{geo}) were calculated following the procedure proposed by Muller (1981) and Ruiz (2001):

$$I_{geo}=\log_2\frac{CM\ (sample)}{1.5\ x\ CM\ (Background)}$$

Where $CM_{(Sample)}$ is the measured concentration of heavy metal in the sample, $CM_{(Background)}$ is the background value for the same metal and 1.5 is a multiplying factor intended to offset natural variability in background data resulting from lithological variations (Ruiz, 2001).

The classification system of geo–accumulation index includes seven classes (Ruiz, 2001)

$I_{geo}\leq 0$ uncontaminated, $0< I_{geo}<1$ uncontaminated to moderately contaminated, $1< I_{geo}<2$ moderately contaminated, $2< I_{geo}<3$ moderately to heavily contaminated, $3< I_{geo}<4$ heavily contaminated, $4< I_{geo}<5$ heavily to extremely contaminated, $5\leq I_{geo}$ extremely contaminated.

Overall pollution scores (OPS) will employ to evaluate the extent of multi–metal pollution in soils and will be calculated using the following formula:

$$OPS=\sum pi \qquad Pi=\frac{CM\ (sample)}{CM(Background)}$$

Where Pi is the single pollution index of heavy metal or contamination factor; $CM_{(Sample)}$ is the measured concentration of heavy metal in the sample, $CM_{(Background)}$ is the background value for the same metal.

Potential ecological risk index (RI)

The potential ecological risk index (RI) assesses the degree of heavy metal contamination in soil on the basis of toxicity of heavy metals and environmental response. The following equations are used to calculate the RI (Guo *et al.,* 2010).

$$C^i_f=C^i/C^i_n$$
$$E^i_r=T^i_r X C^i_f$$
$$RI=\sum^n_{i=1}E^i_r$$

Where C^i_f is the contamination factor; C^i is the concentration of heavy metal in the soil; C^i_n is the reference value for the heavy metal (Kabata–Pendias, 2011); E^i_r is the monomial potential ecological risk factor; T^i_r is the heavy metal toxic response factor. The toxic response factors for Ni, Cr, Cu, Zn, As, Cd, and Pb were 5, 2, 5, 1, 10, 30, and 5, respectively (Guo *et al.,* 2010; Islam *et al.,* 2017). Indices and grades of potential ecological risk of heavy metals were followed the procedure of Luo *et al.,* 2007 (Table 1).

Table 1. Indices and grades of potential ecological risk of heavy metal contamination (Luo *et al.*, 2007)

Potential ecological risk factor (E^i_r)	Grade of ecological risk	Potential ecological risk index (RI)	Pollution degree
$E^i_r < 40$	Low risk	RI < 65	Low risk
$40 \leq E^i_r < 80$	Moderate risk	65 ≤ RI < 130	Moderate risk
$80 \leq E^i_r < 160$	Considerable risk	130 ≤ RI < 260	Considerable risk
$160 \leq E^i_r < 320$	High risk	RI ≥ 260	Very high risk
$E^i_r \geq 320$	Very high risk		

Daily Intake of heavy Metals (DIM)

The estimated daily intake of heavy metals through vegetables is calculated with the following equation.

$$\text{DIM}=\frac{Cmetal\ X\ Cfactor\ X\ Dfood\ intake}{Baverage\ weight}$$

Where C_{metal}, C_{factor}, $D_{food\ intake}$ and $B_{average\ weight}$ represent the heavy metal concentrations in vegetables (mg/kg), conversion factor, daily intake of vegetables (Kg) and average body weight (Kg), respectively. According to the method of Rattan *et al.,* (2005), the fresh to dry weight conversion factor of green vegetables is 0.085. The daily intake of vegetables for adult persons was considered as 0.1673 kg (BBS, 2016). The average body weight of adult person in Bangladesh was considered as 66.50 kg (Khadem and Islam, 2014).

Health Risk Index (HRI)

The health risk index is the quotient between daily intake of heavy metals (DIM) and their reference dose (RfD), which is calculated as follows (Pierzynski *et al.,* 2000).

$$\text{HRI}=\frac{DIM}{RfD}$$

Where RfD represents the oral reference doses, which are 0.003, 0.04, 0.02, 0.0005, and 0.0014 mg/kg for Cr, Cu, Ni, Cd, and Pb, respectively (JECFA, 1993; USEPA, 2007). HRI> 1 means that the exposed population is in a potential health risk.

Data analysis:

Data calculations, analysis, and the creation of graphical representations were carried out using Excel version 16.90, Numbers version 14.0, and Origin Pro 8 software. ArcMap 10.3 was employed for mapping the study location.

RESULTS AND DISCUSSION

Assessment of heavy metals in irrigation water, soil and Vegetables of Narayanganj study area

Heavy metal contamination in irrigation water

Heavy metals are inherent components of soil, and their levels are dependent on the parent materials, as outlined by Barbieri in 2016. The concentration of these metals is subject to influences from both natural and human–induced factors. Human activities, notably the disposal of industrial waste, have led to an escalation in heavy metal levels within the Narayanganj study area, adversely affecting water and soil health.

The heavy metal concentration in irrigation water (wet and dry season) are shown in Fig. 2. Out of five heavy metals, the mean Cu (5.19 ug/ml) had the highest mean concentration followed by Cr (2.39 ug/ml), Pb (1.97 ug/ml) and Ni (1.43 ug/ml) in dry season whereas in wet season the concentration was also highest in Cu (2.95 ug/ml) followed by Cr (1.93 ug/ml), Pb (0.69 ug/ml) and Ni (0.22 ug/ml). The lowest concentration was observed in Cd (0.17 ug/ml and 0.01 ug/ml) in dry and wet season, respectively. In the study area, the mean concentration of each heavy metal exceeded the FAO standard except for Pb which are accepted by FAO permissible limit in both seasons (Cr: 0.1 ug/ml; Cu: 0.2 ug/ml; Ni: 0.2 ug/ml; Cd: 0.01 ug/ml and Pb: 5 ug/ml) (Ayers and Wetcot, 1985). According to pair t test the concentration were significantly ($P < 0.05$) higher in dry season compared to wet season. Therefore, the water is identified to be inappropriate to use for irrigation purposes. The order of heavy metal concentrations in the irrigation water was as follows: Cu > Cr > Pb > Ni > Cd in both seasons.

Heavy metal contamination in soil

In the soil's heavy metal analysis, chromium (Cr) exhibited the highest mean concentration at 46.54 μg/g in wet season, followed by nickel (Ni) at 38.98 μg/g, copper (Cu) at 38.27 μg/g, and lead (Pb) at 33.51 μg/g, whereas cadmium (Cd) registering the lowest concentration at 2.95 μg/g (Fig. 3a). In dry season, the highest concentration was observed in Cr (74.46 ug/g) followed by Ni (55.6 ug/g), Cu (50.23 ug/g) and Pb (53.40 ug/g). The lowest concentration was observed in Cd (6.26 ug/g). Uneven distribution across the study site was observed for copper, nickel, and lead, indicated by their elevated standard errors in both seasons. However, with the exception of cadmium, which slightly exceeded the permissible limit, the concentrations of the other heavy metals in the soil accepted to the standards in both seasons set by the Ministry of Environment in Finland (Cr: 100 ug/g; Cu: 100 ug/g; Ni: 50 ug/g; Cd: 1 ug/g and Pb: 60 ug/g) (Ministry of Environment in Finland, 2007). The concentrations in dry season were significantly higher than the wet season (according to paired t test). Fluctuations in heavy metal concentrations in the soil may be linked to variations in the distri-

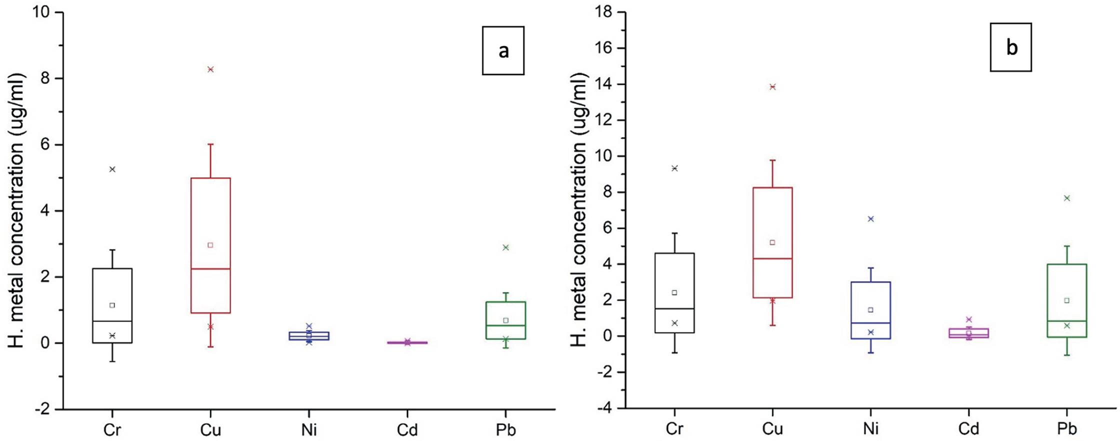

Fig. 2. Heavy metal concentration in irrigation water of Narayanganj district a) wet season b) dry season.

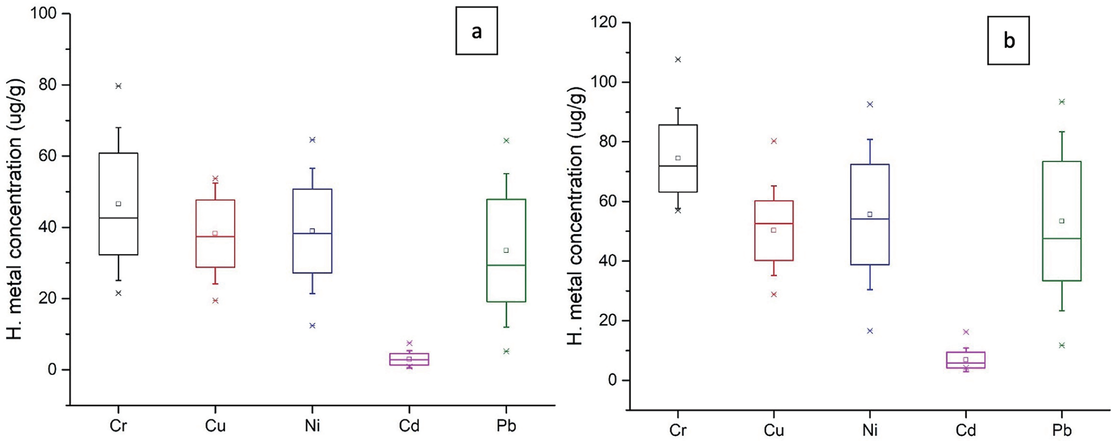

Fig. 3. Heavy metal concentration in soil of Narayanganj district a) wet season b) dry season.

bution of irrigation water from discharge points to surrounding areas, as proposed by Ahmed and Goni in 2010. In Bangladesh, agricultural soil is frequently irrigated by the recurrent use of wastewater from diverse industries and other human–related sources, mirroring the situation in the Narayanganj study site. Overall, the hierarchy of heavy metal concentrations in the soil was similar to irrigation water like: Cr > Ni > Cu > Pb > Cd in wet season and Cr > Ni > Pb > Cu > Cd in dry season.

In the soil's heavy metal analysis, chromium (Cr) exhibited the highest mean concentration at 46.54 μg/g in wet season, followed by nickel (Ni) at 38.98 μg/g, copper (Cu) at 38.27 μg/g, and lead (Pb) at 33.51 μg/g, whereas cadmium (Cd) registering the lowest concentration at 2.95 μg/g (Fig. 3a). In dry season, the highest concentration was observed in Cr (74.46 ug/g) followed by Ni (55.6 ug/g), Cu (50.23 ug/g) and Pb (53.40 ug/g). The lowest concentration was observed in Cd (6.26 ug/g). Uneven distribution across the study site was observed for copper, nickel, and lead, indicated by their elevated standard errors in both seasons. However, with the exception of cadmium, which slightly exceeded the permissible limit, the concentrations of the other heavy metals in the soil accepted to the standards in both seasons set by the Ministry of Environment in Finland. The concentrations in dry season were significantly higher than the wet season (according to paired t test). Fluctuations in heavy metal concentrations in the soil may be linked to variations in the distribution of irrigation water from discharge points to surrounding areas, as proposed by Ahmed and Goni in 2010. In Bangladesh, agricultural soil is frequently irrigated by the recurrent use of wastewater from diverse industries and other human–related sources, mirroring the situation in the Narayanganj study site. Overall, the hierarchy of heavy metal concentrations in the soil was similar to irrigation water like: Cr > Ni > Cu > Pb > Cd in wet season and Cr > Ni > Pb > Cu > Cd in dry season.

Heavy metal contamination in vegetables

Different types of summer and winter vegetables are grown in the Narayanganj study area. Heavy metal concentrations in different vegetables are shown in Fig. 4. In case of summer season, the highest mean concentration of all vegetables was observed in Ni (8.34 ug/g) followed by Cu (4.48 ug/g), Cr (4.18 ug/g) and Pb (3.19 ug/g). The lowest mean concentration was observed in Cd (1.63 ug/g). Among the vegetables, taro

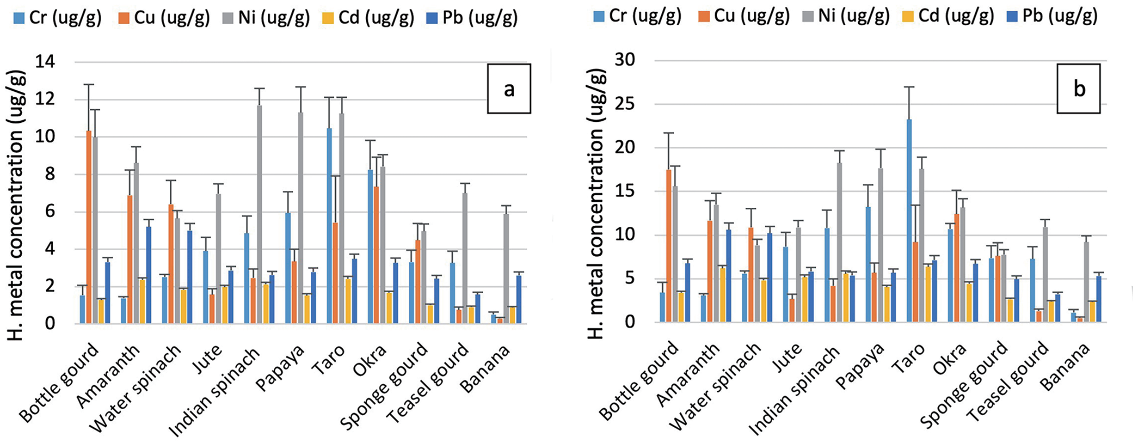

Fig. 4. Heavy metal concentration in different vegetables of Narayanganj district a) summer season b) winter season.

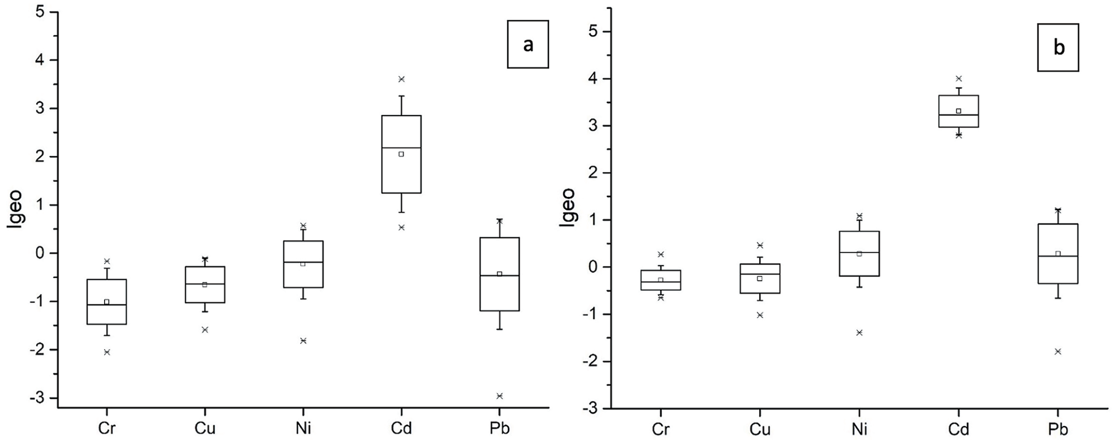

Fig. 5. Geo–accumulation index of Narayanganj study area a) wet season b) dry season.

(root vegetables) showed the highest concentration in all heavy metals followed different leafy vegetables like Indian spinach, amaranth, water spinach, okra, sponge gourd and papaya. The concentrations were very much low in banana for almost all heavy metals. Similarly in winter season, the mean concentration of heavy metals was high in Ni (13.03 ug/g) followed by Cr (8.59 ug/g), Cu (8.59 ug/g) and Pb (6.52 ug/g). The lowest mean concentration was also observed in Cd (4.30 ug/g). The mean Cr, Cd and Pb concentrations exceeded the permissible limit of FAO/WHO whereas Ni and Cu concentrations were accepted by this limit in both seasons. The permissible limits are as follows Cr: 1 ug/g; Cu: 30 ug/g; Ni: 20 ug/g; Cd: 0.2 ug/g and Pb: 0.3 ug/g (FAO/WHO, 2011). Leafy and root vegetables like Indian spinach have the highest concentration of Ni, Cr, Cu and Pb followed by taro, papaya, water spinach and amaranth. On the other hand, the lowest concentrations were observed in banana, teasel gourd, sponge gourd and bottle gourd for all heavy metals. According to paired t test, heavy metal concentrations were significantly ($p< 0.05$) higher in winter season vegetables compared to summer season vegetables. Overall, the hierarchy of heavy metal concentrations in the winter vegetables was Ni > Cr > Cu > Pb > Cd and Ni > Cu > Cr > Pb > Cd in summer vegetables.

Ecological risk assessment of Narayanganj District through different indices

Relying solely on the assessment of heavy metal concentrations in the upper layer of soil may not show a comprehensive understanding of soil contamination, as it fails to differentiate between natural background values and enrichment caused by human activities, as emphasized by Barbieri in 2016. To address this limitation, researchers, including Islam *et al.* in 2017 and 2015, as well as Aktaruzzaman *et al.* in 2014, employ various indices to evaluate soil pollution. These indices, such as the geo–accumulation index (Igeo), contamination factor (CF), pollution load index (PLI), and potential ecological risk index (RI), serve as common tools for grading the extent of soil contamination.

Fig. 5 illustrates the outcomes of the geo-accumulation index (Igeo) calculations for soil heavy metals and their corresponding contamination levels in Narayanganj. In wet season, the computed Igeo values reveal that the average concentrations of Cr (–1.01), Cu (–0.65), Ni (–0.23), and Pb (–0.43) fall within the zero class cate-

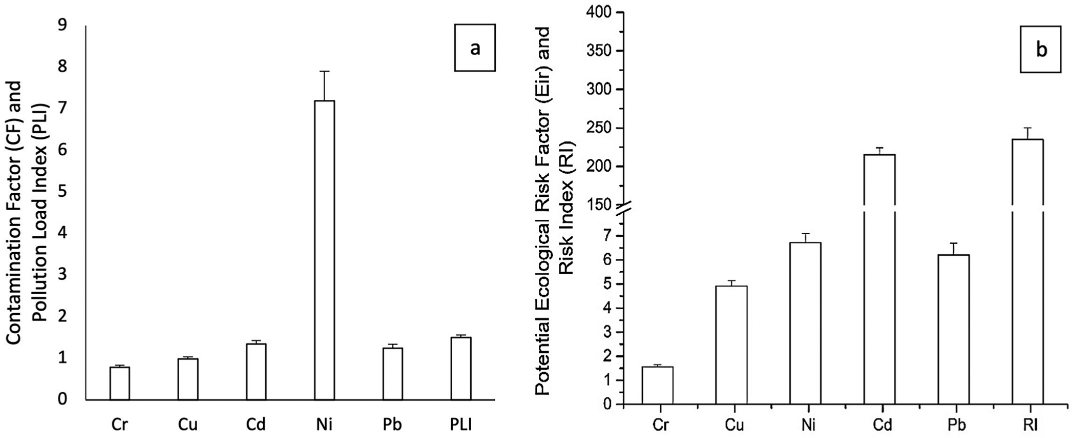

Fig. 6. Contamination Factor (CF), Pollution Load Index (PLI) and Ecological Risk Index (RI) of Narayanganj study area (wet season).

gory, suggesting an absence of contamination in the soil with respect to these heavy metals. Conversely, the average concentration of Cd possesses a positive Igeo value of 2.94, signifying moderately contaminated soil. The highest positive Igeo value for Cd reaches 3.61, indicating a heavy contamination by Cd in the soil. Whereas, in dry season the average Igeo values of Cr (–0.28) and Cu (–0.25) fall within the zero class category. The Igeo values of Ni (0.29), Pb (0.28) and Cd (3.31) showed the positive values suggesting moderately to heavily contaminated soil. The highest Igeo values was observed for Cd (4.00) indicating heavily to extremely contaminated soil. According to paired t test the dry season's Igeo values were significantly ($p<0.05$) higher compared to wet season's values.

The research site exhibited elevated concentrations of Ni and Cd in comparison to background samples, potentially attributed to human activities such as industrial discharge. The Igeo values for Cd ranked highest compared to other heavy metals followd by Ni. This suggests contamination in the research area by these heavy metals originating from human–related sources.

The contamination factor (CF) was employed to evaluate the contamination status of heavy metals in the soil of the study site. The findings revealed that in wet season Ni exhibited the highest average contamination factor at 7.18, followed by Cd, Pb, and Cu, with Cr having the lowest CF value of 0.78 (Fig. 6a). The Ni showed very high contamination of CF values whereas Cd and Pb heavy metals demonstrated a CF value exceeding one, indicative of moderate soil contamination according to Håkanson's classification (Hakanson, 1980). Consequently, the study site was determined to possess a moderate to very high level of soil contamination based on the CF results.

In this study, the pollution load index (PLI) was employed to evaluate the quality and overall toxicity of soil samples. The computed PLI values ranged from 0.73 to 2.31, with the higher value (2.31) indicating slight contamination and/or pollution in the soils of the research site (Fig. 6a). Likewise, the mean PLI value (1.49) suggested that the study site experienced light contamination and/or pollution.

To assess the degree of heavy metal contamination in the study area, an ecological risk index (RI) was calculated based on the toxicity and environmental response of these metals. The potential ecological risk factor (E_i^r) and the risk index (RI) were depicted in Fig. 6b. The E_i^r values for individual heavy metals exhibited notable variation, signifying potential ecological hazards associated with these metals. In wet season, the mean E_i^r values for Cr, Cu, Ni, and Pb were all below 40, the minimum grade for ecological risk, indicating minimal potential ecological risk from these heavy metals. The mean potential ecological risk index (RI) for the Narayanganj in wet season was 234.94, indicative of a high risk.

In dry season Ni exhibited the highest average contamination factor at 16.72, followed by Pb, Cd, and Cu, with Cr having the lowest CF value of 1.25 (Fig. 7a). The Ni showed very high contamination of CF values whereas Cd and Pb heavy metals demonstrated a CF value exceeding one, indicative of moderate soil contamination according to Håkanson's classification (Hakanson, 1980). Consequently, the study site was determined to possess a moderate to very high level of soil contamination based on the CF results. The CF values were very high in dry season as compared to wet season, according to paired t test.

In dry season, the computed PLI values ranged from 1.53 to 3.71, with the higher value (3.71) indicating slight contamination and/or pollution in the soils of the research site (Fig. 7a). Likewise, the mean PLI value (2.46) suggested that the study site experienced mild contamination and/or pollution. Likewise, the CF values, the PLI values were also very much high in dry season as compared to wet season. The PLI serves as a crucial tool for residents seeking a better understanding of environmental quality, and for decision–makers aiming to assess the pollution or contamination status, as highlighted by Islam *et al.* in 2015 and Suresh *et al.* in 2012. Consequently, the PLI results from this study should raise awareness among policymakers and the public regarding the ongoing discharge of heavy metals from industries in the research area, emphasizing the necessity for future remediation efforts.

In dry season, the mean E^i_r values for Cr, Cu, Ni, and Pb were all below 40, the minimum grade for ecological risk, indicating minimal potential ecological risk from these heavy metals. The mean potential ecological risk index (RI) in dry season was 486.19 (Fig. 7b), indicative of a very high risk, with the maximum RI reaching 715.79, also signaling very high ecological risk. The E^i_r values suggest low potential ecological risk, except for Cd, likely attributable to industrial activities in both season (Fig. 6b and 7b) (as suggested by Luo *et al.* in 2012). The RI values underscore the susceptibility of diverse biological communities to toxic compounds and the potential ecological risk posed by heavy metals, as emphasized by Islam *et al.* in 2017. Overall, the range of RI values falls between 330.68 and 715.79, indicating a very high ecological risk in dry season and 80.06 to 574.22 in wet season. These findings underscore the imperative for future remediation efforts to address the persistent discharge of heavy metals from industrial sources in the research area, as identified by the PLI, RI, CF, and E^i_r.

Transfer of heavy metals from soil to vegetables

The transfer of heavy metals from soil to vegetables is considered to be vital factor for human exposure via food consumption (Garg *et al.*, 2014). Despite the soil heavy metal concentration was under permissible level, vegetable's heavy metal concentration exceeded its permissible level. For this reason, transfer ability of heavy metals from soil to vegetables might be large. Therefore, the bioconcentration factor (BCF) of heavy metals was examined in this section. BCF shows the transferability of heavy metals from soil to vegetables, and is calculated as the ratio of heavy metal concentration in vegetables to that in soil (based on dry weight) (Ye *et al.*, 2015). BCF (shown in Table 2) is important in the dry season, because soil appears to be responsible for heavy metal accumulation in vegetables. The average of BCF values for heavy metal and vegetable are also shown in the Table 2.

BCF was the highest in Cd (0.76), followed by Ni

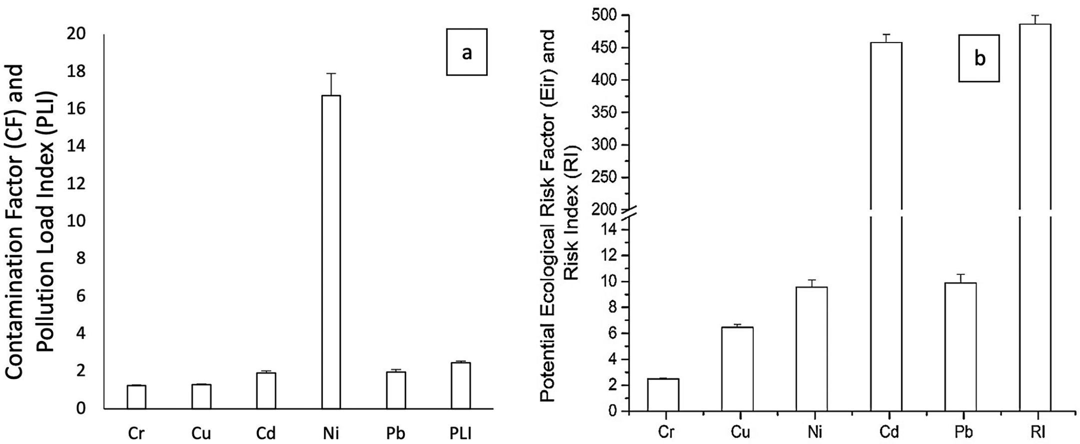

Fig. 7. Contamination Factor (CF), Pollution Load Index (PLI) and Ecological Risk Index (RI) of Narayanganj study area (dry season).

Table 2. Mean bio–concentration factor (BCF) of heavy metals for respective vegetables of Narayanganj study area

Vegetables	Cr	Cu	Ni	Cd	Pb	Ave.
Bottle gourd *(n=3)*	0.05	0.32	0.19	0.57	0.17	0.26
Amaranth *(n=3)*	0.04	0.21	0.25	1.00	0.33	0.37
Water spinach *(n=3)*	0.07	0.21	0.20	1.04	0.14	0.33
Jute *(n=3)*	0.13	0.05	0.20	0.92	0.17	0.29
Indian spinach *(n=3)*	0.14	0.14	0.30	1.16	0.10	0.37
Papaya *(n=3)*	0.21	0.18	0.46	0.65	0.15	0.33
Taro *(n=3)*	0.34	0.24	0.32	0.92	0.15	0.40
Okra *(n=3)*	0.15	0.23	0.22	0.82	0.15	0.31
Sponge gourd *(n=3)*	0.11	0.14	0.10	0.56	0.09	0.20
Teasel gourd *(n=3)*	0.12	0.04	0.19	0.33	0.07	0.15
Banana *(n=3)*	0.02	0.01	0.25	0.37	0.11	0.15
Ave	0.13	0.16	0.24	0.76	0.15	

Table 3. Estimated daily intake (DIM) of heavy metals and health risk index (HRI) of Narayanganj study (wet season)

Vegetables		Cr	Cu	Ni	Cd	Pb	Total
Bottle gourd	DIM	0.0003	0.0023	0.0021	0.0003	0.0007	0.0057
	HRI	0.11	0.055	0.11	0.55	0.51	1.33
Amaranth	DIM	0.0003	0.0015	0.0018	0.0005	0.0011	0.0052
	HRI	0.10	0.037	0.09	1.01	0.79	2.03
Water spinach	DIM	0.0005	0.0014	0.0012	0.0004	0.0011	0.0046
	HRI	0.18	0.034	0.06	0.78	0.76	1.82
Jute	DIM	0.0008	0.0003	0.0015	0.0004	0.0006	0.0037
	HRI	0.28	0.008	0.07	0.84	0.44	1.64
Indian spinach	DIM	0.0010	0.0005	0.0025	0.0005	0.0006	0.0051
	HRI	0.35	0.013	0.13	0.91	0.40	1.79
Papaya	DIM	0.0013	0.0007	0.0024	0.0003	0.0006	0.0053
	HRI	0.42	0.018	0.12	0.66	0.42	1.64
Taro	DIM	0.0022	0.0012	0.0024	0.0005	0.0007	0.0071
	HRI	0.75	0.029	0.12	1.03	0.53	2.46
Okra	DIM	0.0018	0.0016	0.0018	0.0004	0.0007	0.0062
	HRI	0.59	0.039	0.09	0.72	0.50	1.94
Sponge gourd	DIM	0.0007	0.0010	0.0011	0.0002	0.0005	0.0035
	HRI	0.24	0.024	0.05	0.43	0.37	1.11
Teasel gourd	DIM	0.0007	0.0002	0.0015	0.0002	0.0003	0.0029
	HRI	0.23	0.004	0.07	0.39	0.24	0.94
Banana	DIM	0.0001	0.0001	0.0013	0.0002	0.0006	0.0022
	HRI	0.04	0.002	0.06	0.38	0.40	0.88
Ave.	DIM	0.0009	0.0010	0.0018	0.0003	0.0007	
Ave.	HRI	0.30	0.02	0.09	0.70	0.49	

(0.24) and then by Cu (0.16), while the lowest was Cr (0.13), according to the averages of BCF data. Average BCF of Cd and Ni was >0.20, showing high values that indicates a high heavy metal absorption from the soil. According to data of FAO/WHO (2011), the BCF of vegetables higher than 0.20 is thought to be contaminated highly by anthropogenic activities and have a high health risk. For the respective vegetables, taro (0.4) showed the highest value, followed by amaranth and Indian spinach (both 0.37), according to their averages of BCF data. These vegetables (belonging to leafy vegetables) showed significant high absorption. Water spinach (0.44) (leaf vegetables) showed also a high absorption. These characteristics might contribute to the high heavy metal concentration that exceeded the permissible level.

Therefore, every vegetable is identified to be contaminated by heavy metals with an alarming level. The variation of heavy metal concentrations in vegetables may be ascribed to those of soil in the dry season. The higher contaminations of heavy metals in the cultivated vegetables were due to plant uptake of the heavy metals from the soil.

Estimated daily intake of heavy metals and health risk index

The level of heavy metals toxicity to human being depends upon their daily consumption or intake (Singh *et al.*, 2010). Long term exposure to heavy metals through the consumption of vegetables hamper biochemical process in humans (Anhwange *et al.*, 2013). Thus, to assess the toxicity level of vegetables for human consumption in heavy metal concentrations, estimated daily intake of heavy metals (DIM) was calculated. DIM of heavy metals of vegetables grown in the dry and wet season is shown in Table 3 and 4, respectively.

In the vegetables of the wet season (Table 3), the highest intakes of Cr, Cu, Ni, Cd and Pb were observed in taro followed by okra, bottle gourd, amaranth and Indian spinach. Indian spinach showed the highest intake for Ni and Cd, whereas amaranth exhibited the highest intake for Pb. The DIM values for vegetables in the wet season were lower than in the dry season, which may be due to the lower concentrations (heavy metals) in the wet season. The DIM values for Cr, Cu, Ni, Cd and Pb were ranged from 0.0001 to 0.0022, from 0.0001 to 0.002, from 0.0011 to 0.0025, from 0.0002 to 0.0005, and from 0.0003 to 0.0011, mg/kg per day respectively. The order of heavy metal intake for all vegetables are Ni > Cu > Cr > Pb > Cd.

In the vegetables of the dry season, the DIM values for Cr, Cu, Ni, Cd and Pb were ranged from 0.0002 to 0.050, from 0.0001 to 0.0027, from 0.0017 to 0.0039,

Table 4. Estimated daily intake (DIM) of heavy metals and health risk index (HRI) of Narayanganj study area (dry season)

Vegetables		Cr	Cu	Ni	Cd	Pb	Total
Bottle gourd	DIM	0.0007	0.0037	0.0033	0.0007	0.0014	0.0100
	HRI	0.24	0.094	0.17	1.45	1.03	2.98
Amaranth	DIM	0.0007	0.0025	0.0029	0.0013	0.0023	0.0096
	HRI	0.22	0.062	0.14	2.65	1.62	4.70
Water spinach	DIM	0.0012	0.0023	0.0019	0.0010	0.0022	0.0086
	HRI	0.40	0.058	0.09	2.05	1.56	4.16
Jute	DIM	0.0019	0.0006	0.0023	0.0011	0.0012	0.0071
	HRI	0.62	0.014	0.12	2.22	0.89	3.86
Indian spinach	DIM	0.0023	0.0009	0.0039	0.0012	0.0011	0.0094
	HRI	0.77	0.022	0.20	2.38	0.82	4.19
Papaya	DIM	0.0028	0.0012	0.0038	0.0009	0.0012	0.0099
	HRI	0.94	0.030	0.19	1.72	0.87	3.75
Taro	DIM	0.0050	0.0020	0.0038	0.0014	0.0015	0.0136
	HRI	1.66	0.049	0.19	2.72	1.09	5.70
Okra	DIM	0.0023	0.0027	0.0028	0.0009	0.0014	0.0101
	HRI	0.76	0.066	0.14	1.89	1.02	3.88
Sponge gourd	DIM	0.0016	0.0016	0.0017	0.0006	0.0011	0.0065
	HRI	0.52	0.041	0.08	1.13	0.75	2.53
Teasel gourd	DIM	0.0016	0.0003	0.0023	0.0005	0.0007	0.0054
	HRI	0.52	0.007	0.12	1.02	0.49	2.15
Banana	DIM	0.0002	0.0001	0.0020	0.0005	0.0011	0.0039
	HRI	0.08	0.003	0.10	1.00	0.81	1.99
Ave.	DIM	0.0018	0.0016	0.0028	0.0009	0.0014	
Ave.	HRI	0.61	0.04	0.14	1.84	1.00	

from 0.0005 to 0.0014, and from 0.0011 to 0.0023, mg/kg per day, respectively (Table 4). Among different vegetables in the dry season, taro showed the highest intake for Cr and Cd, whereas okra and amaranth showed the highest intake for Cu and Pb, respectively. Indian spinach indicates the high intake of Ni. The average DIM values of vegetables decreased in the order of Ni > Cr > Cu > Pb > Cd.

The health risk index (HRI) calculated for the consumption of vegetables in the wet and dry season for the respective heavy metals, are presented in Table 3 and Table 4, respectively. The health risk index (HRI) is the ratio of daily intake of heavy metals (DIM) and reference dose (R_fD) (Pierzynski *et al.*, 2000). In the dry season (Table 4), taro showed the highest HRI followed by amaranth, Indian spinach and water spinach. Taro exhibited the highest HRI for Cr and Cd, whereas bottle gourd and Indian spinach presented the highest HRI values for Cu and Ni. However, the HRI value (range) was observed for Cr (from 0.08 to 1.66), Cu (from 0.003 to 0.094), Ni (from 0.08 to 0.20), Cd (from 1.00 to 2.72) and Pb (from 0.49 to 1.56). In total, all vegetables showed more than 1 HRI values. In the wet season (Table 3), taro indicated the highest HRI values for Cr and Cd. Indian spinach showed the highest HRI values for Ni, whereas amaranth showed the highest HRI value for Pb. HRI values for vegetables were lower in the wet season than in the dry season. The mean HRI values were found to be higher for Cd (0.70) followed by Pb (0.49), Cr (0.30) and Ni (0.09). The lowest HRI value was observed for Cu (0.02). In total, all vegetables except teasle gourd and banana showed more than 1 HRI values.

CONCLUSIONS

For irrigation water and vegetables, heavy metal concentrations exceeded their permissible levels, while in soil, nearly all heavy metals concentrations were below the permissible level. Therefore, irrigation water is unsafe for vegetables production. The evaluation of heavy metal contamination in the study area using diverse indices indicated a range from moderately to heavily contaminated soil, with particular concern of Cd and Ni. Both the contamination factor and pollution load index highlighted a moderate to high level of contamination. The potential ecological risk index underscored a high risk associated with heavy metal contamination in the Narayanganj environment. The vegetables grown in the study areas were assessed unsafe for human consumption due to high heavy metals concentrations especially Cr, Ni, Cd and Pb. In summary, these results suggest the potential necessity for remediation measures in the irrigation water, soil and vegetables of the study area to mitigate the risks associated with heavy metal contamination.

AUTHOR CONTRIBUTIONS

Minhaz Ahmed played a role in conceptualizing and designing the study, as well as in the preparation of materials and samples, conducting analyses, and drafting the initial manuscript. Md. Abiar Rahman supervised the research efforts. Muhammad Ziaul Hoque contributed to mapping the study site and participated in subsequent revisions. Shohana Parvin and Jahid Hasan assisted in revising the manuscript. Masaru Matsumoto critically reviewed the manuscript with valuable suggestions and comments. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

The authors extend their thanks to the research management wing (RMW), Bangabandhu Sheikh Mujibur Rahman Agricultural University for the financial supports to carry out this research (Project ID: 012).

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