Asian Journal of Applied Science and Technology (AJAST)
Volume 7, Issue 2, Pages 204-216, April-June 2023

Heavy Metals in Agricultural Soil and Their Impacts on Rice Production and Human Health: A Review

Most. Serajam Monira & M.G. Mostafa*

Water Research Lab, Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh.
*Corresponding Author Email: mgmostafa@ru.ac.bd**

DOI: https://doi.org/10.38177/ajast.2023.7222

Article Received: 23 April 2023 *Article Accepted: 15 June 2023* *Article Published: 25 June 2023*

ABSTRACT

Rice is one of the most important sources of carbohydrates for humans. The non-degradable and carcinogenic characteristics of heavy metals are the main concerns. Intensive use of farm inputs, industrialization and urbanization cause heavy metals accumulation in the soil, water, and rice grains. This review aimed to assess heavy metals pollution in agricultural soil and their transformation into rice grains. It collected information from different journals, websites, and published reports on heavy metals in soils, water, and accumulated rice grains in the last 13 years. The analysis results illustrated that the amount of heavy metal in the soil and rice of different rice-producing countries was higher than the permissible limits of the WHO, United Kingdom, Tianjin, and European Union standards. The accumulation of heavy metals in agricultural land has become a threat to humans as well as the environment. Reports showed that the higher concentrations of heavy metals in rice grains may cause heart disease, diabetes, possibly stroke, liver changes, hearing changes, changes in blood pressure, diarrhea, flushing of the face, etc. in humans. Regular monitoring and strict regulations of industrial discharge and chemical fertilizer should be recommended for the safety of soil and public health in rice-producing countries.

Keywords: Accumulation; Concentration; Heavy metals; Industrial discharge; Humans; Public health; Rice; Soil.

1. Introduction

Rice is a staple food source for human consumption but grown in soil with contaminated irrigated water cause huge threats to humans. The main sources of heavy metals in soils are wastewater irrigation, solid waste disposal, sludge application, chemical fertilizers, and industrial activities (Tareque et al., 2023; Islam and Mostafa, 2023; Serder et al., 2020; Park et al., 2011; Arao et al., 2010; Ata et al., 2013; Keshav et al.,2016; Bilos et al., 2001; Chandra et al., 2011; Reddy et al., 2013; Chowdhury et al., 2015, 2013; Mukeeb et al., 2008; Fahmida et al., 2017; Domingo et al., 1983). Most of the industries are viewed to discharge their wastage on land or into surface water after partial treatment or without treatment (Monira et al., 2023; Shakil and Mostafa, 2021; Rahim and Mostafa, 2021; Islam and Mostafa, 2022; Jolly et al., 2012; Chowdhury et al., 2016; Chary et al., 2008. Olgun et al., 2012). Rice (Oryza sativa or Oryzaglaberima) serves as the main carbohydrate supplies more than half of the world's population (IRRI 2001; Pearl. S, 2015: Yoneyma et al., 2015; Zhang et al., 2011).

In 2014, global rice production reached 497 million tons, and was consumed 83% as food (FAO, 2014). In Asia alone, more than 2.3 billion people obtain 65 to 75 percent of their caloric intake from rice or rice products (FAO, 2002). Rice provides amino acids, vitamins, and minerals to consumers. In Asian areas, rice, the main alimentary crop, is susceptible to heavy metal pernicious due to the recurrent usage of excess water and metal-enriched agro-chemicals, which are responsible for the deposition of heavy metals inside the topsoil of the ponds (Fangmin et al., 2006; Department of Petroleum Resources, 2002; Emumejaye, 2014). Several research studies found serious metallic contamination of soil, water, and sediments (Islam and Mostafa, 2021a; Zakir et al., 2012, 2013, 2014, 2015; Kamal et al., 2016; Kumar and Seema, 2016; Bakali et al., 2014). Toxic metal levels hinder the metabolic processes of rice plants (Cai et al., 2010), which reduces yield. Chemical fertilizers (Bian et al., 2015; Nessa et al., 2014; Ahmed et al., 2010, 2016; Yasmin et al., 2019; Li et al., 2013) and pesticides (Habib et al., 2012; Shomar, 2006) may increase heavy metal concentrations in soils and plants. Contaminated localities in all aspects of the world are going to be a greater threat to crop plantations. Heavy metals influence almost all countries, but the extent of their severity varies greatly. Heavy metal concentrations in soils and rice plants indicate the threat of toxicity to the health of consumers (Kamani et al., 2018; Jhedioha et al., 2016; McDowell, 2003; Leo et al., 2005; Hu et al., 2014). So, it is essential to determine the toxic levels of heavy metals in agricultural soil and irrigation water. This review article aimed at assessing the heavy metal contamination of soil, their transformation into rice grains, and their effects on humans.

2. Materials and Methods

This study identified over 250 articles on rice production in contaminated soils published in different international peer-reviewed journals, but finally considered the most relevant 35 articles, mainly from rice-producing countries like Bangladesh, India, China, Macedonia and the Philippines. The papers were selected considering the rice produced in heavily metal-contaminated agricultural lands. Most of the industries discharge their effluent without or poorly treated into nearby lowland and or surface water bodies through a main drain. The agricultural lands adjacent to the water body are being irrigated, and the contaminated water threatens food safety and human health. Hence, the rice grains in these areas may be contaminated with heavy metals.

3. Results and Discussions

3.1. Heavy metal standard in soil

The World Health Organization (WHO), United Kingdom, Tianjin, and European Union Standards fixed the permissible limit of heavy metal concentration in soil (Table 1).

Table 1. Permissible limits of heavy metal concentration in soil fixed by WHO and other organizations

Heavy metals (mg/kg) → / **Country/ Organization ↓**	**Cd**	**Zn**	**Cu**	**Cr**	**Pb**	**Ni**	**As**	**Hg**	**References**
WHO	0.8	50	36	100	85	35	-	-	Denneman and Robberse 1991; Ministry of Housing, Netherlands 1994
United Kingdom	1.4	-	63.0	6.4	70.0	-	-	-	Ediene et al., 2017
Tianjin Standard, China (2nd grade)	0.159	115	43.71	107D 124P	32.83	-	16.64P* 14.64D*	0.258	Zuwei et al., 2015
European union standard (EU2002)	3.0	300	140	150	300	-	-	-	Zuwei et al., 2015

D: upland soil, P: paddy soil

Table 1 shows that the heavy metals contamination levels fixed by the WHO is lower than that of other organizations. The World Health Organization (WHO), the Tianjin standard, and the European standard fixed the permissible limit for rice fields. The European Standard, which has a fixed Cd permissible limit of 3.0 mg/kg (Zuwei et al., 2015), was the highest, and the Tianjin Standard, China (2nd grade), is fixed at 0.159 (Zuwei et al., 2015), which was the lowest among the standards. The European Union standard (EU 2002) fixed the Cu concentration at 140 mg/kg (Zuwei et al., 2015), which is approximately three times higher than permissible limit of the WHO (36 mg/kg) (Denneman and Robberse, 1991; Ministry of Housing, the Netherlands, 1994). The European Union standard (EU 2002) fixed the Pb limit at 300 mg/kg (Zuwei et al., 2015), which is approximately 9 times higher than the lower limit of 32.83 mg/kg fixed by the Tianjin Standard, China (2nd grade) (Zuwei et al., 2015). The Tianjin Standard, China (2nd grade), fixed the Hg limit at 0.258 mg/kg, but the other organizations have no standard limit for this element. The organizations fixed the permissible limit of heavy metals in soils, which is helpful for building sustainable soils and agricultural management.

3.2. Heavy metal concentration in soil

Heavy metals were determined in industrial areas (Savar, Gazipur, Ashulia) of Bangladesh, the Philippines (Solana, Cagayan Valley, Sta. Cruz, Zambales, Central Luzon, Sta. Rosa City, Laguna), China (Hunan Province), India (East Coast), and Macedonia (Kocani Field).

In Bangladesh, three major industrial areas are Savar, Gazipur, and Ashulia. Most of the industry discharges its untreated effluent into the soil, which is then transferred to crops and accumulated in edible grains. The study shows that the Fe concentration was found to be 976.12 mg/kg in the Ashulia area, which was higher than the Savar area (873.61 mg/kg) and Gazipur (668.32 mg/kg). The concentration of Cu (31.54 mg/kg) in the Savar area was higher than that in the Gazipur (19.76 mg/kg) and Ashulia (29.65 mg/kg) areas, while the Cd concentration (18.56 mg/kg) was the highest among the other two areas. Concerning Cr (46.93 mg/kg) and Co (43.09 mg/kg) concentrations, they were highest in the Savar and Ashulia areas, respectively, among the three areas of Bangladesh. The AS (3.76 mg/kg) in Ashulia was higher than the others (Table 2). All the concentrations of heavy metals exceeded the standard limits of the WHO (Table 1).

In the Philippines, three important rice-producing areas are the Solana and Cagayan Valleys. Sta. Criz, Zambales, Central Luzon Sta. Rosa City, B. Laguna The Cu content in soil was almost double in Sta. Rosa City, Laguna (115.9 mg/kg) due to the location near urban areas with urban waste than in Solana, Cagayan Valley (53.3 mg/kg), where in Sta. Cruz, Zambales, Central Luzon (<25.0 mg/kg), the Cu content of Sta. Rosa City, Laguna (115.9 mg/kg), Solana, Cagayan Valley (53.3 mg/kg) was higher than the permissible limits of the WHO (36mg/kg), the Tianjin standard (43.71mg/kg) (Table 1). Cr content in Sta. Cruz, Zambales, Central Luzon (1126.5 mg/kg), which is almost 31 times higher than Solana Cagayan Valley (36.6 mg/kg) and Sta. Rosa City (36.8 mg/kg), Cr content of Sta. Cruz, Zambales, Central Luzon was more alarming than the limit of the WHO (100 mg/kg), the Tianjin Standard (107D, 124P), and the European Union standard (150 mg/kg) (Table 1). Ni content is 2624.1 mg/kg in Sta. Cruz, Zambales, and Central Luzon, is 52 times higher than in Solana, Cagayan Valley, and Sta. Rosa City (<50.0 mg/kg). The Ni content in Sta. Cruz, Zambales, Central Luzon were alarming compared to the WHO (35 mg/kg) and the United Kingdom (100) (Table 1). In China, Cd concentration was 1.40 mg/kg, which was higher than the

Asian Journal of Applied Science and Technology (AJAST)
Volume 7, Issue 2, Pages 204-216, April-June 2023

WHO (0.8 mg/kg) and the Tianjin standard (0.159 mg/kg), and Ni concentration was 33.9 mg/kg, which was higher than the WHO (35 mg/kg) and the United Kingdom (100.0 mg/kg). The concentrations of Hg and Pb were 14.9 and 51.4 mg/kg, respectively, which were higher than the Tianjin standard (0.258 and 32.83 mg/kg) (Table 1).In India, Zn concentration was 3.8–33.8 and Pb concentration was 5.3–19.8, which was lower than the permissible limits of the WHO, the Tianjin standard, and the European Union (Table 1). In Macedonia, Cd concentration was 0.9 mg/kg, which was higher than the WHO (0.8 mg/kg) and the Tianjin standard (0.159 mg/kg), Zn was 206 mg/kg, which was higher than the WHO (50 mg/kg) and the Tianjin standard (115 mg/kg), and Pb was 128 mg/kg, which was higher than the WHO (85 mg/kg) and the Tianjin standard (32.83 mg/kg) (Table 1).

The study observed that Cu (115.9 mg/kg) concentration was higher in Sta. Rosa City, Laguna, Philippines, than in the other countries. Cd (18.56 mg/kg) was highest in the Ashulia area of Bangladesh, Cr (1126.5 mg/kg) was highest in Sta. Cruz, Zambales, Central Luzon, the Philippines, and Hg (14.9 mg/kg) and Pb (51.4) levels were found to be highest in Hunan Province, China. The results showed that the Cd concentrations in the soil of Bangladesh, the Philippines, China, and Macedonia exceeded the standard permissible limits set by the WHO and other organizations (Tables 1 and 2). The Cr concentration in the Philippines (Sta. Cruz, Zambales, and Central Luzon) was the highest among the countries that exceeded the permissible limits. The study observed that heavy metal concentrations in agricultural fields were found to be higher due to anthropogenic activities in different countries.

Table 2. Average concentration of heavy metal in soil of rice producing Countries

Heavy metal (mg/kg) / Country	Fe	Cu	Cd	Cr	Co	As	Hg	Ni	Zn	Pb	Area	References
Bangladesh	873.61	31.54	14.98	46.93	28.65	3.32	-	-	78.65	38.07	Savar	Hasan et al., 2022
	668.34	19.76	11.08	40.76	9.56	2.98	-	-	64.98	42.78	Gazipur	
	976.12	29.65	18.56	34.87	43.09	3.76	-	-	81.9	34.09	Ashulia	
Philippines	-	53.3	<10.9	<36.8	-	<9.0	<7.0	<50.0	44.3	>8.0	Solana, Cagayan valley	Sanchez et al., 2015
	-	<25.0	<10.0	1126.5	-	<9.0	>8.0	2624.1	<15.0	>8.0	Sta. Cruz, Zambales, Central Luzon	
	-	115.9	<10.0	<36.8	-	<9.0	<7.0	<50.0	81.2	16.2	Sta. Rosa City, Laguna	
China	-	-	1.40	27.2	-	-	14.9	33.9	-	51.4	Hunan province	Zeng et al., 2015
India	-	-	0.02-0.6	1.3-7.8	-	-	-	-	3.8-33.8	5.3-19.8	East coast	Satpathi et al., 2014
Macedonia	-	33	0.9	-	-	-	-	-	206	128	Kocani field	Rogan et al., 2009

Table 3. Standard level of heavy metal concentration in rice grain

Heavy metal (mg/kg) / Country	As	Cd	Cu	Pb	Zn	References
Chinese standardized value	0.5	0.2	10	0.2	50	Kong et al., 2018
International standardized value	0.2	0.4	-	0.2	-	

*Permissible limit of heavy metal in rice grains in the National Food Safety Standard of the People's Republic of China (GB 2762-2017) and the Agricultural Industry Standards of the People's Republic of China (NY 861-2004). From the Codex Alimentarius Commission (CAC) Standard Codex Stan 1993-1995 adopted in 1995; revised in 1997, 2006, 2008, and 2009; amended in 2010, 2012, 2013, and 2014.

3.3. Heavy metal concentration in rice grain of different countries

Table 4 shows the concentration of heavy metals in rice in different areas of Bangladesh, the Philippines, China, India, and Macedonia. This study illustrated that in Bangladesh, the Cd concentration in rice was found to be highest (1.61 mg/kg) in Ashulia among the three areas of Bangladesh, while the Cu concentration in rice was highest in the Savar area (38.12 mg/kg). Concerning Cr (23.67 mg/kg) concentration, rice in the Ashulia area showed the highest level among the three areas of Bangladesh. The study observed that heavy metals may be transported to rice grains due to the industrial discharge of waste and wastewater onto the surface. The concentrations of the above elements exceeded the standard permissible limits for rice grains, indicating human health hazards (Table 3). However, As and Zn concentrations were lower than the permissible limit.

In the Philippines, Solana, Cagayan Valley, Sta. Cruz, Zambales, and Sta. Rosa City was selected for this study. In these areas, Cu, Cr, As, Ni, and Pb content were the same, and Zn was higher (68.6 mg/kg) in Solana, Cagayan Valley than in Sta. Cruz, Zambales, Central Luzon (17.0 mg/kg), and Sta. Rosa City, Laguna (55.7 mg/kg). All the heavy metal content was higher than the standard level (Table 3). In China, Cd content was 0.312 mg/kg, Cr was 0.106 mg/kg, Ni was 0.59 mg/kg, Hg was 0.069 mg/kg, and Pb content was 0.023 mg/kg. In Macedonia, Cu content was 3.0 mg/kg, Cd was 0.069 mg/kg, As was 27.86 mg/kg, and Pb was 0.196 mg/kg.

The Cu (38.12 mg/kg) concentration in rice at Savar, Bangladesh, was the highest among the countries (Table 4), which was far above the permissible limit (Table 3). Cd (<10.0 mg/kg) and Pb (<8.0 mg/kg) concentrations in Solana, Cagayan Valley, Sta. Cruz, Zambales, Central Luzon, and Sta. Rosa City, Philippines, was the highest among the countries (Table 4) and the permissible limit (Table 3).

3.4. Effect of heavy metal on human health

Rice is considering as the most important grain for human nutrition and calorie intake. After consuming contaminated rice grains, they form bio-toxic compounds that mutilate their structures and cause health hazards. The study showed that several heavy metals were present in the rice grains on agricultural lands around industrial areas in different countries, posing a threat to human health. A discussion on how heavy metals in rice may cause harm to humans.

3.4.1. Arsenic (As)

Arsenic is a tasteless and odorless metal. Arsenic present in higher-level at food can affect the pulmonary nervous system and skin and can cause cancer of the respiratory tract, peripheral neuropathy, and perforation of the nasal septum (Islam and Mostafa, 2021b; Mahurpawar, 2015; Zhou et al., 2008, 2016). Lower-level exposure can cause severe hazards, including nausea and vomiting, production of blood cells and vessels, abnormalities in heart rhythm, etc., and long-term low-level exposure can cause a darkening of the skin and the appearance of small corns or warts on the palms, soles, and torso (Martin S. et al., 2015; WHO, 1989, 1993, 1996, 1997; Jolly et al., 2016).

3.4.2. Cadmium (Cd)

Cadmium is a very toxic metal. It affects Renal and Skeletal Pulmonary. It causes diseases like proteinuria, one of the most important signs of kidney damage, Glucosuria occurs when the urine contains more glucose than it should, Osteomalacia (characterized by the softening of the bones), Aminoaciduria, it occurs when the amount of amino acids increases greatly, emphaysemia, it causes shortness of breath (Mahurpawar M. 2015; Garcia et al., 1998; Engwa et al., 2019.).CD causes diarrhea and affects the lung (Martin S. et al., 2015; Deflora et al., 1997; Sobha et al., 2007).

3.4.3. Chromium (Cr)

Chromium affects the lungs and causes ulcers, a discontinuity or break in a bodily membrane, and perforation of the nasal septum, which occurs most commonly along the anterior cartilaginous septum (Mahurpawar M., 2015; Zhuang et al., 2009; Wang et al., 2005).

Table 4. Average concentration of heavy metal of rice in different rice producing country

Heavy metal (mg/kg) / Country	Fe	Cu	Cd	Cr	Co	As	Hg	Ni	Zn	Pb	Area	References
Bangladesh	14.89	38.12	1.43	19.78	12.08	0.075	-	-	121.76	1.21	Savar	Hasan et al., 2022
	9.49	25.34	0.98	11.54	8.54	0.031	-	0.18	107.43	-	Gazipur	
	11.87	19.74	1.61	23.67	18.11	0.048	-	-	97.34	1.32	Ashulia	
Philippines	-	<25.0	<10.0	<36.8	-	<9.0	-	<50.0	68.6	<8.0	Solana, Cagayan Valley	Sanchez et al., 2015
	-	<25.0	<10.0	<36.8	-	<9.0	-	<50.0	17.0	<8.0	Sta. Cruz, Zambales, Central Luzon	
	-	<25.0	<10.0	<36.8	-	<9.0	-	<50.0	55.7	<8.0	Sta. Rosa City, Laguna	
China	-	-	0.312	0.106	-	-	0.069	0.591	-	0.023	Hunan province	Zeng et al., 2015
India	-	-	0.02-0.05	0.1-0.6	-	-	-	-	3.2-7.2	0.01-1	East coast	Satpathi et al., 2014
Macedonia	-	3.0	0.069	-	-	-	-	-	27.86	0.196	Kocani field	Rogan et al., 2009

Asian Journal of Applied Science and Technology (AJAST)
Volume 7, Issue 2, Pages 204-216, April-June 2023

3.4.4. Manganese (Mn)

Manganese is a metal usually found in combination with iron in minerals. It attacks the nervous system and causes central and peripheral neuropathies and muscle weakness in different parts of the body (Mahurpawar, 2015; Wang et al., 2005; Jolly et al., 2016).

3.4.5. Lead (Pb)

Lead attacks the nervous system, hematopoietic and renal systems. Encephalopathy, it alters the function of brain function or structure (Islam and Mostafa, 2021c; Mahurpawar M., 2015). Lead causes anemia and kidney damage (Martin S. et al. 2015).

3.4.6. Nickel (Ni)

Nickel is a toxic heavy metal. The presence of nickel in food grains can attack the nervous and pulmonary systems, causing visual defects, EEG changes, and pneumoconiosis, an interstitial lung disease (Mahurpawar, 2015; Wang et al., 2005; Jolly et al., 2016).

3.4.7. Mercury (Hg)

Mercury attacks the nervous system and the renal system and causes proteinuria (Mahurpawar, 2015; Wang et al., 2005; EPA 2018).

4. Conclusion

This review observed that the Cu concentration (115.9 mg/kg) was higher in the soil of Sta. Rosa City, Laguna, Philippines, is located near the urban waste dumping area. The Cd and Cr concentrations were found to be higher (18.56 and 46.93 mg/kg, respectively) in the Ashulia and Savar industrial areas of Bangladesh, indicating industrial discharge caused heavy metal pollution in soils. The review also observed that Hg concentrations (14.9 mg/kg) in soil were higher in the Hunan Province of China as it was a mining area, and the Pb (128 mg/kg) concentration in Kocani Field, a municipality in the eastern part of North Macedonia, indicated heavy metal pollution in soil was the result of anthropogenic activities.

The highest concentrations of Cu (38.12 mg/kg) and Zn (121.76 mg/kg) were found in rice grains in the Savar industrial area of Bangladesh. Concerning the concentrations of other heavy metals like Cd, Cr, As, Ni, and Pb in rice at Solana, Cagayan Valley, Sta. Cruz, Zambales, Central Luzon, Sta. Rosa City, and Laguna, Philippines, were found to be higher. This review observed that heavy metal toxicity concerns the world's agricultural sector, is intensified by industrialization, intensive use of farm inputs, and urbanization, and poses a threat to human health.

The review showed that heavy metal concentrations in agricultural fields were found to be higher due to anthropogenic activities. The accumulation of heavy metals in rice grains transported from the soil makes the rice toxic for human consumption. People should be conscious of not cultivating rice near industrial waste discharge areas. The industry should dispose of its waste while considering environmental safety and sustainability. The government should take initiatives for awareness-building programs through the newspaper and television and knowledge-based curriculums for primary and secondary education to reduce surface water pollution. Now it is time to formulate the necessary rules and regulations for irrigation water.

Declarations

Source of Funding

The study has not received any funds from any organization.

Competing Interests Statement

The authors have declared no competing interests.

Consent for Publication

The authors declare that they consented to the publication of this study. The work has been submitted for publication with due consent of authorities of their institute.

Authors' Contributions

All the authors equally participated in research and drafting of the manuscript.

Acknowledgement

Most. Serajam Monira would like to thank the Institute of Environmental Science, University of Rajshahi, Rajshahi, Bangladesh, for giving her a fellowship.

References

Ahmad and M.A. Goni (2010). Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh. Environmental Monitoring and Assessment, 166(1–4): 347–357. doi: https://doi.org/10.1007/s 10661-009-1006-6.

Ahmed, A.N.M. Fakhruddin, M.T. Imam (2016). Spatial distribution and source identification of heavy metal pollution in roadside surface soil: a study of Dhaka Aricha highway, Bangladesh. Ecological Processes, 5(1): 1–16. doi: https://doi.org/10.1186/s13717-016-0045-5.

Arao T., Ishikawa S., Murakami M., Abe K., Maejima Y., Makino T. (2010). Heavy metal contamination of agricultural soil and counter measures in Japan. Paddy Water Environ., 8: 247–257. doi: https://doi.org/10.1007/ s10333-010- 0205-7.

Ata S., Tayyab S., Rasool A. (2013). Analysis of non-volatile toxic heavy metals (Cd, Pb, Cu, Cr and Zn) in Allium sativum (Garlic) and soil samples collected from different locations of Punjab, Pakistan by Atomic Absorption Spectroscopy. E3S Web of Conferences, 1: 16004. doi: https://doi.org/10.1051/ e3sconf/20130116004.

Bakali, B., Mia, M.Y., and Zakir, H.M. (2014). Water quality evaluation of Tongi area in Bangladesh: an impact of industrialization. Journal of Chemical, Biological and Physical Sciences, 4(2): 1735–1752.

Bian B., Zhou L.J., Li L., Lv L., Fan Y.M. (2015). Risk assessment of heavy metals in air, water, vegetables, grains and related soils irrigated with biogas slurry in Taihu basin, China. Environ. Sci. Pollut. Res., 22: 7794–7807. doi: https://doi.org/10.1007/s11356-015-4292-2.

Bilos C, Colombo J.C., Skorupka C.N., Rodriguez P.M.J. (2001). Sources, distribution and variability of airborne trace metals in Laplata city, area, Argentina. Environ. Pollut., 111: 149–158. doi: https://doi.org/10.1016/s0269-7491(99)00328-0.

Cai, Y., Lin, L., Cheng, W., Zhang, G., & Wu, F. (2010). Genotypic dependent effect of exogenous glutathione on Cd-induced changes in cadmium and mineral uptake and accumulation in rice seedlings (*Oryza sativa*). Plant Soil Environ., 56(11): 524–533. doi: https://doi.org/10.17221/107/2010-PSE.

Chandra, P. Pandey, N.M.P. Singh, and V. Mishra (2011). Uptake and accumulation of potentially toxic metals (Zn, Cu and Pb) in soils and plants of Durgapur industrial belt. Journal of Environmental Biology, 32: 831–838.

Chary N.S., Kamala C.T., Raj D.S.S. (2008). Assessing risk of heavy metals from consuming food grown on sewage irrigated soils Chary N.S., Kamala C.T., Raj D.S.S., Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer, Ecotox. Environ. Safe, 69: 513–524. doi: https://doi.org/10.1016/j.ecoenv.2007.04.013.

Chowdhury and M.M. Rasid (2016). Heavy metal contamination of soil and vegetation in ambient locality of ship breaking yards in Chittagong, Bangladesh. Journal of Environmental Science, Toxicology and Food Technology, 10(10): 20–27.

Chowdhury, M.G. Mostafa, T.K. Biswas, A. Mandal, and A.K. Saha (2015). Characterization of the effluents from leather processing industries. Env Processes, 2(1): 173–187. doi: https://doi.org/10.1007/s40710-015-0065-7.

Chowdhury, M., Mostafa, M.G., Biswas, T.K., and Saha, A.K. (2013). Treatment of leather industrial effluents by filtration and coagulation processes. Journal of Water Resource and Industry, 3: 11–22. doi: doi: https://doi.org/10.1016/j.wri.2013.05.002.

De Flora S., Camoirano A., Bagnasco M. (1997). Estimates of the Cr (VI) reducing capacity in human body compartments as a mechanism for attenuating its potential toxicity and carcinogenicity. Carcinogenesis, 18: 531–537. doi: https://doi.org/10.1093/carcin/18.3.531.

Denneman, C.A. and Robberse, J.G. (1990). Ecotoxicological Risk Assessment as Base for Development of Soil Quality Criteria. In: Contaminated Soil' 90, Springer, Dordrecht, Pages 157–164.

Department of Petroleum Resources DPR. (2002). Environmental guidelines and standards for soil in Nigeria (revised edition). Department of Petroleum Resources, Nigeria, Ministry of Petroleum and Natural Resources.

Domingo and K. Kyuma (1983). Trace elements in tropical Asian paddy soils. Soil Science & Plant Nutrition, 29(4): 439–452. https://agris.fao.org/agris-search/search.do?recordID=US201302545287.

Ediene V, Umoetok S. (2017). Concentration of heavy metals in soils at the municipal dumpsite in Calabar metropolis. Asian Journal Environment & Ecology, 3(2): 1–11. doi: https://doi.org/10.9734/AJEE/2017/34236.

Emumejaye K. (2014). Heavy and Trace Elements in Some Brands of Rice Consumed in Delta State, Nigeria. IOSR J. Appl. Phys., 6(2): 1–5. https://iosrjournals.org/iosr-jap/papers/Vol6-issue2/Version-2/A06220105.pdf.

Engwa, P.U. Ferdinand, F.N. Nwalo, and M.N. Unachukwu (2019). Mechanism and health effects of heavy metal toxicity in humans, Poisoning in the Modern World-New Tricks for an Old Dog. Intechopen, London, UK, 10. doi: https://doi.org/10.5772/intechopen.82511.

EPA. (2018). Determination of mercury by Cold-vapor Atomic Absorption (CVAA). EPA/SW-846 Methods 7000A/7470A/7471A, 2006. https://clu-in.org/dounload/ert/1832-r30pdf.

Fahmida and I.M. Rafizul (2017). An investigation on soil quality and heavy metal levels in soil of rajbandh waste disposal site at Khulna, Bangladesh. Iranian Journal of Energy and Environment, 8(2): 102–112. doi: https://doi.org/10.5829/ijee.2017.08.02.02.

Fangmin, C., Ningchun, Z., Haiming, X., Yi, L., Wenfang, Z., Zhiwei, Z., Mingxue, C. (2006). Cadmium and lead contamination in japonica rice grains and its variation among the different locations in southeast China. Sci. Total Environ., 359: 156–166. doi: https://doi.org/10.1016/j.scitotenv.2005.05.005.

FAO/WHO. (2002). Schedule 1 maximum and guideline for contaminants and toxins in food. Codex Alimentarius General Standards for Contaminants and Toxins in food. Joint FAO/WHO food standards programme, Codex committee, Rotterdam.

FAO/WHO. (2014). Guidelines for the Simple Evaluation of Dietary Expose to Food Additives CAC/GL 3-1989 Adopted 1989. Revision 2014 (Formerly Guidelines for the Simple Evaluation of Food Additive Intake) FAO, Rome, Italy, Pages 1–12.

Garcia R., Milkan E. (1998). Assessment of Cd, Pb and Zn contamination in roadside soils and grasses from Gipuzkoa (Spain). Chemosphere, 37(8): 1615–1625.

Habib, R.H., Awadh, S.M., & Muslim, M.Z. (2012). Toxic heavy metals in soil and some plants in Baghdad. Iraq. J Al-Nahrain Univ Sci., 15(2): 1–16.

Hasan A., Das A.K., Satter M.A. (2022). Accumulation of Heavy Metals in Rice (*Oryzasativa. L*) Grains Cultivated in Three Major Industrial Areas of Bangladesh. Journal of Environmental and Public Health, Volume 2022.

Hu, Y. Jiang, Y. Shu, X. Hu, L. Liu, and F. Luo (2014). Effects of mining wastewater discharges on heavy metal pollution and soil enzyme activity of the paddy fields. Journal of Geochemical Exploration, 147: 139–150.

International Rice Research Institute. Rice Statistics (2001). http://www.irri.org/gclid=CInQ2LCuj7sCFgB4god8WoAOQ (Accessed: 25 May, 2023).

Islam, M.S. and Mostafa, M.G. (2023). Occurrence, Source, and Mobilization of Iron, Manganese, and Arsenic Pollution in Shallow Aquifer. Geofluids, 2023: 19. doi: https://doi.org/10.1155/2023/6628095.

Islam, M.S., and Mostafa, M.G. (2021). Influence of chemical fertilizers on arsenic mobilization in the alluvial Bengal delta plain: a critical review. Journal of Water Supply: Research and Technology-Aqua, 70(7): 948. doi: https://doi.org/10.2166/aqua.2021.043.

Islam, M.S., and Mostafa, M.G. (2021). Exposure of Trace Metals and Their Effects on Human Health: A Case Study for Groundwater in Part of the Ganges Basin Areas. Intl. J. Wat. Resource. and Env. Sci., 10(1): 01–13. doi: https://doi.org/10.5829/idosi.ijwres.2021.10.1.16141.

Islam, M.S. and Mostafa, M.G. (2021). Groundwater Quality and Risk Assessment of Heavy Metal Pollution in Middle-West Part of Bangladesh. Journal of Earth and Environmental Science Research, 3(2): 1–5. doi: https://doi.org/10.47363/JEESR/2021 (3)143.

Jhedioha J.N., Ujam O.T., Nwuche C.O., Ekere N.R., and Chime C.C. (2016). Assessment of heavy metal contamination of rice grains (*Oryza sativa*) and soil from Ada field, Enugu, Nigeria: Estimating the human health risk. Hum Ecol Risk Asses: An Int. J., 22(8): 1665–1677.

Jolly, Y.N., A. Islam and A.I Mustafa (2012). Impact of dyeing industry effluent on soil and crop. Univ. J. Environ. Res. Technol., 2: 560568.

Jolly, R. Huque, A. Islam et al. (2016). Toxic elements in rice and possible health risk assessment–Bangladesh prospect. Journal of Food Process, 4: 101–109.

Kamal, F. Ahmed, M. Hassan, M. Uddin, and S. M. Hossain (2016). Characterization of textile effluents from Dhaka export processing zone (DEPZ) area in Dhaka, Bangladesh. Pollution, 2(2): 153–161. doi: https://doi.org/10.7508/PJ.2016.02.005.

Kamani, N. Mirzaei, M. Ghaderpoori, E. Bazrafshan, S. Rezaei, and A. H. Mahvi (2018). Concentration and ecological risk of heavy metal in street dusts of Eslamshahr, Iran. Human and Ecological Risk Assessment: An International Journal, 24(4): 961–970.

Keshav Krishna and K. Rama Mohan (2016). Distribution, correlation, ecological and health risk assessment of heavy metal contamination in surface soils around an industrial area, Hyderabad, India. Environmental Earth Sciences, 75(5): 411.

Kong, Xiangyu, Ting Liu, Ziheng Yu, Zhe Chen, Da Lei, Zhiwei Wang, Hua Zhang, Qiuhua and Shanshan Zhang (2018). Heavy Metal Bioaccumulation in Rice from a High Geological Background Area in Guizhou Province, China. Int J Environ Res Public Health, 15(10): 2281. doi: https://doi.org/10.3390/ijerph15102281.

Kumar and Seema (2016). Accumulation of heavy metals in soil and green leafy vegetables, irrigated with wastewater. Journal of Environmental Science, Toxicology and Food Technology, 10: 8–19.

Li X.Y. (2013). Heavy metal contamination of urban soil in an old industrial city (Shenyang) in Northeast China. Geoderma, 192: 50–58.

Liu H.Y., Probst A., Liao B.H. (2005). Metal contamination of soils and crops affected by the Chenzou lead/zinc mine spill (Hunan, China). Sci. Tot. Environ., 339: 153–166. doi: https://doi.org/10.1016/j.scitotenv.2004.07.030.

Mahurpawar M. (2015). Effects of heavy metals on human health. International Journal of Research, 3(9). doi: https://doi.org/10.29121/granthaalayah.v3.i9SE.2015.3282.

Martin S. and Wendy Griswold (2009). Human Health Effects of Heavy Metals. Environmental Science and Technology Briefs for Citizens.

Maukeeb, ARM, Mondal, MF, Saha, M, & Hasan, MK. (2018). Effects of industrial effluents on seed germination and growth of radish. Journal of Sylhet Agricultural University, 5(1): 51–59.

Mc Dowell (2003). Minerals in Animal and Human Nutrition, Elsevier, Amsterdam, Netherlands. Minerals in Animal and Human Nutrition, Elsevier, Amsterdam, Netherlands.

Monira, U., Sattar, G.S., and Mostafa, M.G. (2023). Characterization of Effluent of Central Effluent Treatment Plant (CETP). Asian Journal of Applied Science and Technology, 7(1): 34–43. doi: https://doi.org/10.51983/ajsat-2023.12.1.3511.

Nessa and A.H. Jewel (2014). Analysis of soil nutrient and heavy metal concentration in agricultural land of Zirani industrial area, Savar, Dhaka. International Journal of Innovation and Scientific Research, 10(1): 90–98.

Olgun and G. Sánchez-Galván (2012). Heavy metal removal in phytofiltration and phyco remediation: the need to differentiate between bioadsorption and bioaccumulation. New Biotech, 30(1): 3–8.

Park JH, Lamb D., Paneerselvam P., Choppala G., Bolan N. and Chung JW. (2011). Role of organic amendments on enhanced bioremediation of heavy metal contaminated soils. J. Hazardous Materials, 185: 549–574. doi: https://doi.org/10.1016/j.jhazmat.2010.09.082.

Rahim, M.A. and Mostafa, M.G. (2021). Impact of Sugar Mills Effluent on Environment around Mills Area. AIMS Environmental Science, 8(1): 86–99. doi: https://doi.org/10.3934/environsci.2021006.

Reddy M.V., Satpathy D., Dhiyiya K.S. (2013). Assessment of heavy metals (Cd and Pb) and micronutrients (Cu, Mn and Zn) of paddy (*Oryza sativa L.*) field surface soil and water in a predominantly paddy-cultivated area at Puducherry (Pondicherry, India) and effects of the agricultural runoff on the elemental concentrations of a receiving rivulet. Environ. Monit. Assess., 185: 6693–6704.

Sanchez P. (2015). Levels and Potential Sources of Heavy Metals in Major Irrigated Rice Areas of the Philippines. https://www.researchgate.net/publication/282858958.

Satpathy D., Reddy M.V., Dhal S.P. (2014). Risk assessment of heavy metal contamination in paddy soil, plants and grains (*Oryza sativa L*) at the east coast of India. Biomed. Res. Int. doi: https://doi.org/10.1155/2014/545473.

Serder, M.F., Islam, M.S., Hasan, M.R., Yeasmin, M.S., and Mostafa, M.G. (2020). Assessment of coastal surface water quality for irrigation purpose. Wat. Prac. & Tech., 15(4): 960–972. doi: https://doi.org/10.2166/wpt.2020.070960-972.

Shakil, M.S.Z. and Mostafa, M.G. (2021). Water Quality Assessment of Paper Mills Effluent Discharge Areas. Al-Nahrain Journal of Science, 24(3): 63–72.

Shomar, B.H. (2006). Trace elements in major solid-pesticides used in the Gaza Strip. Chemosphere, 65(5): 898–905. doi: https://doi.org/10.1016/j.chemosphere.2006.03.004.

Sobha, A. Poornima, P. Harini, and K. Veeraiah (2007). A study on biochemical changes in the fresh water fish, catlacatla (*hamilton*) exposed to the heavy metal toxicant cadmium chloride. Kathmandu University Journal of Science, Engineering and Technology, 1(4): 1–11. doi: https://doi.org/10.3126/kuset.v3i2.2890.

Tareque, M.H., Islam, M.A., Mostafa, M.G. (2023). Photocatalytic decomposition of textile dyeing effluents using TiO2, ZnO, and Fe2O3catalysts. Nep J Environ Sci., 10(2): 49–58. doi: https://doi.org/10.3126/njes.v10i2.46704.

Wang, T. Sato, B. S. Xing, and S. Tao (2005). Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. The Science of the Total Environment, 350: 28–37.

WHO. (1989). Evaluation of certain food additives and contaminants. Thirty-third report of the joint FAO/WHO expert committee on food additives, WHO technical series, No. 807, Geneva, Switzerland.

WHO. (1993). Evaluation of certain foods additives and contaminants. Forty-first report of the Joint FAO/WHO Expert Committee on Foods Additives (JEFCA), WHO, Geneva, Technical Report Series, 837: 53.

WHO. (1996). Permissible limit of heavy metals in soils and plants. Geneva, Switzerland.

WHO. (1997). Guideline for drinking water quality, Second Edition, 1.

Yasmin, H.A. Simol, and G.N.N. Sultana (2019). Heavy and trace elements in some varieties of rice consumed in Dhaka city of Bangladesh. International Journal of Sciences, 5(1): 43–47. doi: https://doi.org/10.18483/ijSci.1847.

Yoneyama T., Ishikawa S., Fujimaki S. (2015). Route and regulation of zinc, cadmium and iron transport in rice plants (Oryza sativa L.) during vegetative growth and grain filling: metal transporters, metal speciation, grain Cd reduction and Zn and Fe bio fortification. Int. J. Mol. Sci., 16: 19111–19129. doi: https://doi.org/10.3390/ijms1608 19111.

Zakir, B., Rahman, HM, Rahman, MM, Ahmed, A, and Hossain. M.A. (2012). Heavy metals and major ionic pollution assessment in waters of midstream of the river karatoa in Bangladesh. Journal of Environmental Science and Natural Resources, 5(2): 149–160. doi: https://doi.org/10.3329/jesnr.v5i2.14806.

Zakir, H.M., Hasan, M.N., Qadir, Q., Sharmin,, F.S., & Ahmed, I. (2013). Cadmium and Lead pollution in sediments of midstream of the river karatoa in Bangladesh. International Journal of Engineering Sciences, 2(2): 34–42.

Zakir H.M., Sultana, N., & Akter, M. (2014). Heavy Metal Contamination in Road side Soils and Grasses: A Case Study from Dhaka City, Bangladesh. Journal of Chemical, Biological and Physical Sciences, 4(2): 1661–1673.

Zakir, S.A. Sumi, S. Sharmin, K.M. Mohiuddin, and S. Kaysar (2015). Heavy metal contamination in surface soils of some industrial areas of Gazipur, Bangladesh. Journal of Chemical, Biological and Physical Sciences, 5(2): 2191–2206.

Zeng F., Wei W., Li M., Huang R., Yang F., Duan Y. (2015). Heavy Metal Contamination in Rice-Producing Soils of Hunan Province, China and Potential Health Risks. Int. J. Environ. Res. Public Health, 12(12): 15584–15593. doi: https://doi.org/10.3390/ijerph121215005.

Zhang H., Luo Y., Song J., Zhang H., Xia J., Zhao Q. (2011). Predicting As, Cd and Pb uptake by rice and vegetables using field data from China. J. Environ. Sci., 23(1): 70–78. doi: https://doi.org/10.1016/S1001-0742 (10)60375-0.

Zhou, J. Liu (2008). High levels of heavy metals in rice (*Oryza sativa L.*) from a typical E-waste recycling area in southeast China and its potential risk to human health. Chemosphere, 71(7): 1269–1275. doi: https://doi.org/10. 1016/j.chemosphere.2007.11.065.

Zhuang, M. B. Mc Bride, H. Xia, N. Li, and Z. Li (2009). Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, south China. The Science of the Total Environment, 407(5): 1551–1561.

Zuwei W. Zeng X., Geng M., Chen C., Cai J., Yu X., Hou Y., Zhang H. (2015). Health Risk of heavy metals uptake by crops grown in sewage irrigation area in China. Polish Journal of Environmental Studies, 24(3): 1379–1386.