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Assessment of trace elements in the long-term banana cultivation field's soil

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This work assesses the contamination of trace elements (Cr, Cu, Ni, As, Zn Cd, Mn, Fe, and Pb) in soil and different tissues of the banana plant (*Musa* spp.), the ecological risks of trace elements using various indices, and the probable health risks using a chemometric approach. Soil and different banana plant tissues were collected from banana fields around the industrial area of the capital of old Pundranagar (the earliest urban archaeological location), Bangladesh. Samples were digested by acid digestion, and trace elements were measured by inductively coupled plasma spectrophotometer (ICP-MS). The concentrations of Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn in soil ranged from 1.50–61.7, 2.42–87.4, 2.00–100.8, 0.25–31.2, 0.10–12.7, 0.60–91.8, 11330–23782, 8.69–105.9, and 7.50–125.9 mg/kg, respectively. The mean concentrations of trace elements in four tissues descend in order of roots > leaves > stems > fruits. The abundances of trace elements varied in both soil and plant samples, which apparently occurred due to the variations of soil parent materials and the excessive use of agrochemicals for long-term banana cultivation. The soil exhibited a moderate to high degree of contamination with trace elements, and Cr, Pb, Zn, Cd, and As mainly originated from anthropogenic sources. Both non-cancer and cancer risks were perceived due to Cr and As exposure from the fruit tissue of banana plants in the study area.

KEYWORDS

banana, trace elements, ecological risk, bioconcentration, target cancer risk, Bangladesh

Introduction

The banana plant (*Musa* spp.) is the fourth most important crop in the world after rice, wheat, and maize, and one of the most important horticulture crops in Bangladesh (FAO, 2017). Around the world, bananas are regarded as nutrients-dense fruits. They are grown in many tropical areas where they can be utilized as nutritional complements. Different tissues of the banana plant, including leaves, roots, stems, fruits, and flowers, have been used as pest control for the management of insect bites in the agricultural fields and as a medicinal treatment for new injuries (Onyenekwe et al., 2013). The banana fruit is an important component of the human diet because it supplies nutrients such as potassium, calcium, phosphorus, iron, and vitamins C and E (Kennedy, 2009; Kumar et al., 2012). It also contains cancer chemoprevention activities that could potentially provide human health benefits (Falcomer et al., 2019; Oliveira et al., 2020). Several banana plant tissues, including leaves, stems, fruits, and roots, are used to make ropes, candy, feed for fish and poultry, vermicompost, and fabrics; they are also used in religious ceremonies (Mohiuddin et al., 2014). Bangladesh ranks as number 14 among the top 20 banana-producing nations in the world, and its annual production is approximately 1.0 million tons (Hossain, 2014). Banana plants are highly adaptable to intercropping and diversified agricultural practices and can thrive in various environmental and soil conditions (Israeli and Lahav, 2017).

However, pests and diseases infest banana plants due to the long-term cultivation of bananas on the same land, reducing soil fertility and productivity. To overcome these situations, farmers must apply different chemical fertilizers and pesticides (Lin et al., 2010). Because a banana tree takes many nutrients to develop and thrive, it is critical to give it the fertilizer it demands. A balanced fertilizer is one of the best fertilizers for banana plants because it provides all elements that the banana plant requires to grow strong and healthy. Nitrogen (N), phosphorus (P), and potassium (K) are the primary macronutrients, and the requirement of NPK fertilizer compounds is 150, 90, and 300 g/plant/year (Fonsah et al., 2017). The secondary macronutrients are calcium, magnesium, and sulfur. Micronutrients are elements required in small quantities. Despite being needed in small quantities, micronutrients are essential for the overall performance and health of the banana plant. They include iron, manganese, zinc, copper, molybdenum, and boron. In addition, the banana field's soil may have been contaminated by trace elements (Mohamed et al., 2017; Sahodaran and Ray, 2018). Studies have shown that different banana plant tissues have the potential to accumulate trace elements such as Cu, Co, Fe, Ni, and Zn and toxic elements, such as Cd and Pb, from the soil around industrial areas (Flores et al., 2018). Romero-Estevez et al. (2019) specified that increased toxic element concentrations, especially Cd, As, Ni, and Pb, pose a significant risk to consumer health, especially children. Their presence in legumes, fruits, vegetables, rice, and other foods is also shaped by a variety of variables, including contamination, fertilizers, climate, and the type and physicochemical characteristics of the soil (Ghazali et al., 2012; Marles, 2017; Stambulska et al., 2018; Islam et al., 2021a). Previous studies (Miedico et al., 2017; Bawuro et al., 2018; Kasozi et al., 2018; Islam et al., 2021a; 2022a) demonstrated that a considerable number of toxic metals (Cd, Pb, and As) and essential metals, such as Cu and Zn, have the potential for toxicity to humans and are present in animals, aromatic plants (Dghaim et al., 2015), and other types of foodstuffs (Islam et al., 2022b; Mizan et al., 2023). Therefore, it is very important to assess the trace elements in foods, especially bananas, to maintain their quality for use as a food product (FAO, 2019).

Soil is a natural resource that is needed for all human activities, especially producing crops. In the industrialized urban environment of the earth, surface soil acts as the major receiver of various contaminants, especially trace metal(loid)s (Zabir et al., 2016; Kormoker et al., 2019). Excess accumulation of trace metal(loid)s in surface soil has a destructive impact on the terrestrial ecosystem and thereby poses threats to its inhabitants (Mallick et al., 2019). If a banana plant is cultivated on contaminated soil containing trace toxic elements, it may pose significant risks to human health due to the ingestion of fruits or other parts of the plant (Flores et al., 2018). Continuous banana cultivation on the same land is responsible for trace element accumulation in soil and nearby plants and could potentially cause deterioration of the soil ecology. Hence, research on the possible impact of trace element pollution in the surface soil of banana fields on the environment and public health is important for making policies to reduce pollution and improve soil function.

Bioconcentration factor (BCF) and translocation factor (TF) are index methods employed by researchers to establish the connection between metals in the topsoil used for long-term banana cultivation and their accumulation in various tissues of plants, (Yoon et al., 2006; Igwe et al., 2014; Islam et al., 2021b). There should be concern about the ecotoxicological status of soil used for banana cultivation and human health hazards due to trace element contamination in different banana plant tissues. Methods like the contamination factor (CF), the enrichment factor (EF), the geoaccumulation index (I_{geo}), the pollution load index (PLI), and the Nemerow pollution (P_N) index have been established to assess the contamination level of trace elements in the surface soil of banana fields (Liu et al., 2014; Kormoker et al., 2019). In the current study, surface soil has been considered for trace element analysis because of quick and cost-effective methods of soil sampling that provide reliable information on a wide variety of habitats and storage of bulk contaminants of soil–plant ecosystems (Ravankhah et al., 2016; Proshad et al., 2017). Consequently, the analysis and source identification of trace elements in soil for long-time banana cultivation should be seriously considered to ascertain the degree of pollution, the ecological risk of trace elements in the soil of banana fields, and the formulation of remediation approaches. Numerous methods have been adopted to evaluate health risks. Target cancer risk (TCR) is utilized for carcinogenic risk estimation, while target hazard quotients (THQs) are often predicated on the levels of trace elements in the edible portions in relation to the required dose of the element acceptable by the body (USEPA, 2010).

Islam et al. (2021b) showed that vegetables grown near a waste facility in an urban area of Bangladesh are a major source of toxic substances that cause potential risks to human health. There should be concern about the long-term cultivation of bananas in the urban soil around the ancient city of Pundranagar, Bangladesh. Excessive metal accumulation in soil and plants can cause public health defects. No systematic studies have been conducted to assess the levels of trace elements in the soil used for long-term banana cultivation, nor assesshuman health risks due to the exposure of

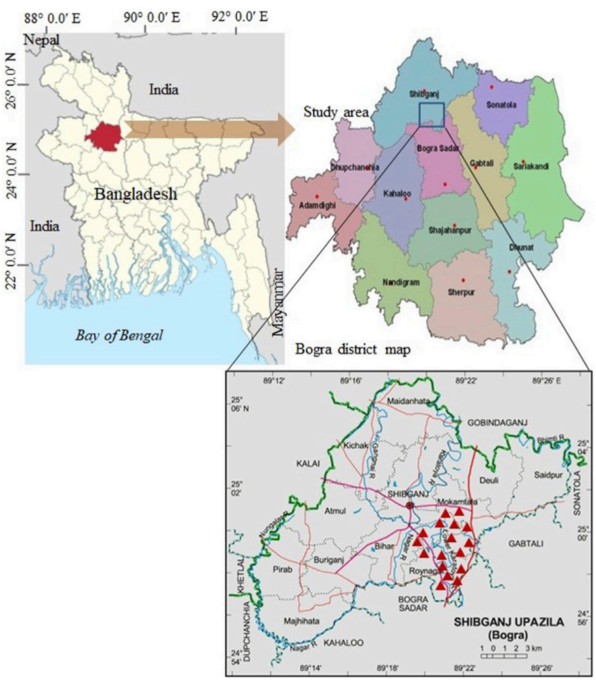

FIGURE 1
Study area map for soil samples from banana fields located around the industrial area of the capital of ancient Pundranagar, Bangladesh.

trace elements from different tissues of banana plants. The biological danger to topsoil from the introduction of trace metals and the risk accompanying the consumption of contaminated banana fruit are sources of concern. The extent of health hazard consequences, ecological risk, and exposure assessments were conducted to explain the effects of soil adulteration by trace components due to long-term banana cultivation. Therefore, the current study hypothesized that long-term cultivation of bananas in the same field has a potential effect on trace element buildup in topsoil as well as various tissues of plants. The current study is the first to evaluate the level of trace elements in surface soil and the ecological risk of trace elements posed by long-term banana cultivation, to observe the accumulation of trace elements using the BCF in various banana plant tissues, and to evaluate the potential health risks for the inhabitants living close to the industrial area of the ancient capital city of Pundranagar, Bangladesh.

Materials and methods

Study area and sampling

The industrial section of the ancient city of historical Pundranagar, Bangladesh, and the farmlands used for long-term banana farming were chosen as the study sites (Figure 1). We selected some virgin fields in the study region to compare the consequences of longstanding banana cultivation on the physicochemical properties of topsoil. The selected site of the current study is one of the earliest urban archaeological locations in Bangladesh, known as Paundravardhanapura or Pundranagara, in the region of Pundravardhana (Hossain, 2006). Pundranagara, a significant city of the Maurya Empire, was occupied until the eighth century. The economy of Bangladesh in the study area comprises various activities, such as agrarian activities, manufacturing events like convenience garments, poultry feed production, food packaging, and agrochemical industries (Zakir et al., 2013). During sampling, we observed that farmers have been using untreated wastes from various industries and chemical fertilizers/pesticides in the banana fields for 10 years or more. A number of surface soil samples (51) were taken at a 0–20 cm depth, and 56 different stem, root, leaf, and fruit tissue samples were collected during January–June 2019. Triplicate plant specimens of the banana (*Musa* spp.) species were randomly selected from the banana fields. The plant tissues and soil samples (approximately 500 g each) were placed in polyethylene bags, carefully labeled, and brought to the lab, where they were dried in the sun for a few days. To achieve the constant weight, samples were then ground, homogenized, and dried for 72 h at 65°C in the oven. Before the chemical analysis, the prepared soil and plant specimens were preserved hermetically in clean Ziploc bags in a refrigerator (4°C).

Sample analysis for trace elements

Trace elements in soil and plant specimens were analyzed in the Laboratory of Plant Nutrition and Fertilizer, using inductively coupled plasma mass spectrometry (ICP-MS, 7800, Agilent Technologies). Approximately 2–4 mg of plant tissues and 3.0 g of dry soil samples were digested by adding 4.0 mL of 65% HNO_3, 1.0 mL concentrated HCl, and 2 mL of 30% H_2O_2 (Wako Chemical Co., Japan), using a microwave digesting apparatus with a Teflon tube (Kühnlenz et al., 2016). A standard solution XSTC-13 (Spex CertiPrep® USA) was employed ($R^2 > 0.999$) to create the calibration plot. Indium, yttrium, beryllium, telium, cobalt, and titanium (1.0 mg/L) were used as internal standards. Ultrapure-grade 5% (v/v) HNO_3 was used for sample preparation and dilution. A similar process was followed to verify the batch-specific accuracy throughout the experimental performance; triple measurement protocol blanks were run and verified using Japanese-certified reference material (NMIJ CRM 7303-a) and Polish-certified reference material (INCT-CF-3) of corn flour (Supplementary Table S1).

Data calculation

Evaluation of metal accumulation and bioavailability

The BCF is widely used to measure the extent to which a living organism (plants and animals) absorbs any element from its environment and transfers it to tissues in the organism. Generally, a BCF value of less than or equal to 1 (BCF ≤1.0) suggests that the organism can uptake trace elements in its environmental compartments (soil, air, or water), but those elements only accumulate in their tissues in a minor quantity. However, a BCF value above 1 (BCF >1.0) implies a considerable accumulation of trace elements in tissues (Liu et al., 2009). The BCF of trace elements in the different banana plant tissues was expressed following the method of Islam et al. (2018):

$$BCF_{banana} = C_{root/stem/fruits/leaves}/C_{soil}, \quad (1)$$

where $C_{root/stem/fruits/leaves}$ stands for the trace element contents (mg/kg dw) in banana roots, stems, fruits, and leaves, while C_{soil} is the measured trace element value in the soil collected from the banana field (Islam et al., 2018).

Ecological risk assessment of trace elements

Contamination factor

To calculate the CF of studied trace elements, the concentration of each element in the soil of the target sites of the banana field was divided by the background value selected from the background samples at the research site:

$$CF = \frac{C_{element}}{C_{background}}, \quad (2)$$

where CF indicates a contamination factor, $C_{element}$ is the abundance of trace elements in the soil sample, and $C_{background}$ is the background abundance of trace elements in preindustrial soil samples. The background abundances of Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn were 3.07, 3.28, 1.99, 1.19, 0.31, 2.09, 11570, 18.97, and 7.77 mg/kg, respectively. For the background sample, a soil sample was collected using a percussion hammer corer (Schottler and Engstrom, 2006). Lead-210 dating by alpha spectrometry was employed to understand the levels of trace elements in the background sample before the industrial or other anthropogenic effects based on the assumption of the "pre-industrialization" state (Islam M. S. et al., 2015). Håkanson (1980) classified four grades of CF for trace element monitoring in any contaminated area over a certain period (Supplementary Table S2).

Degree and modified degree of contamination

The degree of contamination (C_d) and modified degree of contamination (mC_d) in soil were investigated using the following formulae developed by Håkanson (1980). The C_d and mC_d were determined as follows:

$$C_d = \sum_{i=1}^{i=n} CF, \quad (3)$$

$$mC_d = \frac{1}{n}\sum_{i=1}^{n} CF, \quad (4)$$

where CF is the contamination factor and n is the total number of trace elements analyzed in soil samples. Håkanson (1980) proposed four grades, and Abrahim and Parker (2008) proposed seven grades of degree of contamination (C_d) to explain the modified degree of contamination (mC_d) for trace elements in soil (Supplementary Table S2).

Pollution load index

The PLI, which is calculated as the following CF multiplication of the trace elements, is known as the *n*th root:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots\ldots \times CF_n)^{1/n}, \quad (5)$$

Based on the value of PLI, Sadhu et al. (2012) classified three grades of soil due to trace elements contamination in soil (Supplementary Table S2).

Geoaccumulation index

For contamination assessment, the geoaccumulation index (I_{geo}) has been calculated as follows:

$$I_{geo} = \log_2 (C_n/1.5B_n), \quad (6)$$

where C_n is the determined abundance of trace element "n" in the soil sample and B_n is the baseline value of element "n" in the background soil sample. A factor of 1.5 is applied to reduce any fluctuations in the background values caused by lithogenic influences. Müller (1981) interpreted seven classes of I_{geo} for trace elements in soil (Supplementary Table S2).

Enrichment factor

The magnitude of trace elements in any contaminated environment can be assessed by the enrichment factor (EF) (Franco-Uria et al., 2009). For the present study, the Fe value from each field site was used for trace element normalization and calculated as follows:

$$EF = \left(C_n/C_{\text{element normalized by Fe}}\right)_{\text{sample in target}} \Big/ \left(C_n/C_{\text{element normalized by Fe}}\right)_{\text{background sample.}} \quad (7)$$

The ratio of the trace elements in the examined sample (C_n) to the element in the background is standardized by normalizing the amount of the element in the soil and background to the amount of Fe (mg/kg) in the soil and background (Islam et al., 2022a). Birch and Olmos (2008) classified seven CF groups presented in Supplementary Table S2.

Nemerow pollution index

The Nemerow pollution index (PN) is utilized to evaluate the comprehensive status of soil due to trace element contamination (Islam et al., 2022a). Natural changes of trace elements can be seen in the soil environment at any particular location; PN differentiates from other pollution assessment indices in that it considers both the maximum and average abundances of trace elements under consideration. It is calculated as follows:

$$PN = \sqrt{CFmean^2 + CFmax^2/2}, \quad (8)$$

where CF indicates the mean contamination factor value of trace elements in the soil under investigation and CFmax is the highest CF for a specific element in a specific soil sample (Chen, 2010).

Mean effects range median quotient

The mean effects range median quotient (MERM-Q) of trace elements can be calculated by the following equation:

$$MERM - Q = C_n/ERM, \quad (9)$$

where C_n is the concentration of the metal in the soil sample, and the ERM values for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn are 370, 52, 270, 70, 10, 218, 15000, 550, and 410, respectively (Islam et al., 2022b).

Potential ecological risk

The potential ecological risk index (RI) was used to evaluate the degree of trace element contamination of the examined soil that can be used for long-term banana cultivation, and the calculation procedure is as follows:

$$E_r^i = T_r^i \, x \, CF, \tag{10}$$

$$RI = \sum E_r^i, \tag{11}$$

where T_r^i represents the toxic-response factor for a particular element and RI represents the total risk factors for trace elements. The T_r^i values for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn are 2, 6, 5, 10, 30, 5, 20, and 1, respectively (Guo et al., 2010). Five toxicity levels and four RI categories were established by Håkanson (1980) for the potential ecological risk factor (E_r^i) of a single element (Supplementary Table S2).

Health risk assessment

Daily intake of trace elements

The estimated daily intakes (EDIs) of trace elements (mg/kg-bw/day) were computed based on elemental concentration in banana fruits, daily consumption, and the average body weight of the occupants. The calculation procedure is as follows:

$$EDI = \frac{FIR \times C}{BW}, \tag{12}$$

where FIR indicates banana intake (g/person/day), C is the value of the analyzed trace elements [mg/kg, fresh weight (fw)], and BW is the average body weight (60 kg for adults and 16 kg for a child; FAO, 2006). The daily intake rates of banana fruit were given as 50.59 g and 25.33 g for adults and children, respectively (HIES, 2017).

Non-carcinogenic and carcinogenic risks

The THQ and target carcinogenic risk (TCR) were applied to assess the non-carcinogenic and carcinogenic health threats associated with banana fruit intake (USEPA, 1989). THQ can be measured as follows:

$$THQ = \frac{\left(EF_r \times ED \times FIR \times C \times 10^{-3}\right)}{RfD \times BW \times AT}, \tag{13}$$

where EFr is the exposure frequency (365 days/year), ED is the exposure duration (assuming 70 years) (USEPA, 1991), RfD indicates oral reference dose (mg/kg/day), and AT is the averaging time for non-carcinogens (365 days/year × number of exposure years, assuming 70 years). The oral reference doses were 1.5, 0.02, 0.04, 0.0003, 0.003, 0.004, 0.7, 0.14, and 0.3 mg/kg/day for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn, respectively (USEPA, 2010). Following USEPA (1989), the TCR was estimated using Eq. 14:

$$TCR = \frac{\left(EF_r \times ED \times FIR \times C \times CSFo \times 10^{-3}\right)}{BW \times AT}, \tag{14}$$

where *CSFo* represents the oral carcinogenic slope factors 0.5 and 1.5 $(mg/kg/day)^{-1}$ for Cr and As, respectively (USEPA, 2010).

Statistical analysis

The data were evaluated using the statistical package SPSS 20.0 (SPSS, USA). Nine trace elements in the soil of banana farms were chosen, and their means, standard deviations, variances, relative standard deviations, kurtosis, and skewness were computed. Principal component analysis (PCA) was used to identify potential pathways or origins of the trace elements by measuring the variable's average value. The isolated component's eigenvalue and loading value were greater than 1 and 0.5, respectively. Statistical analysis, such as analysis of variance (ANOVA), was carried out to check the variability of metal concentration in soil and banana tissues. We applied bivariate correlations analysis with a Tukey *post hoc* test to verify significant differences in metal concentrations in soil and different tissues of banana plants among sampling sites. Microsoft Excel 2010 was also used for other calculations.

Results and discussion

Descriptive statistics of trace elements in soil

Table 1 and Supplementary Figure S1 show the descriptive statistics of Cr, Cu, Ni, As, Pb, Cd, Fe, Mn, and Zn in the topsoil of a banana field used for long-term banana farming. There was a perceptible change in the amounts of the examined trace elements in the soil samples. Among the measured elements, the highest mean value was observed for Fe (15,390 mg/kg), followed by Zn (49.37 mg/kg). The average values of trace elements in soil samples followed the descending order of Fe > Zn > Mn > Cu > Ni > Pb > Cr > As > Cd. As highlighted in Table 1, an elevated standard deviation was observed for the evaluated trace elements in surface soil samples, which exhibited relatively substantial spatial variability. This variation might be due to the application of various metal-contaminated agrochemicals, such as diazinon, trichlorfon, carbofuran, chlorpyrifos, carbaryl, 1,3-dichloropropene, thiabendazole, atrazine, and glufosinate ammonium (Henriques et al., 1997; Dong et al., 2019; Rosa et al., 2020). There was a finding that trace element extents in banana fields were far higher than in the virgin field (Supplementary Figure S1), indicating that the application of various insecticides or pesticides and excavation in the banana fields could be the causes of the increased contaminant content in banana cultivated soil.

The average extents of Cu, Cd, As, and Pb in the topsoil of banana fields in the present study were higher than the average shale values (ASV) (Turekian and Wedepohl, 1961), the BV (background value) in Bangladesh (Kashem and Singh, 1999), and the standard of Dutch soil quality (VROM, 2000), indicating their contamination in the soil and the possibility of potential ecological risk to the banana field soils. Islam et al. (2021b) conducted a study in the soils of Bangladesh, and they stated that toxic-element-contaminated waste from burning or metal processing sites of an industrial area and imbalanced use of pesticides in agricultural fields are responsible for the elevated levels of As, Cu, Pb, and Cd. This study highlighted similar

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TABLE 1 Descriptive statistics for trace elements (mg/kg) in soil collected from the banana fields around the capital of ancient Pundranagar, Bangladesh, compared to the standard values.

Element	Data concentration (mg/kg)									
	Max	Min	Average	Standard deviation	CV	Kurtosis	Skewness	Standard[a]	Standard[b]	Standard[c]
Cr	61.72	1.50	23.75	15.05	0.63	−0.34	0.46	90	NA	100
Ni	87.40	2.42	38.83	25.58	0.66	−1.00	0.42	68	22	35
Cu	100.8	2.00	41.50	28.57	0.69	−1.12	0.39	45	27	36
As	31.22	0.25	9.55	7.06	0.74	0.80	0.88	13	3	29
Cd	12.74	0.10	5.19	3.46	0.67	−0.70	0.23	0.3	0.01–0.2	0.8
Pb	91.84	0.60	35.76	24.84	0.69	−0.87	0.10	20	20	85
Fe	23782	11330	15390	3772	0.25	−0.22	0.84	46000	NA	NA
Mn	105.98	8.69	42.99	27.39	0.64	−0.75	0.66	850	NA	NA
Zn	125.96	7.50	49.37	35.12	0.71	−0.76	0.75	95	NA	140

Note: SD, standard deviation; RSD, relative standard deviation; CV, coefficient of variation.
[a]Average shale value (Turekian and Wedepohl, 1961).
[b]Average background of Bangladesh (Kashem and Singh, 1999).
[c]Dutch soil quality standard (target value) (VROM, 2000).

reasons for elevated trace elements in the soil of banana fields around the industrial area in Bangladesh. In the current study, surprisingly an anomalous concentration of Cd was observed, which was 17.3 times higher than the average shale standard of Cd in soil (Table 1). On the earth's surface, Cd is the most eco-poisonous component; its elevated level in farming soil is a notable concern of environmental scientists due to its adverse effect on the soil ecosystems, especially on soil flora and fauna (Ekere et al., 2020).

The coefficient of variation (CV) of As, Zn, Cu, Cd, and Pb is distinctly greater than that of other examined elements, which demonstrated that the studied trace elements, especially As, Zn, Cu, Cd, and Pb, are distributed unevenly in the surface soil of banana fields and are affected by the human activities of banana cultivation (Zhuang et al., 2021). The value of kurtosis indicates that As in the examined soil had a typical distribution and was likely due to a variety of banana cultivation activities and industries in the study area. Either a positive or negative attribute of skewness is possible where the high values of skewness for the examined trace elements confirm the present situation for banana cultivation in soil over a long period of time. The skewness values of As, Fe, Zn, and Mn were 0.88, 0.84, 0.75, and 0.66, respectively, indicating a positive skewness toward the higher concentrations in soil in the present study (Table 1). In this work, the skewness of the examined metalloids in surface soil was positive, which revealed their asymmetric distribution (Sadhu et al., 2012; Abbasi, 2019).

The concentration of trace elements in banana tissues

The quantities of Ni, Cr, Cu, Cd, As, Pb, Fe, Zn, and Mn (mg/kg dw) in the four main tissues (leaves, stems, fruits, and roots) of the banana plant are presented in Table 2. Varied abundances of trace elements were observed in the soil, which could be reflected in the considerable variations of trace elements in the examined four banana plant tissues. The average level of trace elements in the tissues of banana plants followed the descending order of roots > leaves > stems > fruits. Among the plant tissues, roots accumulate more trace elements than other parts, which may be due to their direct contact with soil. The second highest abundance of trace elements was found in banana leaves, which can be explained by the fact that the large surface area of leaves is regarded as the first recipient of contaminants from industrial emission (Liu et al., 2009; Rosa et al., 2020). An exploration of weed species plants was led by Zhao and Duo (2015), who stated that leaves accumulate higher levels of trace elements than other parts. Interestingly, Cu was detected in substantial amounts in plant leaves, possibly as a result of the chloroplasts' photosynthetic activity, plant respiration, and assistance in the plant metabolism of carbohydrates and proteins. Because Cu regulates enzymatic activity for lignin formation, and chloroplasts are the typical component of leaves, substantial Cu buildup is anticipated in plant leaves (Islam et al., 2021b).

Mean abundances of Cr (mg/kg) were found to be 5.98 in leaves, 5.03 in stems, 2.30 in fruits, and 8.54 in roots (Table 2). Islam et al. (2015a) reported that Cr content in banana fruits in Bangladesh was 1.2 mg/kg (range 0.06–3.6 mg/kg), and Shaheen et al. (2016) also observed 0.32 mg/kg Cr in banana, which was in line with the present study. The mean concentrations of Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn in leaves, stems, fruits, and roots are presented in Table 2. Significant differences were observed for trace elements in different tissues of plants, which indicated that plant tissues had different accumulation potentials for trace elements. In contrast to soil and water, food is the predominant supplier of possibly dangerous substances to humans, including Cr, Pb, Cd, and As (Ma et al., 2018; Kuerban et al., 2020). However, mean extents of Cr, As, Cd, Pb, Mn, and Zn in banana plants were higher than the permissible limits proposed by FAO/WHO (2011) (Table 2),

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TABLE 2 Mean concentrations (mg/kg fw) of trace elements in different tissues of banana plants collected from the fields around the industrial area of the capital of ancient Pundranagar, Bangladesh (n = 3).

Plant part		Cr	Ni	Cu	As	Cd	Pb	Fe	Mn	Zn
Leaves	Range	2.06–11.49	4.22–15.1	5.62–22.1	2.45–7.89	0.26–1.31	0.54–2.56	29.56–92.56	5.04–16.2	36.85–80.06
	Mean ± SD	5.98 ± 2.79^a	8.50 ± 4.03^a	12.84 ± 5.98^a	4.56 ± 1.37^a	0.82 ± 0.36^a	1.49 ± 0.60^a	64.72 ± 17.04^a	10.59 ± 3.24^a	50.87 ± 11.82^a
Stems	Range	2.11–8.30	2.95–14.10	2.70–18.34	2.02–6.62	0.14–1.35	0.32–1.81	45.90–96.60	6.59–14.23	35.67–74.23
	Mean ± SD	5.03 ± 2.10^a	8.02 ± 3.59^a	8.12 ± 4.09^b	3.84 ± 1.60^a	0.58 ± 0.41^a	0.82 ± 0.52^b	71.53 ± 17.69^a	10.74 ± 2.59^a	54.95 ± 11.58^a
Fruits	Range	0.59–8.30	2.05–14.1	1.01–18.34	1.04–6.62	0.05–1.35	0.08–2.61	29.69–96.67	5.88–16.43	22.2–74.23
	Mean ± SD	3.20 ± 1.83^b	5.74 ± 3.60^b	3.87 ± 2.41^c	2.52 ± 0.97^b	0.26 ± 0.24^b	0.73 ± 0.63^b	58.16 ± 17.49^b	9.95 ± 3.08^a	38.57 ± 9.99^b
Roots	Range	3.39–13.92	2.74–17.73	2.3–9.59	2.04–9.29	0.48–2.48	0.55–6.08	51.1–129.05	9.56–22.31	29.5–63.7
	Mean ± SD	8.54 ± 2.93^c	9.97 ± 5.11^a	6.38 ± 1.98^b	5.65 ± 2.17^a	1.34 ± 0.63^c	2.29 ± 1.61^a	89.21 ± 23.85^c	15.02 ± 3.62^b	52.87 ± 9.05^a
MAC (FAO/WHO, 2011)		2.3	66.9	40	0.10	0.05	0.10	400	10	50

Note: The letters a, b, and c indicate statistically significant difference at the 0.05 level of trace elements among the plant parts; MAC, maximum allowable concentration of trace elements.

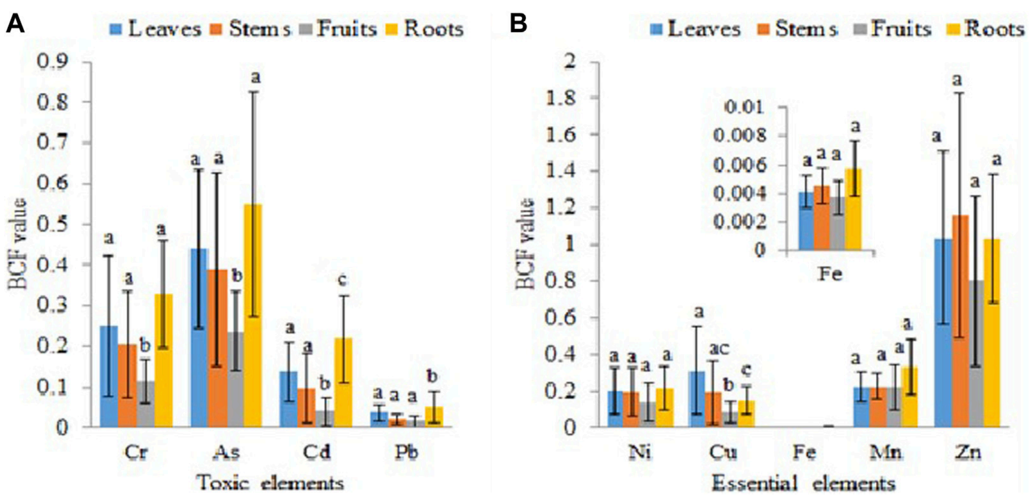

FIGURE 2
Bioconcentration factor (BCF) of toxic **(A)** and essential **(B)** elements in leaves, stems, fruits, and roots of banana plants cultivated in the capital of ancient Pundranagar, Bangladesh. Error bars represent the standard deviation (n = 3). Letters a, b, and c indicate a statistically significant difference at the 5% level.

suggesting the contamination of different banana plant tissues by those elements and potentially imposing risks to consumers. The enhanced levels of Zn, Mn, Cr, As, Pb, and Cd in banana tissues might be due to the effects of applying various wastes from the waste piles around the industrial area and imbalanced application of fertilizers, pesticides, and other agrochemicals to the banana fields (Lin et al., 2010; Ahmed et al., 2016; Rosa et al., 2020). The mean extents of trace elements in various tissues of the banana plant followed the descending order of Fe > Zn > Mn > Cu > Ni > Cr > As > Pb > Cd.

Bioconcentration of trace elements

Trace elements are absorbed from the soil by the banana plant roots and are dispersed to other parts of the plant. The calculated values of the BCF are shown in Figure 2. The BCF values of As, Cr, Cd, Fe, and Pb in roots were higher than those in stems, fruits, and leaves (Figures 2A, B), indicating that roots have more accumulation potential of these elements. This was in line with earlier research by Bonanno (2013), who reported that essential micronutrients can be easily ingested by the lower parts of plants like the roots. Although the BCF value for trace elements in fruits was relatively lower than the other three tissues, fruits could have a direct adverse health impact on the consumers who frequently consume bananas from the study sites. Considering all the examined tissues, the mean BCF values of trace elements followed in the descending order of Zn > As > Mn > Cr > Ni > Cu > Cd > Pb > Fe. Among the studied elements, the most concerning toxic elements are Cd and Pb, which showed a relatively lower BCF value, possibly due to their stable form in the soil of the cultivated field (Khairiah et al., 2009; Islam et al., 2021a) or the situation of their oxide form in the topsoil (Juen

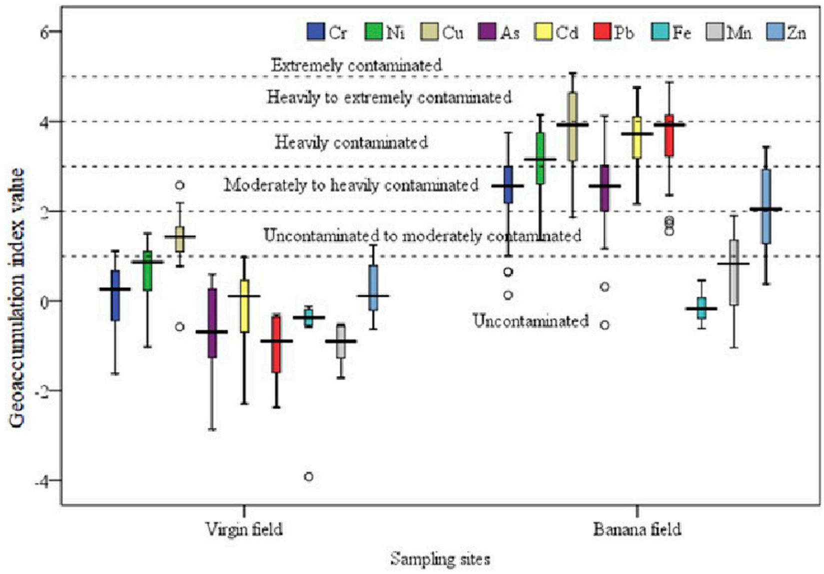

FIGURE 3
Geoaccumulation index (I_{geo}) of trace elements in banana field soil around the capital of ancient Pundranagar, Bangladesh. The horizontal dotted line indicates the class of the I_{geo} value.

et al., 2014; Islam et al., 2022b). The BCF values of Zn in leaves, stems, fruits, and roots were 1.03, 1.16, 0.80, and 1.04, respectively, which were slightly higher than 1.0, suggesting that the bioavailability of Zn is high, and plants can easily accumulate this element from soil and disperse it to the aboveground tissues. Previous studies by Subramanian et al. (2022) and Islam M. D. et al. (2020) stated that variations in the plants' element adsorption capacity, species of plant, the anchoring behavior of nutrients by root systems, and the prevailing ecological conditions of soil account for the variation of trace element accumulation by banana plants.

Soil contamination assessment

The contamination of soil by trace elements was assessed by various chemometric approaches such as the geoaccumulation index (I_{geo}), the contamination factor (CF), the enrichment factor (EF), the pollution load index (PLI), the degree of contamination (C_d), the modified degree of contamination (mC_d), the mean effects range median quotient (MERM-Q), the potential ecological risk index (PERI), and the Nemerow pollution index (P_N). The data are presented in Figure 3 and Figure 4 and Supplementary Figures S2, S3. The I_{geo} values are presented in Figure 3. Considering the virgin and banana fields, the I_{geo} values are in the descending order of Cu > Cd > Pb > Ni > Cr > As > Zn > Mn > Fe (Figure 3). According to Müller (1981), I_{geo} values indicated that the studied soil was moderately to heavily contaminated with Cu, Cd, Pb, and Ni, whereas it was uncontaminated to moderately contaminated with Cr, As, and Zn (Figure 3). Based on I_{geo} values, the soil of virgin land was not contaminated by trace elements, unlike the soil of long-term banana cultivation, confirming that long-term banana cultivation practices are responsible for elevated trace elements in banana field soil.

EF is a tool that can categorize the natural or anthropogenic origin of trace elements (Proshad et al., 2019; Asomba et al., 2023). Trace elements were somewhat enriched in the soils of the virgin field, whereas severe to very severe modification was observed for trace elements except Fe and Mn in the banana field (Supplementary Figure S2). Altogether, the EF of the studied elements were in the descending order of Cu > Pb > Cd > Ni > As > Cr > Zn > Mn > Fe (Supplementary Figure S2). The EF value of studied trace elements in the banana field was larger than 1.5, indicating man-made activity. Industries are responsible for the high enrichment of trace elements in the surface soil of the examined positions (Islam M. S. et al., 2020; Ustaoğlu and Islam, 2020). Shirani et al. (2020) stated that anthropogenic activity accounted for the higher enrichment of Cd, Pb, Cr, and Ni in the aquatic setting of Iran, which is consistent with this study.

According to the classification system of Håkanson (1980), the examined trace elements in the soil of virgin fields demonstrated little significant pollution whereas, in banana fields, soil presented very high contamination for most of the trace elements, except for Fe and Mn, which showed moderate contamination (Supplementary Figure S3).

The PLI acts as an effective technique for pollution evaluation. A PLI of zero indicates the suitability of soil for crop production, a PLI value of 1 indicates background levels of trace elements, and PLI values greater than 1 designate the soil as contaminated by trace elements (Proshad et al., 2021). The mean values of PLI were observed as 1.49 and 8.12 for virgin and banana fields, respectively (Figure 4A), which indicated that the soils of the current study are polluted by trace elements (PLI >1). The PLI of the banana field was significantly higher than that of the virgin field, indicating the effect of long-term banana cultivation on trace element accumulation in soil. The PLI value for the virgin field was greater than one, confirming the operation of metal processing

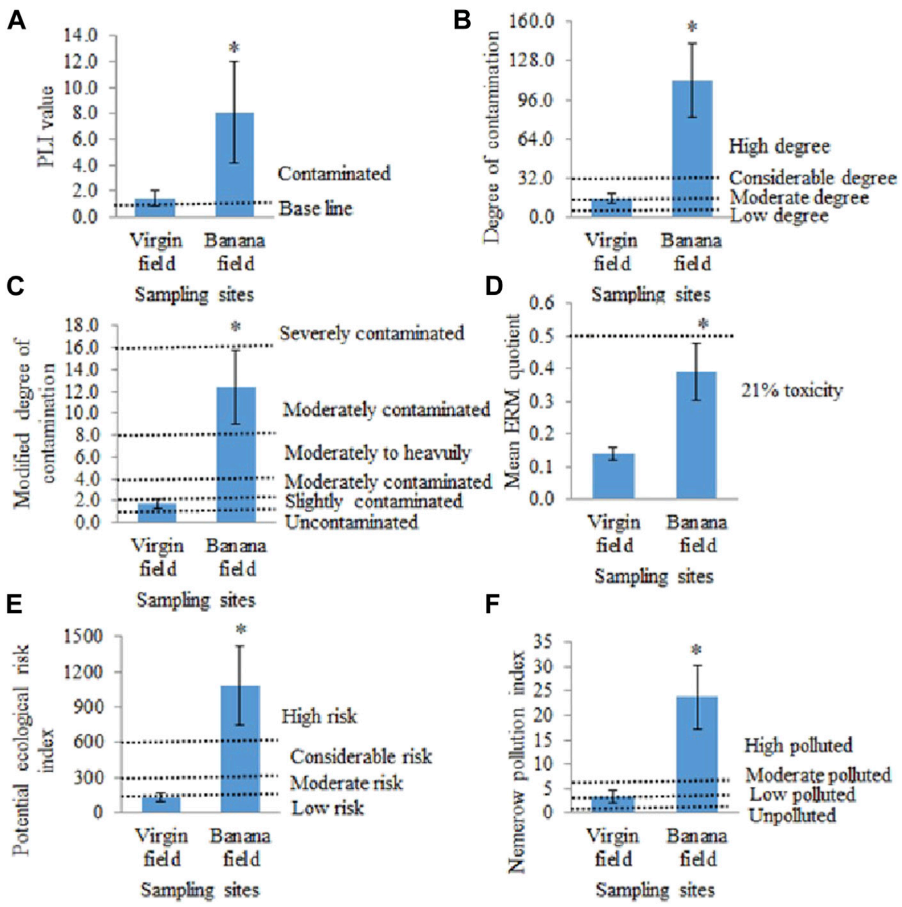

FIGURE 4
Distribution of the ecological risk index value. **(A)** Pollution load index (PLI), **(B)** degree of contamination (C_d), **(C)** modified degree of contamination (mC_d), **(D)** mean effects range median quotient (MERM-Q), **(E)** potential ecological risk index (PERI), and **(F)** Nemerow pollution index (P_N) due to trace elements in banana field soil around the capital of ancient Pundranagar, Bangladesh. Horizontal dotted lines indicate the level of contamination for different risk indices. "*" indicates a statistically significant difference at the 0.01 level.

industries and open waste-burning activities in the studied area (Islam et al., 2015b).

Similar spatial patterns to PLI were observed for the degree of contamination (C_d) and modified degree of contamination (mC_d), where their values in banana field samples were significantly higher than those of the virgin field samples (Figures 4B, C). The values of C_d and mC_d for the virgin field samples demonstrated a low to moderate degree of trace element contamination. However, the banana field samples presented a high degree of contamination ($C_d > 32$ and mC_d value as $8 \leq mC_d < 16$) (Figures 4B, C), which could be due to the impact of agricultural operations and banana plantation cultivation methods (Lin et al., 2010; Kumar et al., 2021). The obtained values of MERM-Q for studied trace elements in surface soil showed 21% toxicity (Figure 4D). Håkanson (1980) described a potential ecological risk factor (E_r^i) for evaluating soil ecological hazards based on trace element contamination. The value of potential ecological risks (E_r^i) for specific elements in soil samples decreased in the order of Cd > Cu > Pb > As > Ni > Fe > Cr > Zn > Mn. The PERI was observed as being high risk for banana field soil and low risk for the virgin field (Figure 4E), which indicated that banana cultivation might create a probable biological danger compared to virgin field. High latent environmental jeopardy observed in the banana field was mainly contributed by Cd, Cu, Pb, Ni, and As, which might originate from industrial effluents used to add carbon-based substances to the banana field and from the agrochemicals applied for banana cultivation (Islam et al., 2015b; Kabir et al., 2020). Rodrguez Martin et al. (2013) concluded that the use of phosphate fertilizers in crop fields and untreated industrial waste created high ecological risks in agricultural soil after the release of Cd, Cu, Pb, Ni, and As. The Nemerow pollution index (PN) value also showed high soil pollution in the banana fields of the study area in Bangladesh (Figure 4F). Therefore, special attention should be paid to managing the banana field soil using sustainable agricultural practices to reduce the accumulation of trace elements, especially Cd, Cu, As, Pb, and Ni, and protect public health in Bangladesh.

Sources of trace elements

In this study, the sources of trace elements in surface soil and banana plants were identified using PCA (Figure 5). The PCA was utilized based on the profusions of trace elements in soil and plant trials with the varimax rotation technique. Three principal components accounted for the variability of trace elements in both soil and banana plants and cumulatively explained 58.58%

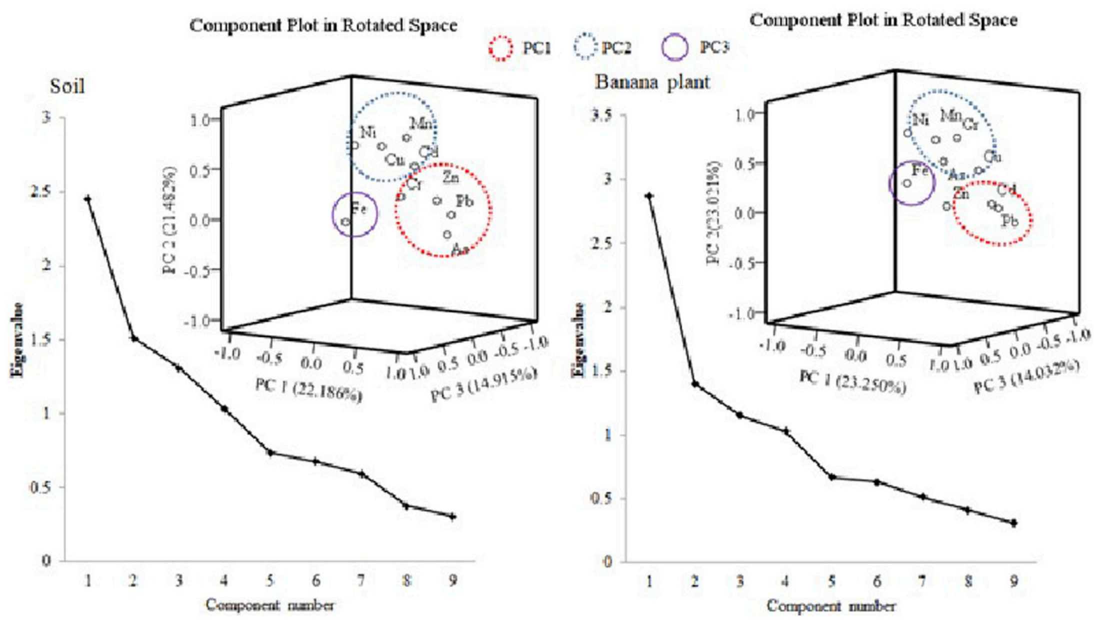

FIGURE 5
Principal component analysis (PCA) of trace elements in soil and banana plants around the capital of ancient Pundranagar, Bangladesh.

and 60.30% in soil and plant samples, respectively (Figure 5). The first principal component (PC1) contributed 22.18% and 23.25% of the total variance in soil and plant samples, respectively, and loading with Cr, Zn, Pb, and As in soil and Zn, Cd, and Pb in plant samples (Figure 5). The sources of Cr, Zn, Pb, As, and Cd in the soil and plant samples from the study area may arise from paint flakes, leakage of oil and lubricants, waste from old scrap batteries, metal workshops, and industrial exhaust emissions (Ekere et al., 2017; Zglobicki et al., 2018; Roy et al., 2019). The second component explained 21.48% of the total variance in soil and presented positive loading for Ni, Mn, Cu, and Cd, whereas 23.021% of the total variance in plant showed positive loading with Cr, Cu, Ni, As, and Mn (Figure 5). These elements in soil and plant samples could arise from multiple origins, viz., waste burning, industrial emissions, excess use of fertilizers and pesticides in banana fields, or lithogenic sources (Pandey et al., 2012; Islam et al., 2021a). The PC3 accounted for 14.91% and 14.03% of the total variance in soil and plant samples, respectively, and presented positive loading for Fe (Figure 5). A study by Iqbal and Shah (2011) mentioned that Fe is a crucial component of the earth's topsoil and crust and is mainly attributed to some general causes. From the PCA, we have observed diverse distributions of identical types of trace elements in soil and plant samples that may be caused by the element's source emission characteristics as well as the variation of its accumulation in the soil and plants. The ANOVA results showed that there were significant differences in metal concentrations in soil and different banana plant tissues, whereas no significant difference was observed for Zn concentration in soil and different tissues of banana plants (Table 3). Multivariate analysis revealed that anthropogenic sources, rather than geogenic, are the leading factors which agrees with the previous demonstrations of Bhuiyan et al. (2021).

Health risk

Data are shown in Table 4 for the exposure of adults and children to the trace elements in banana fruits. The mean values of EDI from banana fruits followed the descending order of Fe > Zn > Mn > Ni > Cu > Cr > As > Pb > Cd. Compared to the maximum acceptable daily ingestion of trace elements (JECFA 2011), EDI levels for the studied elements were found to be lower than the MTDI (Table 4), indicating that the studied elements had a minor effect on human health via banana consumption in the considered area. The non-carcinogenic risk (THQ) for eight elements (except Pb) and TR of Cr and As of adult and child consumption of banana fruit are shown in Table 4. Except for children, the THQs for the studied elements were lower than the threshold value (THQ <1), indicating no probable non-carcinogenic concerns associated with banana consumption. However, the total THQ of multiple elements from banana fruits was higher than the allowable levels for adults and children (THQ >1), indicating a potential risk to human health.

The target cancer risk for Cr and As was determined to be 1.3×10^{-3} and 7.9×10^{-4}, respectively (Table 4). These values were somewhat larger than the permitted value (10^{-4}), indicating a cancer risk to adult consumers (USEPA, 2010, USEPA 2015). The current study considered 50% of inorganic As in banana fruit for carcinogenic risk calculation (Saha and Zaman, 2013). In the current study, only the edible part of the banana was considered for health risk estimation. Other food items, such as cereals, vegetables, other fruits, and non-piscine protein source foodstuffs (meat, milk, and egg), from the research area should be considered in order to gain the real scenario of health benefits from dietary intake of bio-accessible forms of trace elements (Praveena and Omar 2017). This is a limitation of this study.

Findings from the present study also supported the idea that the manufacturing of deleterious substances, especially those that

TABLE 3 Analysis of variance (ANOVA) for metal concentrations in soil and different tissues of banana plants.

Metals		Sum of Squares	df	Mean Square	F	Sig.
Cr	Between Groups	3789.58	1	3789.58	79.002	0.000
	Within Groups	1343.10	28	47.96		
	Total	5132.69	29			
Ni	Between Groups	11446.48	1	11446.48	86.53	0.000
	Within Groups	3703.92	28	132.28		
	Total	15150.41	29			
Cu	Between Groups	10812.04	1	10812.04	51.90	0.000
	Within Groups	5832.58	28	208.30		
	Total	16644.62	29			
As	Between Groups	350.46	1	350.46	43.032	0.000
	Within Groups	228.04	28	8.14		
	Total	578.51	29			
Cd	Between Groups	232.76	1	232.76	153.78	0.000
	Within Groups	42.38	28	1.514		
	Total	275.14	29			
Pb	Between Groups	13500.55	1	13500.55	256.08	0.000
	Within Groups	1476.15	28	52.72		
	Total	14976.70	29			
Fe	Between Groups	1.92E+09	1	1.92E+09	645.535	0.000
	Within Groups	8.34E+07	28	2980004.76		
	Total	2.01E+09	29			
Mn	Between Groups	11746.58	1	11746.58	132.83	0.000
	Within Groups	2476.00	28	88.42		
	Total	14222.58	29			
Zn	Between Groups	314.98	1	314.98	0.84	0.367
	Within Groups	10486.95	28	374.53		
	Total	10801.94	29			

generate trace elements, should be curtailed by adopting tough measures such as the imposition of higher taxes on those products that cause food insecurity or have a negative impact on public health. Proper education on soil nutrients in banana plant systems could assist residents in comprehending some likely risks from trace elements. Therefore, result-oriented approaches should be adopted by the concerned authorities for better management of trace-element-contributing sources in the banana field soil in Bangladesh. Presently, no efficient management approach has been developed for addressing trace elements pollution in Bangladesh. However, the present research revealed different untapped research themes such as economic and ecological aspects of soil–banana plant systems and ecotoxicological profiles, trace elements in agro-food, their hazards, and potential remedies through intervention options and proper regulatory measures (Figure 6). The available literature on soil–plant management systems should be incorporated into these untapped research themes to address the present challenges of assessment and identification of trace elements in the banana field soils. Strict enforcement of any existing policy concerning the use of agrochemicals on agrarian soils will restrict trace element pollution in the soil–banana plant systems of Bangladesh. More so, the transfer of trace elements along the food chain and their toxicity in other agroecosystems should be studied. Additionally, eco-friendly and reliable technology should be incorporated with modern global approaches for the mitigation of potentially toxic elements. Thus, a careful evaluation of existing research gaps and global policy synchronization should be undertaken by authorized bodies to ensure proper management of trace element pollution in the soils of banana fields and other agroforestry systems in Bangladesh.

TABLE 4 Estimated daily intake (EDI), carcinogenic (TR) and non-carcinogenic (THQ) risks of trace elements from consumption of banana fruit in the study area, Bangladesh.

Elements	EDI		MTDI	THQ		TR
	Adults	Child		Adults	Child	Adults
Cr	0.162	0.081	2.3	0.002	0.003	1.3×10^{-3}
Ni	0.290	0.145	10	0.242	0.454	
Cu	0.196	0.098	40	0.082	0.153	
As	0.127	0.064	0.10	0.707	1.327	7.9×10^{-4}
Cd	0.013	0.007	0.05	0.073	0.137	
Pb	0.037	0.018	0.10	-	-	
Fe	2.942	1.473	NA	0.070	0.132	
Mn	0.503	0.252	NA	0.060	0.113	
Zn	1.951	0.977	20	0.108	0.204	
Total	6.222	3.115		1.344	2.523	2.14×10^{-3}

MTDI: Maximum tolerable daily intake (JECFA, 2011).

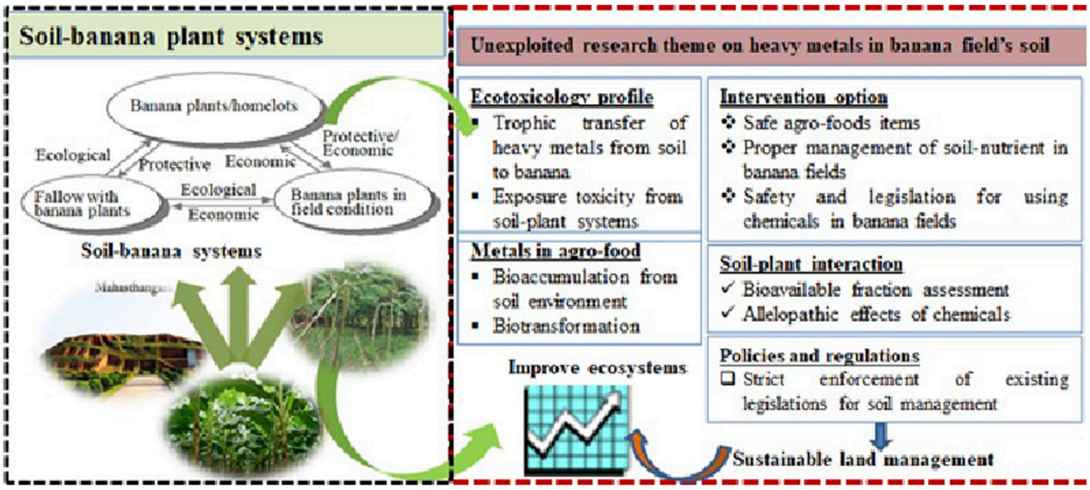

FIGURE 6
Regulatory acts for safety assessment of heavy metals in the banana field soil with the conceptual policy framework for sustainable soil management in Bangladesh.

Conclusion

In the current study, we found the average concentrations of Cu, Pb, As, and Cd in the soils of banana fields were higher than the world average shale standard; the background values of trace elements in soils of the ancient city of historical Pundranagar, Bangladesh; virgin fields; and the Dutch soil quality standard, indicating their contamination in the soil and the possibility that it may destroy the soil ecosystems of long-term cultivated banana fields. The concentrations of As, Cr, Pb, Cd, Zn, and Mn in four tissues of banana plants exceeded the maximum allowable concentration of trace elements, suggesting that their contamination represents a potential threat to the local inhabitants of the study area. The most elevated concentrations were observed in roots followed by leaves. Considering all the examined tissues, the mean BCF values of trace elements followed the descending order of Zn > As > Mn > Cr > Ni > Cu > Cd > Pb > Fe. The mean values of EF, I_{geo}, CF, PLI, C_{d}, mC_{d}, MERM-Q, PERI, and P_N indicated a moderate to high degree of contamination for trace elements in banana field soil. Three principal components accounted for the variability of trace elements in both soil and banana plants where Cr, Zn, Pb, As, and Cd were enriched due to anthropogenic activities. The total THQ of multiple elements from the consumption of banana fruits was higher than the allowable levels for adults and children (THQ >1), indicating a potential risk to human health. The TCRs of Cr and As crossed the threshold limit (1×10^{-6}), showing a cancer risk for the adult inhabitants of the study area who consume and use these banana plant tissues. Therefore, it is critical that Cr and As levels are managed, as they have already entered the banana plants and are present in the soil. Continuous monitoring of trace elements in bananas and other foods in the study area is recommended to understand the reasons for the accumulation of trace elements in soil and banana plants around the intensively cultivated agricultural regions of the capital of earliest Pundranagar, Bangladesh.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding authors.

Author contributions

MSI: conceptualization, methodology, validation, and writing–original draft. MTI: investigation, methodology, validation, and writing–review and editing. ZI: writing–review and editing, conceptualization, data curation, validation, and visualization. AI: conceptualization, investigation, project administration, and writing–review and editing. RK: data curation, formal analysis, investigation, and writing–review and editing. FH: investigation, methodology, project administration, and writing–review and editing. MK: conceptualization, formal analysis, methodology, and writing–review and editing. BE: conceptualization, formal analysis, and writing–review and editing. KI: conceptualization, funding acquisition, validation, and writing–review and editing. AI: conceptualization, funding acquisition, investigation, supervision, and writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1272840/full#supplementary-material

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