Critical Review of Lead Pollution in Bangladesh

Ahmad Kamruzzaman Majumder, Abdullah Al Nayeem, Mahmuda Islam, Mohammed Mahadi Akter, William S. Carter

Center for Atmospheric Pollution Studies (CAPS), Department of Environmental Science, Stamford University Bangladesh

Corresponding Author: Abdullah Al Nayeem nayeem@stamforduniversity.edu.bd

Introduction

The advancement of technology has led to the expansion of urbanization and industrialization, resulting in an upsurge of heavy metal pollution into the environment, especially in low- and middle-income countries (LMIC). Anthropogenic activities are a significant contributor to the amplification of heavy metal emissions into the earth's atmosphere, cultivated land, and water bodies. Rapid and unplanned urbanization and industrialization have led to toxic substances like arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), zinc (Zn), nickel (Ni), tin (Sn), and lead (Pb) being discharged to the surrounding environment. Planned urbanization also increases the risk of releasing toxic materials due to unregulated development activities. These metals contaminate the air, soil, and water through various pathways, including vehicle exhaust, fossil fuel combustion, suspended atmospheric particles, untreated municipal sewage, fertilizer and pesticides, municipal solid waste, and mining activities. Suspended air particles hold heavy metals, which eventually deposit onto the soil through the natural sedimentation and precipitation processes. Through various exposure routes such as diet, smoking, breathing, and drinking, toxic heavy metals can accumulate in various parts of the human body and cause severe health disorders.

Background. Lead (Pb) poses a severe threat to human health and the environment. Worldwide Pb production and consumption have significantly increased along with unplanned industrialization and urbanization, lead smelting, and lead-acid battery processing. The improper management of Pb-containing elements is responsible for Pb pollution. Lead's persistence in nature and bioaccumulation in the food chain can lead to adverse health impacts.

Objectives. The present study aims to describe Pb contaminated sites in Bangladesh and Pb concentration in the atmosphere, water, sediments, soil, vegetables, fish, and other foods in Bangladesh.

Methods. The present study searched a total of 128 peer-reviewed articles based on a predefined set of criteria (keywords, peer-reviewed journals, and indexing in Scopus, Science Direct, Web of Science, Springer, PubMed, Directory of Open Access Journals (DOAJ), and Bangladesh Journals Online (BanglaJOL) and exclusion criteria (predatory journal and absence of full text in English) and finally selected 63 articles (58 research articles and five (5) reports). The relevant findings on Pb exposure, sources, routes, diet, and impacts in Bangladesh were combined and presented.

Results. The reviewed studies identified 175 Pb contaminated sites through soil sample assessment in Bangladesh. The study determined Pb concentrations in air (0.09-376.58 µg/m³, mean 21.31 µg/m³), river water (0.0009-18.7 mg/l, mean 1.07 mg/l), river sediments (4.9-69.75 mg/kg, mean 32.08 mg/kg), fish (0.018-30.8 mg/kg, mean 5.01 mg/kg), soil (7.3-445 mg/kg, mean 90.34 mg/kg), vegetables (0.2-22.09 mg/kg, mean 4.33 mg/kg) and diet items (0.001-413.9 mg/kg, mean 43.22 mg/kg) of which 38.8%, 27.8%, 54.5%, 68.8%, 9.7% and 100% of samples, respectively, exceeded related World Health Organization (WHO), Food and Agriculture Organization (FAO), United States Environmental Protection Agency (USEPA) and Bangladesh Standard Testing Institution (BSTI) guidelines. The present study found that industrial soils are severely polluted with Pb (7.3-445 mg/kg) in Bangladesh. A high Pb concentration has been found in fish muscle and foods, including leafy and non-leafy vegetables collected from different places in Bangladesh.

Conclusions. Lead-contaminated foods can enter the human body through dietary intake and consequently lead to long-term adverse health effects. This study may help policymakers to formulate national policies with effective mitigation plans to combat the adverse health impacts of Pb in Bangladesh.

Competing Interests. The authors declare no competing financial interests.

Keywords. lead, concentration, contamination, polluted, impacts, Bangladesh.

Received January 22, 2021. Accepted May 16, 2021.
J Health Pollution 31: (210902) 2021
© Pure Earth
biodegradable toxic heavy metal that is soft, corrosion resistant, highly malleable and ductile. As a result, Pb has been used in many industries. Lead has acute and chronic effects on human health and the environment. Due to the rapid growth of industrial activities, the high demand for lead-acid batteries (LAB) is now a concern in low- and middle-income countries. Since the early days of the industrial revolution, use of Pb has increased globally (Figure 1), and over the last decade, the exponential growth rate has become much more significant. In the 20th century, Pb contamination has increased significantly due to the use of leaded gasoline in motor vehicles. The global usage of Pb in 2012 was 10.7 million tons (Figure 1). The demand for motor vehicles has led to increased LAB demand. This Pb is 100 percent recyclable, but the process is conducted chiefly through informal processes, especially in developing countries, resulting in soil contamination. The sector-based global annual consumption rate of Pb is shown in Table 1. Around 85% of Pb is used during the LAB manufacturing process. About 98.9% of used LAB (ULAB) were recycled in the United States in 2014, and around 99% in the European Union (EU) from 2010-2012.

Lead can have adverse environmental and health effects resulting from various anthropogenic activities. Table 2 summarizes the routes and activities that cause Pb contamination in the environment. Emissions from informal ULAB processing, automobiles that burn leaded gasoline, industrial dust, waste burning, open dumping, the paint industry, industrial sludge, mining activities, and low-grade fertilizer application are the leading causes of Pb contamination in air, soil, and water bodies. Soil can be contaminated with Pb through atmospheric deposition from various point sources like smelting and industrial processes. Several non-point sources such as fertilizers, sewage sludge, organic manure and compost are critical pathways of Pb contamination in vegetables and other crops.

Lead as an antiknock agent in petrol is one of the prime contributors to total atmospheric Pb pollution. Hence, people can be exposed to Pb through inhalation of Pb particles released from burning of Pb-containing material and or ingestion of dust, soil, diet, and drinking water that contains Pb. Lead intake can cause various health disorders, including kidney damage, DNA damage, change in blood composition, impaired hemoglobin synthesis, decreased red blood cell counts, and oxidative stress. Other adverse effects include impaired cognitive development in children, adverse effects on the development of the central nervous system, maternal death, mental retardation in children, and harmful effects on thyroid and growth hormones. Due to vulnerability to developmental effects, children are more greatly affected by Pb toxicity. Even low concentrations of Pb in human blood can cause adverse consequences. One study reported a Pb level in the blood of workers in battery manufacturing industries of around 47 μg/dL and 64
μg/dL in recycling plants in low- and middle-income countries, which exceeds the current United States standard of 5 μg/dL.10 Child laborers in low- and middle-income countries are at higher risk because of acute exposure to Pb as measured by blood Pb levels; levels exceeding 150 μg/dL may cause death.11,12 According to the Institute for Health Metrics and Evaluation (IHME) 2017,13 Pb exposure was responsible for 1.06 million deaths worldwide, with the highest Pb-related death rate in low- and middle-income countries. Lead not only affects the human body, but also has an adverse impact on soil microbial communities and the growth of plants.13 A summary of the effects of Pb poisoning on soil, plants, and humans is presented in Table 3.

Bangladesh is a highly populated and polluted country.25 Along with rapid economic growth, it has experienced a dramatic shift in exposure to Pb over the past three decades. Bangladesh has a limited capacity for waste treatment and recycling facilities. Untreated wastes are discharged into nearby agricultural lands, rivers, roadside canals, or streams. Lead from these sources can persist in the soil and water bodies that humans can take up through the food chain. A previous study found that the deposition of Pb in soil, crops, water, air, and vegetables is higher in the vicinity of Bangladesh’s industrial and urban areas.3 Since the 20th century, two and three-stroke engines have been major contributors to atmospheric Pb pollution in Bangladesh.5 There are 148 known informal recycling sites conducting ULAB and 97 LAB manufacturing sites in Bangladesh. This presents a threat to human health as people living near urban or industrial areas have higher blood Pb levels in their bodies.8 The present study aims to determine potential Pb contaminated sites in Bangladesh and Pb concentrations in different environmental spheres.

Methods

A systematic literature search was conducted of research findings on Pb exposure from relevant sources such as peer-reviewed articles, textbooks, and reports of Pb contamination and poisoning in Bangladesh. The literature search focused on seven prioritized aspects of Pb pollution and pathways (atmosphere, water, sediment, fish, soil, vegetables, and foods) along with hotspots and impacts on living organisms. The search was performed through electronic databases using the following terms: “Pb in atmosphere,” “Pb pathway,” “Pb exposure,” “Pb in river water,” “trace metals in water,” “Pb in river sediment,” “Pb from industrial emission,” “heavy metal concentration in soil,” “Pb in food,” “Pb in vegetables,” “pathways and routes of Pb,” “Pb in the food chain,” “health effects of Pb,” “Pb effects on plants.”

One hundred and twenty-eight (128) related research papers were identified from accepted publication platforms around the world (Science Direct, PubMed, Institute for Scientific Information (ISI), Web of Science, Springer Link, National Center for Biotechnology Information (NCBI), Directory of Open Access Journals (DOAJ), and JSTOR); prominent national libraries (BanglaJOL, Department of Environment, Ministry of Health, International Center for Diarrheal Disease Research, Bangladesh (icddr,b), Bangladesh Atomic Energy Commission (BAEC), Bangladesh Standards & Testing Institution (BSTI)); and international organizations (Asian Development Bank, Clean Air Asia, Norwegian Institute for Air Research, School of Environmental Science Murdoch University, Australia, Stockholm Environment Institute (SEI), Sweden, World Health Organization (WHO), Pure Earth, International Lead Association (ILA), and the World Bank).

Eligibility criteria

The following inclusion criteria were adopted: (i) peer-reviewed with mentioned database (ii) articles investigating Pb in the atmosphere, water, sediment, fish, soil, vegetables, and foods; (iii) full texts published in English; (iv) use of scientific analytical methods; (v) discussion and interpretation of the main findings;
| Name of component | Major sources                                                                 | Pathways                                      | Reference |
|-------------------|-------------------------------------------------------------------------------|-----------------------------------------------|-----------|
| Air               | • Automobile exhausts                                                        |                                               | 11-19     |
|                   | • Industrial dust emission                                                    |                                               |           |
|                   | • Building material damage                                                    |                                               |           |
|                   | • Burning of solid waste                                                     |                                               |           |
|                   | • Fumes from automobile exhaust                                              |                                               |           |
|                   | • Cement factory                                                             |                                               |           |
|                   | • Fertilizer factory                                                         |                                               |           |
|                   | • Fuel as anti-knock agent                                                    |                                               |           |
|                   | • Tire wear and motor oils                                                    |                                               |           |
|                   | • Smoke and dust emissions of coal and gas-fired power stations              | Atmospheric transmission and deposition       |           |
|                   | • The laying of lead sheets by roofers as well as the use of paints and anti-rust agents |                                               |           |
|                   | • Lead smelter industry                                                      |                                               |           |
|                   | • Battery manufacturing industry                                             |                                               |           |
|                   | • Lead-based paint in buildings, bridges, and other structures                |                                               |           |
|                   | • Interior house dust                                                        |                                               |           |
| Water             | • Chemical mixed effluent from tannery industries                            | Surface runoff and weathering                 | 12, 20-22 |
|                   | • Seepage wastes of Riverside textile mills, dyeing                         |                                               |           |
|                   | • Domestic solid waste                                                       |                                               |           |
|                   | • Municipal wastes and pesticides                                            |                                               |           |
|                   | • Run off of wastes and atmospheric depositions                              |                                               |           |
|                   | • Paint industry                                                             |                                               |           |
|                   | • Industrial sludge                                                          |                                               |           |
|                   | • Mining industry                                                            |                                               |           |
| Soil              | • Agrochemicals (Pesticides, herbicides, Basudin, Rifit)                      | Accumulation, sedimentation and deposition     | 2, 8,23,24 |
|                   | • Steel and iron industries                                                  |                                               |           |
|                   | • Livestock manure, and unused metallic parts                                |                                               |           |
|                   | • Dry cell batteries                                                         |                                               |           |
|                   | • Used Pb acid batteries, Auto repair shops                                  |                                               |           |
| Others            | • Pb in cooking oil cans                                                      | -                                             | 8         |
|                   | • Pb in rice grinding and flour mills                                         |                                               |           |

**Table 2 — Source Identification of Lead in the Environment**
| Source          | Effects                                                                 | Reference       |
|-----------------|-------------------------------------------------------------------------|-----------------|
| Soil            | - Inactivates enzymes of living cells                                  | 17, 34-36       |
|                 | - Inhibits the uptake of essential nutrients by plant tissues from the soil |                 |
|                 | - Influences soil microorganisms by affecting their growth, morphology, and biochemical activities |                 |
|                 | - Affects soil enzyme activity                                          |                 |
|                 | - Changes the composition of soil microbial communities                |                 |
|                 | - Affects soil microbial respiration rate                               |                 |
|                 | - Inhibits microorganism reproduction                                   |                 |
|                 | - Reduces synthesis and metabolism of microbial enzymes                 |                 |
|                 | - Decreases mineralization activity of microorganisms                   |                 |
| Plants          | - Delays maturity and stunts growth of rice and wheat                  | 28, 37-39       |
|                 | - Reduces rice yield                                                   |                 |
|                 | - Retards benthos growth on the sea bottom                              |                 |
|                 | - Affects philological functions                                        |                 |
|                 | - Retards nitrogen fixation, chlorosis, and metabolism                 |                 |
|                 | - Affects stoma function, photosynthesis activity and accumulation of other nutrient elements |                 |
|                 | - Damages root system                                                  |                 |
| Human health    | - Impairs cognitive development of children                            | 8, 12, 40-42    |
|                 | - Affects developing central nervous system                             |                 |
|                 | - Irreversibly decreases IQ                                             |                 |
|                 | - Reduces energy levels                                                 |                 |
|                 | - Damages kidneys and DNA                                               |                 |
|                 | - Alters gene expression                                                |                 |
|                 | - Changes blood composition                                             |                 |
|                 | - Impairs hemoglobin synthesis                                          |                 |
|                 | - Impairs renal function, deafness, blindness, retardation             |                 |
|                 | - Decreases libido, fatigue                                             |                 |
|                 | - Neurobehavioral problems                                              |                 |
|                 | - Changes the genetic code and causes rheumatoid arthritis              |                 |
|                 | - Significantly decreases red blood cell counts, hemoglobin levels and hematocrit values |                 |

Table 3 — Effects of Lead Pollution on Environmental Components
Review

(vi) limitations of the study (e.g., process of data collection, lack of data, lack of ethics clearance, lack of coherence in data analysis) and (vii) conclusions and implications within the scope of the study design. There were no restrictions on the date of publication. Criteria for exclusion were: (i) publication in predatory journals (predatory journals defined as not indexed, rapid publication process, contact email address is non-professional and non-journal affiliated, peer review process and publication timelines too short etc.), and websites (ii) published papers with English abstracts but without full texts in English.

Data processing

We followed two screening (abstract and full text) procedures on retrieved literature to determine article eligibility based on this study's objective. During the first screening, the title and abstract were reviewed based on Pb sources, route and impacts in Bangladesh. Next, the full text of those related abstracts was assessed to identify whether a study was fully or partially related to the study's objectives. Finally, 63 studies were selected for review. An overview of the literature selection procedure is shown in Figure 2. Lastly, findings were processed and analyzed following the cross-tabulation technique to list and compare Pb concentrations from various sources. For hotspot mapping and tabulation, ArcGIS 10.2.1 and Microsoft Excel 10 were used, respectively.

Study characteristics

Table 4 presents the characteristics of the included papers. We considered 58 research articles from seven different media. In addition, five studies were examined for the standard concentration of various spheres. Two (2) of the 58 reviewed articles' key objectives was to classify the sources of heavy metal pollution, 48 articles described metal concentration, and six described health risks from Pb exposure. Lead concentrations in soil was the focus of 22 (32%) studies, and water and sediment results were reported in 12 papers (16%). Most of

![Figure 2 — PRISMA flow diagram indicating Pb-related article collection, screening, inclusion and exclusion process](http://meridian.allenpress.com/jhp/article-pdf/11/31/210902/2888406/i2156-9614-11-31-210902.pdf)
the first authors of these peer-reviewed articles were from Bangladesh, followed by the United States.

Results

In collaboration with the Department of Geology of the University of Dhaka and the Department of Environment, Bangladesh, Pure Earth investigated Pb contaminated hotspot areas in Bangladesh. The investigators collected soil samples, following the Initial Site Screening (ISS) protocol provided by Pure Earth, and determined the hotspot zones based on the analyzed results. One hundred and seventy-five (175) of the assessed sites were found to be contaminated with Pb. Eighty-five (85) battery recycling/manufacturing/repairing and 84 Pb smelting industries were identified as sources of Pb pollution in Bangladesh. In addition, tannery and dye operations, heavy industry, chemical, and fertilizer manufacturing were identified as sources of Pb pollution in different districts of Bangladesh. Figure 3 shows the spatial distribution of Pb-contaminated hotspot areas in Bangladesh. Dhaka and Khulna districts were found to be the most polluted and have more smelting and ULAB industries than other districts.

Lead in air

Table 5 shows Pb concentrations (µg/m³) in the ground-level atmosphere in Bangladesh. Woo, et al. (2018) recorded a Pb concentration of 376.58 µg/m³, the highest among the 18 studied areas, and around the battery manufacturing plant of Munshiganj Sadar, the Pb level of a nearby residential area was 1.22 µg/m³. Ahmed et al. (2012) determined Pb concentrations in places in...
Figure 3 — Map of district-wise Pb contaminated sites screened through the Toxic Sites Identification Program in Bangladesh between 2011 to 2018 (Adopted from McCartor, 2018)
### Table 5 — Lead Concentration (µg/m³) in Ground Level Atmosphere in Bangladesh

| District  | Site description/Location                                      | Concentration (µg/m³) | Reference | Arithmetic mean (µg/m³) |
|-----------|----------------------------------------------------------------|-----------------------|-----------|-------------------------|
| Dhaka     | Dhaka                                                          | 0.29                  |           |                         |
| Dhaka     | Mukarram Hussain Khundkur Science Building, Department of Chemistry, University of Dhaka, Bangladesh | 0.31                  |           |                         |
| Munshiganj| Residential area                                               | 1.22                  |           |                         |
|           | Battery manufacturing plant                                     | 376.58                |           |                         |
| Chittagong| New market                                                     | 0.74                  |           |                         |
|           | Bahaddarhat                                                    | 0.42                  |           |                         |
|           | Nasirabad                                                      | 0.3                   |           |                         |
|           | GEC Circle                                                     | 0.16                  |           |                         |
|           | Director’s office                                              | 0.55                  |           |                         |
| Dhaka     | Farmgate                                                       | 0.5                   |           |                         |
| Chittagong| Alfalah Housing Society, Khulshi                               | 0.15                  |           |                         |
| Kustia    | Daulotpur                                                      | 0.26                  |           |                         |
| Noakhli   | Karachi Bazar                                                  | 0.09                  |           |                         |
| Faridpur  | Faridpur Medical College                                       | 0.09                  |           |                         |
| Dhaka     | KMHV, Dhaka University Campus                                  | 0.2                   |           |                         |
|           | Tejgaon                                                        | 1.0                   |           |                         |
|           | Hazaribaghas                                                    | 0.1                   |           |                         |
|           | Uttar model town                                               | 0.6                   |           |                         |
|           | Standard value for air (Annual mean)                          | 0.5                   |           | 21.31                   |

Abbreviations: KMHV, Kazi Motahar Hossain Bhaban
| Sampling site                                                                 | Water body                          | Concentration (mg/l) | Reference | Arithmetic mean (mg/l) |
|------------------------------------------------------------------------------|-------------------------------------|----------------------|-----------|------------------------|
| Heavy industrial zone of Chittagong                                          | Karnafuli River, Chittagong        | 0.14                 | 52        | 1.07                   |
| Rajfulbaria area in Savar                                                    | Dhaleshwari River, Dhaka            | 18.7                 | 50        |                        |
| Tongi heavy industrial area                                                  | Turag River, Dhaka                  | 0.015                | 22        |                        |
| Balughat, Shawaryghat and Foridabad station                                  | Buriganga River, Dhaka              | 0.06                 | 53        |                        |
| Belanagar and Drenerghat station                                             | Old Brahmaputra River               | 0.11                 | 48        |                        |
| Industrial and municipal effluent discharge area                             | Khiru River, Mymensingh             | 0.02                 | 54        |                        |
| Ghorashal bridge, Katchpur bridge, Kerosene ghat                             | Shitalakhya, Dhaka                  | 0.05                 | 10        |                        |
| Industrial discharge point                                                   | Rupsha River, Khulna                | 0.02                 | 55        |                        |
| Bogra district urbanized area                                                 | Karatoa River, Bogra                | 0.04                 | 56        |                        |
| Pasur River                                                                  | Pasur River, Khulna                 | 0.02                 | 49        |                        |
| Chilmari                                                                     | Brahmaputra                         | 0.04                 | 57        |                        |
| Dhaka metropolitan area                                                       | Dhanmondi Lake                      | 0.0009               | 51        |                        |
|                                                                              | Ramna Lake                          | 0.001                |           |                        |
|                                                                              | Crescent Lake                       | 0.0009               |           |                        |
|                                                                              | Gulshan Lake                        | 0.0009               |           |                        |
|                                                                              | Bonani Lake                         | 0.001                |           |                        |
|                                                                              | Rampura Lake                        | 0.005                |           |                        |
| Standard for irrigation                                                      |                                     | 0.01                 | 58        |                        |
| Standard for inland water                                                    |                                     | 0.05                 | 47        |                        |

Table 6 — Lead Concentration in Surface Water in Bangladesh (mg/l)
Chittagong city and found that the New Market area of Chittagong city had the highest concentration of Pb (0.74 µg/m$^3$). Rahman et al. (2013) showed that the air at various locations of Dhaka city had a range of 0.1-1 µg/m$^3$. In summary, 9 out of 18 sites in Dhaka and its vicinity exceeded the Bangladesh National Ambient Air Quality Standard (BNAAQS) for Pb concentration in air. In Dhaka city, Tejgaon heavy industrial area had the highest concentration level in the present study. The mean concentration was 21.31 µg/m$^3$, nearly 47 times higher than the standard set by BNAAQS. Used LAB and smelting industries, fertilizers, dye, cement, and paint industries, and vehicle exhausts were identified as primarily responsible for atmospheric Pb pollution in Bangladesh in these reviewed articles.

Three of the reviewed studies indicated that in Bangladesh, metal pollution, especially Pb, is increasing in river water and sediment. Table 6 presents the Pb concentrations in both river and lake water of Bangladesh. Most of the studies were in the industrialized areas on the river banks near Dhaka and Chittagong. Eighteen water bodies were studied from 14 areas with the highest concentration found in the Dhaleshwari River near the Savar industrial area. Lead concentrations in most studied rivers exceeded the standard of irrigation water, especially rivers near Dhaka and Chittagong city and the rivers near to any urbanized or industrialized area. However, Mokaddes et al. (2013) reported that the water in the lakes of Dhaka city was acceptable. The arithmetic mean of the concentration of Pb in surface water was 1.07, 107-fold higher than the irrigation water standard and 21.4-fold higher than the inland water standard set by the Department of Environment (DoE).

Untreated and partially treated effluents from industries were

| Sampling location/City                                                                 | River name       | Concentration (mg/kg) | Ref. | Arithmetic mean (mg/kg) |
|--------------------------------------------------------------------------------------|------------------|-----------------------|------|-------------------------|
| Fourteen (14) sediment samples were collected from different areas upstream of Dhaka | Buriganga        | 31.4                  | 21   | 32.08                   |
| Thirty-four (34) stations distributed uniformly all over the Ganges-Brahmaputra-Meghna basin | Turag            | 24                    | 59   |                         |
| Tongi Industrial Area, Dhaka                                                        | Padma            | 17                    | 60   |                         |
| Belanagar and Drencerghat station, Mymensingh                                      | Turag            | 33.8                  | 61   |                         |
| Dhaka export processing zone                                                         | Karnafuli        | 4.9                   | 62   |                         |
| Ten different stations from upstream to downstream of the river, Rajshahi            | Turag            | 26.3                  | 22   |                         |
| Mongla, Khulna                                                                      | Buriganga River  | 69.75                 | 53   |                         |
| Old                                                                                 | Old Brahmputra   | 7.6                   | 46   |                         |
| Bangshi                                                                             | Karatoa          | 54                    | 56   |                         |
| Patuakholi                                                                          | Pairs            | 49                    | 64   |                         |
| Standard                                                                            | Pasur            | 7.3                   | 49   |                         |
|                                                                                     |                  | 31                    | 65   |                         |

Table 7 — Lead Concentration in River Sediment (mg/kg) in Bangladesh
| River          | Local name/species | Genus and species       | Concentration (mg/kg) | Reference | Arithmetic mean (mg/kg) |
|---------------|--------------------|-------------------------|-----------------------|-----------|-------------------------|
| Buriganga river | Chapila            | Gudusia chapra          | 10.23                 | 53        | 5.01                    |
|               | Baila              | Glossogobius giuris     | 9.91                  |           |                         |
|               | Tatkeni            | Cirrhinus reba          | 8.93                  |           |                         |
|               | Taki               | Channa punctatus        | 9.91                  |           |                         |
|               | Tengra             | Mystus vittatus         | 11.68                 |           |                         |
|               | Batashi            | Pseudeutropius atherinoides | 9.18               |           |                         |
| Korotoa River | Pangas             | Pangasius pangasius     | 0.74                  | 3         |                         |
| Rupsha River  |                   |                         |                       |           |                         |
|               | Chingri             | Asian tiger shrimp      | 0.033                 | 55        |                         |
|               | Tara baim           | Lesser spiny eel        | 0.036                 |           |                         |
|               | Gudusia chartra     | Indian river shad       | 0.027                 |           |                         |
|               | Tank goby           | Glossogobius giuris     | 0.018                 |           |                         |
|               | Trout barb          | Raiamas bola            | 0.09                  |           |                         |
| Kawran Bazar fish market | Rui         | Labeo rohita           | 15.33                 | 67        |                         |
|               | Katla               | Catla catla            | 15.86                 |           |                         |
|               | Pangas              | Pangasius pangasius     | 30.8                  |           |                         |
| Paira River   | Koi                 | Cyprinus rubrofuscus    | 0.25                  | 4         |                         |
|               | Shing               | Heteropeustes fossilis | 0.27                  |           |                         |
|               | Kholaish            | Colisa fasciata        | 0.18                  |           |                         |
|               | Shoil               | Channa striata         | 0.25                  |           |                         |
|               | Foli                | Notopterus notopterus | 0.25                  |           |                         |
|               | Hilsha              | Tenualosa ilisha       | 0.51                  |           |                         |
|               | Watchki             | Corica soborna         | 0.37                  |           |                         |
| Karnafuly River | Poua               | -                       | 0.886                 | 62        |                         |
|               | Chring              | -                       | 1.84                  |           |                         |
|               | Tengra              | Mystus armatus         | 2.86                  |           |                         |
|               | Chapila             | Gudusia chapra         | 7.7                   |           |                         |
|               | Ticto barb          | Puntius ticto          | 3.05                  | 68        |                         |
|               | Pool barb           | Puntius sophore        | 3.16                  |           |                         |
|               | Chala punti         | Puntius chola          | 2.32                  |           |                         |
|               | Rohu                | Labeo rohita           | 6.98                  |           |                         |
|               | Bele                | Glossogobius giuris    | 1.77                  | 66        |                         |

**Table 8 — Lead Concentration in Fish Species (mg/kg) in Bangladesh**
| Soil category                        | District/City     | Concentration (mg/kg) | Reference | Arithmetic mean (mg/kg) |
|-------------------------------------|-------------------|-----------------------|-----------|-------------------------|
| Road dust                           | Dhaka             | 67.6                  | 11        | 90.36                   |
| Road dust from industrial area      | Dhaka             | 36                    | 69        |                         |
| Soil from industrial area           | Dhaka             | 98                    | 20        |                         |
| Soil from industrial area           | Narayanganj      | 445                   | 2         |                         |
|                                    | Jashore           | 12.6                  | 70        |                         |
|                                    | Tangail           | 64.8                  | 71        |                         |
|                                    | Mymensingh        | 59.3                  | 72        |                         |
|                                    | Bogra             | 9.6                   | 5         |                         |
|                                    | Chittagong        | 7.3                   | 73        |                         |
| Dust from auto repair shop          | Dhaka             | 54.4                  | 12        |                         |
| Crop soil                           | Gazipur           | 17.8                  | 15        |                         |
| Crop soil                           | Dhaka             | 97.5                  | 74        |                         |
|                                    | Narayanganj      | 105.9                 |           |                         |
|                                    | Norshindi         | 119                   |           |                         |
|                                    | Gazipur           | 79                    |           |                         |
|                                    | Chittagong        | 106.2                 |           |                         |
|                                    | Sylhet            | 86.7                  |           |                         |
| Soil from industrial area           | Tangail           | 12.1                  | 75        |                         |
| Soil from Pb smelting site          | Khulna            | 224.43                | 7         |                         |
| Soil from industrial area           | Dhaka             | 21.9                  | 76        |                         |
| Commercial and residential areas    | Pabna             | 21.29                 | 77        |                         |
| Mine affected farmland soil         | Dinajpur          | 433                   | 48        |                         |
| Bank of Brahmaputra River           | Kurigram          | 26.7                  | 57        |                         |
| Medical industry area               | Barisal           | 26.55                 | 78        |                         |
| Garden Soil                         | Dhaka city        | 86.9                  | 79        |                         |
|                                    | Chittagong        | 56.4                  |           |                         |
|                                    | Rajshahi city     | 68.9                  |           |                         |
|                                    | Khulna city       | 68.9                  |           |                         |
| Roadside soil from 20 locations     | Dhaka city        | 45.6                  | 80        |                         |
| Road dust from Dhaka City Standards | Dhaka             | 147.52                | 81        |                         |
|                                    | 200               |                       | 82        |                         |

*Table 9 — Lead Concentration in Soil (mg/kg) in Bangladesh*
### Table 10 — Lead Concentration in Vegetables (mg/kg) in Bangladesh

| Sampling site | Common name          | Concentration (mg/kg) | Reference | Arithmetic mean (mg/kg) |
|---------------|----------------------|-----------------------|-----------|-------------------------|
| Satkhira district | Cauliflower          | 3.4                   | 83        | 4.33                    |
|               | Tomato               | 11.3                  |           |                         |
|               | Sweet gourd          | 13.1                  |           |                         |
|               | Eggplant             | 1.6                   |           |                         |
|               | Papaya               | 5.2                   |           |                         |
| Gazipur Industrial zone | Bottle gourd        | 2.66                  | 15        |                         |
|               | Pumpkin              | 2.9                   |           |                         |
| Bogura district | Potato               | 1.5                   | 3         |                         |
|               | Chili                | 1.8                   |           |                         |
| Surrounding Dhaka Export Processing Zone | Eggplant           | 11.97                 | 84        |                         |
|               | Chili                | 13.81                 |           |                         |
|               | Tomato               | 14.15                 |           |                         |
|               | Lady's finger        | 15.72                 |           |                         |
|               | Cabbage              | 22.09                 |           |                         |
| Industrial areas of Jhenaidah district | Tomato            | 0.41                  | 85        |                         |
|               | Bean                 | 0.53                  |           |                         |
|               | Brinjal              | 0.54                  |           |                         |
|               | Cabbage              | 0.26                  |           |                         |
|               | Potato               | 0.57                  |           |                         |
|               | Radish               | 0.49                  |           |                         |
| Leather industry area of Dhaka city | Spinach           | 11.48                 | 86        |                         |
| Around the Paira River, Patuakhali | Tomato            | 0.2                   | 3         |                         |
|               | Potato               | 0.4                   |           |                         |
|               | Green amaranth       | 1.2                   |           |                         |
|               | Red amaranth         | 0.9                   |           |                         |
|               | Brinjal              | 0.3                   |           |                         |
|               | Bottle gourd         | 0.4                   |           |                         |
|               | Chili                | 0.2                   |           |                         |
|               | Carrot               | 0.5                   |           |                         |
|               | Onion                | 0.4                   |           |                         |
|               | Bean                 | 1.0                   |           |                         |
| Industrial Area, Chittagong | Water spinach      | 0.73                  | 87        |                         |
|               | Bottle gourd         | 1.16                  |           |                         |
|               |                      | 0.01                  | 88        |                         |
identified as the leading causes of Pb pollution in river water.\textsuperscript{50}

The results of the analysis of Pb concentrations in river sediment are reported in Table 7. Ahmed et al. (2010)\textsuperscript{55} recorded the highest Pb concentration in Buriganga river sediment (69.75 mg/kg). In Turag, the concentration varied from 24-33.8 mg/kg. The next highest concentration (31.4 mg/kg) was found in the Bangshi River sediment near the Dhaka Export Processing Zone (Mohiuddin et al., 2015).\textsuperscript{21} That study reported that in Dhaka city more than 5 thousand tons of solid wastes are produced every day from domestic sources, of which 63% were dumped in nearby rivers.\textsuperscript{21}

Seven research studies and monitoring programs on Pb accumulation in fish in Bangladesh were identified (Table 8). In these studies, 21 of 32 samples in various fish species from different rivers of Bangladesh exceeded the WHO food safety guidelines for Pb of 0.5 mg/kg. Fish samples collected from the Karwan Bazaar fish market had the highest concentration of Pb and the Pangus fish ranked highest with nearly 62 times more than the WHO standard.\textsuperscript{64}

All the samples collected from the Buriganga and Karnafuli River also contained high concentrations of Pb with average concentrations 10 times higher than the standard. Fish were identified as a significant protein source in the human diet in two of the reviewed papers. These fish assimilate Pb through ingestion of suspended particulate matter from water, ingestion of food, and surface adsorption by both tissues and membranes.\textsuperscript{67,68}

### Lead in soil samples, vegetables and diet

Twenty-two (22) studies reported soil samples contaminated with Pb in different districts of Bangladesh. The listed primary sources were atmospheric deposition from smelting, mining, and other industrial
activities, and fertilizers, pesticides, sewage sludge, organic manures, and composts.\textsuperscript{11} Industrial sites, Pb smelting, and mining areas were found to be polluted, as seen in Table 9. The Pb concentration of soil exceeded the limit in only three areas: Narayanganj industrial area (445 mg/kg), Pb smelting area in Khulna (224.43 mg/kg), and mine-affected area in Dinajpur (433 mg/kg). The average concentrations for all the studied samples were within acceptable limits. Lead can remain in soil for thousands of years without any changes, although insect activity, plowing, adding compost, and other activities do lower Pb in soil over time.\textsuperscript{36}

Eight (8) studies in Bangladesh reported high Pb concentrations in different types of vegetables (Table 10). Uddin \textit{et al.} (2019)\textsuperscript{39} stated that Pb concentrations in vegetables were 1.6-13.1 mg/kg in the Satkhira district. High concentrations of Pb were found in vegetable samples collected from the surrounding area of Dhaka Export Processing Zone (DEPZ). All vegetable samples in this study exceeded the Food and Agriculture Organization (FAO)/WHO guideline and the average concentration was 433-fold higher than the standard. According to three of the reviewed articles, the main reason for the higher concentration was cultivating vegetables in Pb-contaminated soil.\textsuperscript{83,84,85}

One of the reviewed studies stated that diet, including cereals, vegetables, and seafood are the primary sources of Pb exposure in Bangladesh.\textsuperscript{3} Seven (7) studies in Bangladesh examined the concentration of Pb in different foods and dietary items (Table 11). Forsyth \textit{et al.} (2019)\textsuperscript{37} reported a Pb concentration in turmeric powder that was up to 100 times greater than the Bangladesh Standard Testing Institution’s (BSTI) limit of 2.5 mg/kg.\textsuperscript{92} Islam \textit{et al.} (2015)\textsuperscript{1} found that almost all collected food samples exceeded BSTI limits.

**Discussion**

After the banning of two and three-stroke motor vehicles in 2002, the most significant Pb emission sources in Bangladesh are now industries that use substances containing Pb, mostly informal ULAB, and the smelting industry. Figure 3 shows that most of the contaminated sites are either ULAB or smelters. Heavy traffic congested areas and highly industrialized zones in Dhaka and Chittagong had atmospheric Pb levels exceeding the Bangladesh standard of 0.5 µg /m\textsuperscript{3}.\textsuperscript{41} In Chittagong, the New Market and Director’s office areas are two of the city’s busiest areas, and road dust and vehicle exhaust were the primary sources of Pb pollution in Chittagong.\textsuperscript{28} Near a battery manufacturing plant in Munsiganj Sadar Upazila, including the surrounding residential areas, the concentration was higher than other locations.

Being a river-fed country, resources from rivers help the country’s economic growth, but contaminated and polluted resources like water, sediment, and fish can harm humans through the food chain and bio-magnification process. The reviewed studies have shown that all rivers near to an industrial site, urbanized area, or port such as Dhaleswari, Buriganga, Karnaphuli, Old Brahmaputra, and Shitalakhya, have Pb-polluted water except for the Turag River and Tongi Lake (joined to the Turag River). However, these two water bodies’ contamination levels increased from 2012 to 2016.\textsuperscript{25,61} Lead concentrations in other rivers in this study, including the Khiru, Pashur, Brahmaputra, Rupsha, and Karoata rivers, were found to be within the inland water standard and some exceeded the irrigation water standard.\textsuperscript{48} The water in the lakes of Dhaka metropolitan city had lower Pb levels due to regular maintenance and the absence of any industry adjacent to them.\textsuperscript{31} Sediments from some of the rivers have significant Pb levels. Surprisingly, two rivers’ sediments, the Padma and Karnaphuli, had Pb within the acceptable range even though the latter is adjacent to the urbanized port city of Chittagong, which has eight Pb production sites. The strong current and wave action of the Padma and Karnaphuli Rivers may reduce the potential for depositing sediment. Fish samples collected from the Buriganga, Karnaphuli and Karwan Bazar contained high levels of Pb.\textsuperscript{51-62,66} The sediment of the Payra River in the Khulna area was found to be polluted with Pb, but the concentration of Pb in all the fish studied from this river was within the WHO food safety guidelines for Pb of 0.5 mg/kg, except Hilsa, the national fish of Bangladesh.\textsuperscript{66} The fish Pb levels captured from the Rupsha River in the Khulna area were also below the WHO food safety guidelines, whereas the water and sediment from this river were contaminated with Pb.\textsuperscript{55} It would seem the fish of coastal areas are safer to eat even though the water and sediment are polluted with Pb. The sources of the fish sold in the Karwan Bazar fish market were not stated, however it can be assumed that these fish are from anthropogenic sources cultured with Pb-contaminated food.\textsuperscript{66}

In the present study, most of the surveyed soils were safe according to the United States Environmental Protection Agency (USEPA) standard.\textsuperscript{55} Nonetheless, all of them contained some contamination. Although atmospheric deposition is a major pathway of Pb concentration, the soil and dust of Dhaka city is seen to have Pb within the limit of the USEPA standard, but the vegetables grown on these soils had very high
Pb levels exceeding the standard of FAO/WHO, 2011\(^{18}\) of .01 mg/kg. In Satkhira, the soil was not polluted with Pb but the Pb content in vegetables was 56-65-fold higher than the FAO/WHO food safety standard.\(^{88}\) This intrusion may be happening because of atmospheric deposition, irrigated water from nearby Pb-containing water bodies, Pb-loaded fertilizer, pesticide, organic manure, poultry feed, and compost.\(^{3}\) One of the reviewed studies indicated that the concentration of Pb in soil and vegetables decreased with increased distance from the roadside in Gazipur, Bangladesh indicating that traffic was the reason for increased concentrations of Pb in roadside soil and associated vegetables.\(^{15}\) The current study found that chicken egg, duck egg, and cow milk accumulated a significant amount of Pb due to accumulation from Pb-contaminated poultry feed.\(^{1}\) The elevated Pb levels in cereals and vegetables could be due to Pb smelting, emissions from vehicles and other industrial activities in the urban area and its vicinity.\(^{3}\) Elevated Pb concentrations in rice have become a global problem.\(^{18}\) Data were compiled into a frequency table (Table 12) to determine the most contaminated sector. Based on the percentage of contaminated samples, the most polluted sector was vegetables, where 100% of the studied samples were found to be contaminated with Pb followed by 68.8% of the fish species. Soil was found to be the least contaminated sector in Bangladesh. The authors did not find any direct relationship in Pb concentration between soil and associated vegetables or foodstuff. Since all the spheres of the environment are interrelated, there is a need for more research on Pb concentration in air, water, soil, and foodstuff grown in specific areas. Comparing the average concentration with the standards of each sector, the most polluted sector was found to be vegetables.

Several studies have reported that Bangladeshi populations are exposed to excessively high levels of Pb in their diet and through inhalation.\(^{3,48,49,89}\) This risk has been verified by blood lead level (BLL) in Bangladesh. Forsyth \textit{et al.} (2019) found that 36 out of 45 pregnant women had a BLL greater than 5 µg/dL in three rural districts. Higher BLLs have been associated with the consumption of adulterated turmeric. Several studies found higher BLLs in the residents of urban areas like Dhaka and Narayanganj, industrialized areas, and rural agrarian regions (Munshigonj and Dinajpur).\(^{8,9,32}\) These studies tried to determine the significant pathways of Pb absorption in blood.

### Study limitations

Documents published in languages rather than English were excluded, and we focused on papers that were available online only, thus potentially excluding some useful sources. Another limitation of the study was the heterogeneity in the sample collection procedures in included papers. Despite these limitations, the present study can provide an overview of Pb pollution in Bangladesh.

| Sphere          | Total Sample | Standard Guideline          | Exceeded Sample | Percentage of Exceeded Sample |
|-----------------|--------------|------------------------------|-----------------|------------------------------|
| Atmosphere      | 18           | ECR- 0.5 µg/m\(^3\)         | 7               | 38.8                         |
| Surface water   | 18           | ECR-0.05 mg/l                | 5               | 27.8                         |
| River sediment  | 11           | USEPA-31 mg/kg               | 6               | 54.5                         |
| Fish species    | 32           | WHO- 0.5 mg/kg               | 22              | 68.8                         |
| Soil            | 31           | USEPA- 200 mg/kg             | 3               | 9.7                          |
| Vegetables      | 33           | FAO/WHO-0.01 mg/kg           | 33              | 100.0                        |

**Table 12 — Percentage of Samples Exceeding Standard**

Abbreviations: ECR, Environment conservation rules; FAO/WHO, Food and Agriculture Organization/World Health Organization; USEPA, United States Environmental Protection Agency.
Conclusions

Lead contamination in the environment from various sources has become a major issue for the people of Bangladesh. This study demonstrates that Pb risk in Bangladesh is associated with ULAB, smelting, mining, and industrialization procedures. In the present study, the average Pb concentration was found to be 21.31 µg/m³ in the local air, 1.07 mg/l in river water, 32.41 mg/kg in river sediments, 5.01 mg/kg in fish, 90.36 mg/kg in soil, 4.33 mg/kg in vegetables, and 43.223 mg/kg in food items. Atmospheric Pb in Dhaka and Chittagong city was found to exceed the BNAAQS. Lead concentrations in residential areas adjacent to industrial zones may pose a serious health risk to the inhabitants, especially children. Since Bangladesh is a part of the great Ganga-Brahmaputra-Meghnaz basin, it drains a large volume of water through its narrow neck. That enables Pb to accumulate in the south of Bangladesh. Eventually, foodstuff like rice, wheat, maize, fruits, turmeric, fish, and vegetables may be contaminated with Pb, and in the present analysis, the most contaminated sector was found to be vegetables, (0.2-22.09 mg/kg) both in percentage and average concentration.

The food chain in Bangladesh is severely contaminated by Pb, which can contribute to fatal and chronic diseases through bio-concentration and bio-magnification. The present study found Pb in human blood in Bangladesh, which suggests adsorption through food stuff and the food chain. The adverse health effects of inhalation and ingestion of Pb are well known. Hence further research is needed to assess human exposure through consumption of potable water, fish, vegetables, and other foodstuff. Soil was the biggest potential source for Pb contamination in the reviewed papers. Additional studies are needed to determine the relationship between soil Pb level and Pb in associated vegetables and other agricultural products. Since the toxicity of Pb depends on its chemical state, a study could be initiated to determine the solubility of inorganic lead in contaminated locations and determine if there are any residual amounts of organic lead (tetaethyl lead). The appropriate authority should take mitigation measures to stop the unauthorized operation of Pb smelters and ULAB. Institutional frameworks and national policies are required to combat the adverse health impacts of Pb pollution in Bangladesh.

Acknowledgments

This study was funded as part of employment.

Copyright Policy

This is an Open Access article distributed in accordance with Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0/).

References

1. Hossain MS, Latifa GA, Prianoja, Nayem A Al. Review of cadmium pollution in Bangladesh. J Heal Pollut. 2019;9(23): 1-10. https://doi.org/10.5696/2156-9614.9.23.190913

2. Akter S, Khatun R, Ahasan MM, Uddin ME, Jamil HM, Monika AN, Rahman MA, Rahman M, Das RP, Sharmin RA. Heavy metals content in soil sample collected from Narayanaguri Industrial Area, Bangladesh using proton induced x-ray emission. American J Environ Eng. 2019;9(1):8-11. https://doi.org/10.5923/j.ajee.20190901.02.

3. Islam MS, Ahmed MK, Mamun MHA, Raknuzzaman M. The concentration, source and potential human health risk of heavy metals in the commonly consumed foods in Bangladesh.

Ecotoxicol Environ Saf. 2015;122:462-469. https://doi.org/10.1016/j.ecoenv.2015.09.022

4. Islam MS, Mamun MHA. Accumulation of trace elements in sediment and fish species of Paira River, Bangladesh. AIMS Environ Sci. 2017; 4(2): 310-322. https://doi.org/10.3933/envirosci.2017.2.310

5. Begum K, Mouhiuddin KM, Zakir HM, Rahman MM, Hasan MN. Heavy metal pollution and major nutrient elements assessment in the soils of Bogra city in Bangladesh. Canadian Chem Trans. 2014; 2(3): 316–326. https://doi.org/10.13179/ canchemtrans.2014.02.03.0088.

6. International Lead Association (ILA). Lead uses-statistics. 2012 Accessed [2020 September 20]. Available from: https://www.ila-Lead.org/Lead-facts/Lead-uses--statistics

7. Akber MA, Rahman MA, Islam MA, Islam MA. Potential ecological risk of metal pollution in Lead smelter-contaminated agricultural soils in Khulna, Bangladesh. Environ Monit Assess. 2019;191(6): 1-12. https://doi.org/10.1007/s10661-019-7483-3

8. Forsyth JE, Islam MS, Parvez SM, Raqib R, Rahman MS, Muehe EM, Fendorf S, Luby SP. Prevalence of elevated blood lead levels among pregnant women and sources of lead exposure in rural Bangladesh: a case control study. Environ Res. 2018;166:1-9. https://doi.org/10.1016/j.envres.2018.04.019

9. Kaiser R, Henderson AK, Daley WR, Naughton M, Khan MH, Rahman M, Kieszak S, Rubin CH. Blood Lead levels of primary school children in Dhaka, Bangladesh. Environ Health Perspect. 2001;109(6):563-6. https://doi.org/10.1289/ ehp.01109563

10. Islam MM, Rahman SL, Ahmed SU, Haque MKI. Biochemical characteristics and accumulation of heavy metals in fishes, water and sediments of the river Buriganga and Shitalakhya of Bangladesh. J Asian Sci Res. 2014; 4(6):270-279. https://ideas.repec.org/a/asi/joars/2014p270-279.html

11. Rakib MA, Ali M, Akter MS, Bhusiyan MAH. Assessment of heavy metal (Pb, Zn, Cr and Cu) content in roadside dust of Dhaka Metropolitan City, Bangladesh. Int J Environ Sci. 2014; 3(1): 1-5. http://www.isca.in/IJENS/Archive/v3/i1/1.ISCA-IJR/EnV5-2013-2.46.php#references

12. Uddin MK, Majumder AK, Hossain MS, Nayem A Al. Pollution and perceptions of lead in automobile repair shops in Dhaka, Bangladesh. J Heal Pollut. 2019;9(22):190609. https://doi.org/10.5696/2156-9614.9.22.190609

13. Khbria MG. Dynamics of cadmium and lead in
some soils of Chittagong, Bangladesh. JOSR J Environ Sci Toxicol Food Technol. 2013;2(6):64–71. https://doi.org/10.9790/2402-026647

14. Ikeda M, Zhang ZW, Shimbo S, Watanabe T, Nakatsuka H, Moon CS, MatsudaInoguchi N, Higashikawa K. Urban population exposure to lead and cadmium in east and south-east Asia. Sci Total Environ. 2000; 249 (1-3): 373-384. https://doi.org/10.1016/S0048-9697(99)00527-6

15. Naser HM, Sultana S, Gomes R, Noor S. Heavy metal pollution of soil and vegetable grown near roadside at Gazipur, Bangladesh. J Agric. Res. 2012;37(1):9–17. https://10.3329/bjar.v37i1.11770

16. Logan TJ, Chaney RL. In: Utilization of municipal wastewater and sludge on land: proceedings of the 1983 workshop. University of California, Riverside 1983; 235–326.

17. Doelman P, Haanstra L. Effects of lead on soil respiration and dehydrogenase activity. Soil Biol Biochem.1979; 11(5): 475–479. https://doi.org/10.1016/0038-0717(79)90005-1

18. Shen F, Liao R, Ali A, Mahar A, Guo D, Li R, Sun X, Awasthi MI, Wang Q, Zhang Z. Spatial distribution and risk assessment of heavy metals in soil near a Pb/Zn smelter in Feng County, China. Ecotoxicol Environ Saf. 2017; 139: 254–262. https://doi.org/10.1016/j.ecoenv.2017.01.044

19. ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological profile for lead, US Department of Health and Human Services. 2020 Accessed [2021 March 20]. Available from: https://www.atsdr.cdc.gov/toxprofiledocs/index.html

20. Mondol M, Asia A, Chamon A, Faiz S. Contamination of soil and plant by the Hazaribagh Tannery Industries. J Asiatic Soc Bangladesh Sci. 2017;43(2):207–22. https://10.3329/jasbs.v43i2.46518

21. Mohiuddin K, Alam M, Ahmed I, Chowdhury A. Heavy metal pollution load in sediment samples of the Buriganga river in Bangladesh. J Bangladesh Agric Univ. 2016;13(2):229-38. https://doi.org/10.3329/jbau.v13i2.28784

22. Sarkar M, Islam JB, Akter S. Pollution and ecological risk assessment for the environmentally impacted Turag River, Bangladesh. J Mater Environ Sci. 2016;7(7):2295–304. https://www.jmaterevirosci.com/Document/vol7/vol7_N7/247-JMES-2311-Sarkar.pdf

23. Zheng N, Liu J, Wang Q, Liang Z. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Sci Total Environ. 2010; 408(4): 726–733. https://doi.org/10.1016/j.scitotenv.2009.10.075

24. Zhuang P, Mchridge BB, Xia HP, Li NY, Li ZA. Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. Sci Total Environ. 2009; 405(15): 1551–1561. https://doi.org/10.1016/j.scitotenv.2008.10.061

25. Biswas SK, Tervahattu H, Kupiainen K, Khaliquzzaman M. Impact of unleaded gasoline introduction on the concentration of lead in the air of Dhaka, Bangladesh. J Air Waste Manag Assoc. 2003;53(11):1355–1362. https://10.1002/tol.10473

26. Geier DA, Geier MR. A prospective study of mercury toxicity biomarkers in autistic spectrum disorders. J Toxicol Environ Health Sci. 2007; 70(20): 1723-1730. https://doi.org/10.1080/15287390701457712

27. Roos PM, Dencker L. Mercury in the spinal cord after inhalation of mercury. Basic Clin Pharmacol Toxicol. 2012; 111(2): 126–132. https://10.1111/j.1742-7843.2012.00872.x

28. World Health Organization (WHO). Recycling used lead-acid batteries: health considerations. 2017 Accessed [2021 December 3]. Available from: https://www.who.int/publications/i/item/recycling-used-lead-acid-batteries-health-considerations

29. Grandjean P, Landrigan PJ. Neurobehavioural effects of developmental toxicity. Lancet Neurol. 2014;13(3):330-8. https://doi.org/10.1016/S1474-4422(13)70278-3

30. Center for Disease Control and Prevention (CDC). Blood lead reference value. 2021 Accessed [2021 May 4]. Available from: https://www.cdc.gov/nceh/lead/data/blood-lead-reference-value.htm

31. Aboli IJ, Sampson MA, Nyaab LA, Caravanos J, Aboh IJ, Sampson MA, Nyaab LA, Caravanos J. Body metal concentrations and glycogen reserves in earthworms (Dendrobaena octaedra) from contaminated and uncontaminated forest soil. Environ Pollut. 2011; 159:190-197. https://doi.org/10.1016/j.envpol.2010.09.005

32. Kumar A. Accumulation of heavy metals in soil and green leafy vegetables, irrigated with wastewater. J Environ Sci Toxicol Food Technol. 2016; 10: 8–19. https://www.romicscholar.org/paper/Accumulation-of-heavy-Metals-in-Soy-and-Grain-%2C-Kumar-Seema/cc534bd06e6b83a862d618a999d61cb260eadc

33. Holmstrup M, Sorensen JG, Overgaard J, Bayley M, Bindesbol AM, Slotsbo S, Fisker KV, Maraldo K, Waagner D, Labouriau R, Asmund G. Body metal concentrations and glycogen reserves in earthworms (Dendrobaena octaedra) from contaminated and uncontaminated forest soil. Environ Pollut. 2011; 159:190-197. https://doi.org/10.1016/j.envpol.2010.09.005

34. Jomova K, Jenisova Z, Feszterova M, Baros S, Dikinya O, Areola O. Lead on root growth. Front Plant Sci. 2013;4:175. https://doi.org/10.3389/fpls.2013.00175

35. Dikinya O, Areola O. Comparative analysis of heavy metal concentration in secondary treated wastewater irrigated soils cultivated by different crops. Int J Environ Sci. 2010;7(2):337-46. https://doi.org/10.1007/BF03326143

36. Beley RJF, Stotzky G. Effects of cadmium and zinc on microbial activity in soil; influence of clay minerals. Sci Total Environ. 1983; 31: 41–55. https://doi.org/10.1016/0048-9697(83)90055-4

37. Chamson AS, Gerzabek MH, Mondol MN, Ullah SM, Rahman M, Blum WEH. Heavy metal uptake into crops on polluted soils of Bangladesh. J Bangladesh Agric Sci. 2013; 3(5):7-12. https://doi.org/10.1007/s10281-013-0007-3

38. London, John L, Freeman A. Human and animal health effects of heavy metal pollution from the ship breaking area of Bangladesh. Coastal Environ: Focus on Asian Regi. Springer. 2012 Accessed [2020 November 23]. Available from: https://doi.org/10.1007/978-90-481-3002-3_6.

39. Kumar A. Accumulation of heavy metals in soil and green leafy vegetables, irrigated with wastewater. J Environ Sci Toxicol Food Technol. 2016; 10: 8–19. https://www.romicscholar.org/paper/Accumulation-of-heavy-Metals-in-Soy-and-Grain-%2C-Kumar-Seema/cc534bd06e6b83a862d618a999d61cb260eadc

40. Holmstrup M, Sorensen JG, Overgaard J, Bayley M, Bindesbol AM, Slotsbo S, Fisker KV, Maraldo K, Waagner D, Labouriau R, Asmund G. Body metal concentrations and glycogen reserves in earthworms (Dendrobaena octaedra) from contaminated and uncontaminated forest soil. Environ Pollut. 2011; 159:190-197. https://doi.org/10.1016/j.envpol.2010.09.005

41. Jomova K, Jenisova Z, Feszterova M, Baros S, Dikinya O, Areola O. Lead on root growth. Front Plant Sci. 2013;4:175. https://doi.org/10.3389/fpls.2013.00175

42. Ghorbe F, Boujelbene M, Makni-Ayadi F. Effect of chronic lead exposure on kidney function in male and female rats, determination of Lead exposure biomarker. Arch Phyto Biochem. 2001; 109(5): 457-463. https://doi.org/10.1007/s10281-013-0007-3

43. Nayeem et al
Lead Pollution in Bangladesh

43. McCartor, A. Toxic Sites Identification Program in Bangladesh. Prepared for: UNIDO. 2018 Accessed [2020 June 23]. Available from: https://www.pureearth.org/project/bangladesh-tsip-toxic-sites-identification-program/

44. Ahmed MJ, Ali MK, Hossain M, Siraj S, Ahsan MA. Determination of trace metals in air of Chittagong city-Bangladesh. European J Chem. 2012; 3(4):416-20. https://doi.org/10.5155/eurjchem.3.4.416-420.645

45. Rahman MA, Rahim A, Siddique N, Alam AMS. Studies on selected metals and other pollutants in urban atmosphere in Dhaka. Dhaka Univ J Sci. 2013;61(2):41-6. https://doi.org/10.3329/dusj.v61i1.15094

46. Islam MF, Majumder SS, Al Mamun A, Khan MB, Rahman MA, Salam A. Trace metals concentrations at the atmosphere particulate matters in the Southeast Asian Mega City (Dhaka, Bangladesh). Open J Air Pollut. 2015;4(2):86. https://doi.org/10.4236/ojap.2015.42009

47. Department of Environment (DoE), Government of the People's Republic of Bangladesh. Environment Conservation Rules (ECR). 1997 Accessed [2020 July 23]. Available from: http://www.doee.gov.bd/site/page/4071101-9fa2-45f1-bfee-512c27103284/

48. Bhuiyan MAH, Parvez L, Islam MA, Dampare SB, Suzuki S. Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. J of Hazard Mater. 2010; 173(1-3): 384-392. https://doi.org/10.1016/j.jhazmat.2009.08.085

49. Ali MM, Ali MI, Islam MS, Rahman MZ. Assessment of toxic metals in water and sediment of Passur River in Bangladesh. Water Sci Technol. 2018; 77(5): 1418-1430. https://doi.org/10.2166/wst.2018.016

50. Ahmed AT, Mandal S, Chowdhury DA, Tareq AR, Rahman MM. Bioaccumulation of some heavy metals in Ayre Fish (Sperata Aor Hamilton, 1822), sediment and water of Dhaleshwari River in dry season. Bangladesh J Zoology. 2012; 40(1):147-53. https://doi.org/10.3329/bjz.v40i1.12904

51. Mokaddes, MAA, Nahar BS, Baten MA. Status of heavy metal contaminations of Lake water of Dhaka Metropolitan City. J Environ Sci Natural Resour. 2012; 5(2): 345-348. https://doi.org/10.3329/jesnr.v52i2.14841

52. Islam F, Rahman M, Khan SS, Ahmed B, Bakar A, Halder M. Heavy metals in water, sediment and some fishes of Karnofuly River, Bangladesh. Pollut Res. 2013;32:715-21. http://www.envirobiotecnjournals.com/article_abstract.php?aid=4763&uid=1658&jid=4

53. Ahmad MK, Islam S, Rahman S, Haque M, Islam MM. Heavy metals in water, sediment and some fishes of Buriganga River, Bangladesh. Int J Environ Res. 2010; 4(2):321-332. https://doi.org/10.22059/IJER.2010.24

54. Rashid H, Hasan MN, Tanu MB, Parveen R, Sukhan ZP, Rahman MS, Mahmod Y. Heavy metal pollution and chemical profile of Khiri River, Bangladesh. Int J Environ Res. 2012; 2: 57-63. http://benjapan.iej/IJERvol02no01/ije0210103.html

55. Samad MA, Mahmud Y, Adhikary RK, Rahman SB, Haq MS, Rashid H. Chemical profile and heavy metal concentration in water and freshwater species of Rupsaha River, Bangladesh. American J Environ Protect. 2015;3(6):180-6. https://doi.org/10.12691/env-3-6-1

56. Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Islam MK. Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. Ecolog Indicat. 2015; 48:282-91. https://doi.org/10.1016/j.ecolind.2014.08.016

57. Rahman MT, Ziku ALME, Choudhury TR, Ahmed JU, Mottaleb MA. Heavy metal contaminations in vegetables, soils and river water: A comprehensive study of Chilmari, Kurigram, Bangladesh. Int J Environ Ecol Fam Urban Stud. 2015; 5(5): 29-42. http://www.ijje.com/view_paper.php?id=5552

58. Pescod, M.B. Wastewater Treatment and Use in Agriculture; Food and Agriculture Organization of the United Nations: Rome, Italy, 1992. Accessed [2020 July 27]. Available from: https://www.sussana.en/ knowledge-hub/resources-and-publications/library/details/3061

59. Zakir HM, Sharmin S, Shikazono N. 2006. Heavy metal pollution in water and sediments of Turag river at Tongi area of Bangladesh. Int J J Lakes Rivers. 2006; 1(1): 85-96. https://www.ripublication.com/ijlr.htm

60. Datta DK, and Subramanian V. Distribution and fractionation of heavy metals in the surface sediments of the GangesBrahmaputra-Meghna river system in the Bengal basin. Environ Geo. 1998; 36(1-2): 93-101. https://doi.org/10.1007/s002540050324

61. Sikder MNA, Huq SMS, Mamun MAA, Hoque KM, Bhuiyan MS, Abu Bakar MA. Assessment of physicochemical parameters with its effects on human and aquatic animals giving special preference to effective management of Turag river, IOSR J Environ Sci Toxico Food Tech. 2016; 10: 41-51. https://doi.org/10.9790/2402-16314151

62. Islam F, Rahman M, Khan SS, Ahmed B, Bakar A, Halder M. Heavy metals in water, sediment and some fishes of Karnofuly River, Bangladesh. Pollut Res. 2013;32:715-21. http://www.envirobiotecnjournals.com/article_abstract.php?aid=4763&uid=1658&jid=4

63. Rahman MS, Saha N, Molla AH. Potential ecological risk assessment of heavy metal contamination in sediment and water body around Dhaka export processing zone, Bangladesh. Environ Earth Sci. 2014; 71: 2293-2308. https://doi.org/10.1007/s12665-013-2631-5

64. Shill SC, Islam MS, Irin A, Tusher TR, Hoq ME. Heavy metal contamination in water and sediments of Passur River near the Sundarbans Mangrove of Bangladesh. J Environ Sci Nat Res. 2017; 10(1): 15-19. https://doi.org/10.3329/jsen.v10i1.34688

65. United States Environmental Protection Agency. Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities. In EPA530-D-99-001C; U.S. Environmental Protection Agency: Washington, DC, USA, 1999 Accessed [2020 July 27].

66. World Health Organization (WHO). Codex Alimentarius-General standards for contaminants and toxins in food. In Reference CX/FAC 02/16; Joint FAO/WHO Food Standards Programme, Codex Committee: Rotterdam, The Netherlands. 2002 Accessed [2021 April 28]. Available from:https://www.federalregister.gov/documents/2002/01/29/02-2134/codex-alimentarius-commission-34th-session-of-the-codex-committee-on-food-additives-and-contaminants

67. Shovon MN, Majumdar BC, Rahman Z. Heavy metals (Lead, Cadmium and Nickel) concentration in different organs of three commonly consumed fishes in Bangladesh. Fisheries and Aquaculture Journal. 2017; 7(3):1000207. https://doi.org/10.4172/2150-3508.1000207

68. Ahmed MK, Baki MA, Kundu GK, Islam MS, Islam MM, Hossain MM. Human health risks from heavy metals in fish of Buriganga river, Bangladesh. Springer Plus. 2016;5(1):1-2. https://doi.org/10.1186/s40064-016-3357-0

69. Chamon AS, Mondal MN, Ullah SM. Effects of different organic amendments on growth and elemental composition of tomato grown on polluted soil. Journal of the Asiatic Society of Bangladesh. 2006; 32 (1): 127-139. http://lib.ewubd.edu/article_index/effects-different-organic-amendments-growth-and-elemental-composition-tomato-grown

70. Ara MH, Mondul UK, Dhar PK, Uddin MN.
Presence of heavy metals in vegetables collected from Jashore, Bangladesh: Human health risk assessment. J Chem Health Risk. 2018; 8(4): 277-287. https://doi.org/10.22034/JCHR.2018.544710

71. Tusher TR, Piash AS, Latif MA, Kabir MH, Rana MM. Soil quality and heavy metal concentrations in agricultural lands around dyeing, glass and textile industries in Tangail district of Bangladesh. J Environ Sci Natural Resources. 2017;10(2):109-16. https://doi.org/10.3329/jesnr.v10i2.39020

72. Zabi AA, Wahid M, Zazaman U, Hossen MZ, Uddin MN, Islam MS. Spatial dissemination of some heavy metals in soil adjacent to Bhalka industrial area, Mymensingh, Bangladesh. American J Appl Sci Res. 2016; 2: 38–47. https://doi.org/10.11648/j.ajasr.20160206.12

73. Alamgir M, Islam M, Hossain N, Kimber MG, Rahman MM. Assessment of heavy metal contamination in urban soils of Chittagong city Bangladesh. Int J Plant Soil Sci. 2015; 7(6): 362-372. https://doi.org/10.9734/IJPS/2015/18424

74. Hossain M, Mostofa M, Alam M, Sultana M, Rahman M. Assessment of lead contamination in different samples around the industrial vicinity in selected areas of Bangladesh. Bangladesh J Vet Med. 2014;12(1):83–9. http://dx.doi.org/10.3329/bjvm.v12i1.20468

75. Mallick SR, Proshad R, Islam MS, Sayeed A, Uddin M, Gao J, Zhang D. Heavy metals toxicity of surface soils near industrial vicinity: A study on soil contamination in Bangladesh. Arc Agri Environ Sci. 2019;4(4):356-68. https://doi.org/10.26832/24566632.2019.040401

76. Faisal BM, Majumder RK, Uddin MJ, Deeba F, Paul D, Haydar MA, Ali MI. Assessment of heavy metals pollution and natural radioactivity in topsoil of Savar industrial area, Bangladesh. J Environ Sci. 2015;5(5):964–79. https://doi.org/10.6088/ijes.20140501.100091

77. Tasrina RC, Rowshon A. Heavy metals contamination in vegetables and its growing soil. J Environ Anal Chem. 2015; 3(3). https://doi.org/10.4172/2380-2391.1000142

78. Begum M, Huq SI. Heavy metal contents in soils affected by industrial activities in a southern district of Bangladesh. Bangladesh J Sci Res. 2016; 29: 11–17. https://doi.org/10.3329/bjsr.v29i1.29753

79. Ashraf MA, Islam MT, Islam MA, Islam MZ. Lead contamination in garden soils at four metropolitan cities of Bangladesh. Progress Agric. 2007;18(1):209–15. https://www.academia.edu/download/57841469/LEAD_CONTAMINATION_IN_GARDEN_SOILS.pdf

80. Zakir HM, Sultana N, Akter M. Heavy metal contamination in roadside soils and grasses: A case study from Dhaka city, Bangladesh. J Chem Biol Phys Sci. 2014;4(2):1661. https://www. semanticscholar.org/paper/Heavy-Metal-Contamination-in-Roadside-Soils-and-A-Zakir-Sultana-d4dc908e5f1995c6620db292e409f7b5c8d8b15

81. Ahammad SS, Siraj S, Ali MS, Kaji MS, Kazi FK. Tracking of possible sources of Dhaka city air pollutants. InProc of Int Conf on Env Asp of Ban (ICEAB, 10) 2010 [2020 October 19]. Available from: http://benjapapa.org/iceab10/34.pdf

82. United States Environmental Protection Agency. Supplemental Guidance for Developing Soil Screening Levels for Superfund Site@; Office of Solid Waste and Emergency Response: Washington, DC, USA. 2002 [2020 October 19].

83. Uddin MN, Hasan MK, Dhar PK. Contamination status of heavy metals in vegetables and soil in Satkhira, Bangladesh. J Mater Environ Sci. 2019;10(6):543-52. https://www.jmaterenvirosici.com/ Document/vol10/vol10_N6/57-JMES-Uddin-2019.pdf

84. Ahmad JU, Goni MA. Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh. Environ Monit Assess. 2010;166(1):347-57. https://doi.org/10.1007/s10661-009-1006-6

85. Islam R, Kumar S, Rahman A, Karmokar J, Ali S, Islam S, Islam MS. Trace metals concentration in vegetables of a sub-urban industrial area of Bangladesh and associated health risk assessment. AIMS Environ Sci. 2018 14(3):130-42. https://doi.org/10.3934/EnvironSci.2018.3.130

86. Mottalib MA, Somoal SH, Aftab M, Shaikh A, Islam MS. Heavy metal concentrations in contaminated soil and vegetables of tannery area in Dhaka, Bangladesh. Int J Cur Res. 2016; 8(5): 30369–30373. https://www.journalcr.com/article/ heavy-metal-concentrations-contaminated-soil-and-vegetables-tannery-area-dhaka-bangladesh

87. Parvin R, Sultana A, Zahid MA. Detection of heavy metals in vegetables cultivated in different locations in Chittagong, Bangladesh. IOSR J Environ Sci Toxicol Food Tech. 2014;8(4):58-63. https://doi.org/10.9790/2402-08425863

88. Food and Agriculture Organization/ World Health Organization (FAO/WHO). Food standards programme on contaminants in foods. In CF/5 INF/1; WHO: Geneva, Switzerland, 2011 Accessed [2021 February 23]. Available from: http://www.fao.org/