Ecological Questions 35 (2024) 4: 39–51 http://dx.doi.org/10.12775/EQ.2024.046

Evaluating the environmental effects of open dumps and waste farming: A case study

Ria Ghosh[1], Tumpa Hazra[1], Indranil Mukherjee[2], Svitlana Ushcats[3,*], Wasim Akram[2], Athar Akram[2], Mohd Sayeed Ul Hasan[2], Tinku Biswas[4], Sheela Malik[5], Anzar Rabbani[4], Oleh Vlasenko[6]

[1] Civil Engineering Department, Jadavpur University, Kolkata-700032, India
[2] Department of Civil Engineering, Aliah University, New Town, Kolkata, -700160, India
[3] Department of Ecology and Environmental Protection Technologies, Admiral Makarov National University of Shipbuilding, Mykolayiv, Ukraine
[4] Ganga Institute of Technology and Management, Bahadurgarh-Jhajjar Road Kablana Jhajjar – 124104 Haryana, India
[5] Jamia Millia Islamia, Jamia Nagar, Okhla, New Delhi, Delhi 110025, India
[6] Department of Environmental Audit and Environmental Protection Technologies, State Ecological Academy of Postgraduate Education and Management, Kyiv, Ukraine
* Corresponding author e-mail address: svitlanaushkats@ukr.net

Received: 22 May 2024 / Accepted: 1 July 2024

Abstract. Dhapa, the landfill situated in Kolkata, is a very active site for municipal dumping. A humongous amount of municipal solid waste is added in this dump daily and the nearby farmlands produce a significant yield for the local population. The current study seeks to examine the environmental associated with leachate migration due to open dumping of unsorted solid waste in Dhapa, Kolkata, India. Also, the second goal of the study is to assess the risk to public health associated with the consumption of agricultural products possibly contaminated with heavy metals through soil and groundwater. The seasonal soil and groundwater sample, and samples of products grown near the landfill were collected around the periphery of Dhapa. The presence of heavy metals in the samples was determined using classical methods in a specialized laboratory. The soil and groundwater results compared to FAO/WHO, and BIS/WHO was found that toxic metal Cd, Cr, Zn, Pb & Hg were present in high concentrations. For the vegetables grown at the site fields, multiple samples were collected as multiple different vegetables are grown around the year, it was found that mainly Cd, Cr, Zn, Pb and Hg exceeding Indian permissible standards of consumptions many fold. Finally by the use of multiple indices like Average Daily Dose (ADD) & Chronic Daily Intake (CDI) along with Hazard Quotient (HQ) it was found that carcinogenic risk, on human health, was highest in the ground water and vegetables. The current study fills the gap associated with the scientific substantiation of actively developing environmental hazards at the regional level.

Keywords: geoaccumulation index, bioaccumulation concentration, toxic metals, ecological risk, health risk.

1. Introduction

The swift socio-economic development and evolving consumption patterns have resulted in a significant increase in the production of municipal solid waste (MSW) (Vambol et al., 2016; Hanoshenko et al., 2022; Vambol et al., 2023). Landfilling is the most commonly practiced method followed in developing countries like India to dispose the non-segregated MSW due to their economic advantages and technological simplicity. Uncontrolled disposal of MSW led to generation of highly pollutant liquid known as leachate, which when percolates through soil contaminates it as well as aquatic resources.

Landfills for storing waste are a source of environmental hazard. The physical and chemical processes occurring in the body of the landfill are capable of producing negative effects (Salam et al., 2021; Vambol, 2016; Nai et al., 2021). Due to diffusion processes, the risk of contamination of soil and nearby water bodies by landfill leachate increases as the duration of landfill operation increases (Nai et al., 2021; Wang et al., 2023). This applies even to landfills that initially had a protective engineered impervious screen at the bottom, since its protective properties also decrease over time (Bhalla et al., 2014; Nai et al., 2021). An additional factor that contributes to the active penetration of toxic landfill leachate into the soil and groundwater should be emphasized – this is the rainy season in India. This is justified by the fact that the degradation of waste materials under the influence of significant amounts of sediment is accelerated and penetration into biosphere components and distribution into them occurs faster (Bhalla et al., 2014). Some studies demonstrate environmental contamination, particularly groundwater, within a radius of 100 m, and sometimes even 200 m (Han et al., 2016). Since waste dumps are a powerful source of bacteria and viruses (Salam et al., 2023), serious epidemics can occur through water (El Morabet et al., 2023). Water contamination requires additional treatment measures before use (Zahorodniuk et al., 2019), which is extremely difficult in low-income countries. Some studies demonstrate significant excesses of standards for the content of heavy metals in water, which is justified by the proximity of water intake sources to solid waste landfills (Alao et al., 2023). This is especially noticeable in shallow water areas. As water sources move away and increase in depth, heavy metal concentrations are observed to decrease (Alao et al., 2023).

On the other hand, rapid increase in population and unplanned extension of cities resulting in excessive demand of foodcrops and reduction of agricultural land. Therefore, land areas adjacent to landfills are used for agricultural purpose using partially degraded MSW popularly known as garbage farming. As a result of uncontrolled landfilling of MSW and garbage farming soils can accumulate various pollutants, such as, Cr, Cd, Cu, Ni, Zn, Pb, As, and Hg. The United States Environmental Protection Agency (USEPA) has these metals categorized as 'priority control pollutants' (EPA, 2014) as they are toxic, have low degradability and their bioaccumulation capacity is high (Hikon & Yebpella, 2024), which necessitates the search for new approaches to soil health (Lahori et al., 2023; Sawicka et al., 2023; Liu et al., 2022). Crops grow using contaminated water on contaminated soil will accumulate these pollutants and toxicity, which in the long run would have adverse effects on human health upon consumption. The current study seeks to examine the environmental associated with leachate migration due to open dumping of unsorted solid waste in Dhapa, Kolkata, India. Also, the second goal of the study is to assess the risk to public health associated with the consumption of agricultural products possibly contaminated with heavy metals through soil and groundwater.

2. Methodology

2.1. Study Area

The Dhapa landfill site (22.561333°N, 88.442254°E) (Fig. 1), a part of famous East Kolkata Wetland, a Ramsar site is situated in the eastern fringe of Kolkata, West Bengal, India. The landfill site is in operation since last 100 years and receives around 4000 tons of MSW daily collected within an area of radius of 20 km. It is a non-engineered type landfill without any leachate collection and treatment facility and

Figure 1. Dhapa Landfill Site Along with Locations of Sampling Points.
Source of Picture B: Assessment Report of Dhapa Disposal Site, File No. 02205942.00, of 2010.

after disposing the wastes it is covered by nominal daily cover every day. Under the Zone III an area of 21.5 ha has reached the height of 17 m to accommodate daily waste dumped here as the space available is scarce (data by SASSMR, 2003). The garbage farming sites surround the Dhapa landfill. Besides being used as primary waste disposal site of Kolkata Municipal Corporation (KMC) Area, the area is also used for vegetable farming popularly known as 'garbage farming' and sewage fed aquaculture. The cultivators and ragpickers whose livelihood depends on landfill site reside villages adjacent to the landfill area.

2.2. Environmental and Health Risk Assessment

To assess the environmental risk to the population due to the consumption of contaminated products, the qualitative and quantitative level of pollution must be understood. Therefore, it is necessary to find out the degree of contamination of products grown in the fields closest to the open-type landfill and, based on the results, determine the degree of risk.

A step by step approach was the most suitable one and thus adopted. Firstly, heavy metals were identified in 1) the soil and fields, 2) groundwater from nearby wells/tube wells/ hand pumps and 3) vegetables grown in the fields nearby the dumping site. In the second step, the assessment of level of soil pollution in terms of geoaccumulation index (Igeo) along with ecological risk of leachate migration were calculated. Transfers of the heavy metals, the contaminants, from soil to the crops were calculated in terms of bioaccumulation concentration (BAC). Calculating the risk to human health involves several steps. Initially, the concentration of heavy metals in groundwater and vegetables, along with the intake rates, are analyzed. Subsequently, a dose-response assessment establishes the relationship between the level of exposure to heavy metals and the corresponding risk. Lastly, risk characterization evaluates the potential impact of the hazard by considering the severity of its effects and the extent of exposure.

2.2.2. Data Collection Regarding Soil of the Agricultural Field

The 16(4×4) number of soil samples were collected from different points of the landfill site and agricultural fields in pre-monsoon season (June, 2019), monsoon season (August, 2019), post monsoon Season (December, 2019) and summer (March, 2020) season. The soils were collected at depth 0-15 cm under the roots of the vegetables from the agricultural lands, periphery of the active landfill site and adjacent to leachate leaking points. Once brought to the laboratory, the soil samples were initially oven-dried at 105°C in a conventional oven. They were then prepared for heavy metal analysis using a graphite furnace atomic absorption spectrometer. Each measurement was performed in triplicate, utilizing chemicals of analytical grade. The average concentrations of heavy metals in the soil are shown in Table 1.

Table 1. Heavy Metals Concentration in Soil

Parameters	Soil collected under Red Spinach, Mar 20	Soil collected under Radish Spinach, Dec 19	Soil collected under Red Spinach, Sep 19	Soil collected under Red Spinach, June 19	Permissible Standard (Bhatnagar & Awasthi, 2000)
Cadmium (Cd) (mg/kg)	285.2	2.32	23.9	11.7	0.07–1.1
Chromium (Cr) (mg/kg)	185.89	35.38	815.0	1333.0	65[a]
Zinc (Zn) (mg/kg)	392.76	332.83	241.67	175.6	300–600
Lead (Pb) (mg/kg)	285.2	851.0	125.67	48.6	250–500
Mercury (Hg) (mg/kg)	0.167	2.0	0.17	0.2	---

Source: FAO/WHO (1995).

From the results it is clear that the soil used for agricultural purpose adjacent to Dhapa landfill site is highly contaminated by heavy metals like Cd, Cr, Zn, Pb and Hg, exceeding standard limits. Maximum concentrations were obtained in pre-monsoon season (March 2020) which is very likely.

2.2.2. Data Collection Regarding Ground Water and Vegetables

Measure the concentrations of heavy metals in vegetables and groundwater prior to initiating the exposure assessment process. Data on groundwater was obtained from the published paper (De et al., 2017) in which the heavy metal concentrations were analyzed in 60 groundwater samples obtained from bore wells and hand pumps in villages within 3.5 km of Dhapa landfill sites in 2014. Samples were collected during the pre-monsoon, monsoon, and post-monsoon seasons. The metals that were predominantly present were arsenic (0.009±0.003 mg/L), cadmium (0.01±0.007 mg/L), chromium (0.05±0.03 mg/L), iron (1.27±1.58 mg/L), mercury (0.19±0.09 mg/L), nickel (0.03±0.02 mg/L) lead (0.20±0.26 mg/L) and zinc (4.16±5.74 mg/L). The permissible limits according to BIS standard and WHO guidelines for safe drinking water for the heavy metals present in groundwater are presented in Table 2.

Table 2. Heavy Metal Concentration Present in Groundwater along with Permissible Standards in Safe Drinking Water

Heavy Metals	Concentration in Ground Water	Drinking Water Quality Standards	
		BIS Standard (IS 10500:2012)	WHO Standard
Arsenic (As) **(mg/L)**	0.009 (±0.003)	0.01	0.01
Cadmium (Cd) **(mg/L)**	0.01(±0.007)	0.003	0.003
Chromium (Cr) (Hexavalent)**(mg/L)**	0.05 (±0.03)	0.05	0.05
Iron (Fe) **(mg/L)**	1.27 (±1.58)	0.3	-
Mercury(Hg)**(mg/L)**	0.19 (±0.09)	0.001	0.006
Nickel (Ni) **(mg/L)**	0.03 (±0.02)	0.02	0.07
Lead (Pb)**(mg/L)**	0.20 (±0.26)	0.01	0.01
Zinc (Zn)**(mg/L)**	4.16 (±5.74)	5.0	-

Source: De et al. (2017).

Table 3. Heavy Metal Concentration Present in Vegetables along with Permissible Standards

Parameters	Red Spinach, Mar 20	Radish Spinach, Dec 19	Red Spinach, Sep 19	Red Spinach, June 19	Permissible Standard (Awasthi, 2000)4
Cadmium (Cd) (mg/kg)	0.2	5.0	7.1	0.38	1.5
Chromium (Cr) (mg/kg)	0.5	343.3	10	3.02	20
Zinc (Zn) (mg/kg)	16.03	315	11.97	20.17	50
Lead (Pb) (mg/kg)	1.0	28.8	25.4	9.35	2.5
Mercury (Hg) (mg/kg)	0.03	0.3	0.01	0.02	0.01-0.3[a]

Source: FAO/WHO (1995).

The groundwater samples' concentrations of zinc and arsenic fell within permissible bounds. However, during exposure evaluation, concentrations of Cd, Cr, Fe, Hg, Ni, and Pb had to be taken into consideration since they exceeded the permissible drinking water level.

In the 2019–20 growing season, pre–monsoon, monsoon, post–monsoon, and summer seasons, multiple vegetable samples were collected based on their growing seasons from different locations in order to evaluate the heavy metal concentration present in vegetables grown at the agricultural fields adjacent to the landfill site. The plant samples were collected right away, tagged, and stored in bags made of plastic until they were transported to the lab for chemical analysis. The plant samples were thoroughly rinsed with fresh running tap water after being brought to the lab, and then with distilled water to get rid of any unnecessary components. Following washing, the plant samples were dried at 105°C in a regular oven until they reached a consistent weight. The dried samples then were grounded and prepared to analyze heavy metals using graphite furnace atomic adsorber spectrophotometer. The compounds utilized were of analytical quality, and all assays were performed in triplicate. The mean heavy metals concentration obtained in vegetables samples in different seasons are presented in Table 3.

From Table 3 it is clear that the vegetables collected from agricultural fields are highly contaminated with heavy metals mainly Cd, Cr, Zn, Pb and Hg exceeding Indian (PFAR, 2004) permissible standards of consumptions many fold. Concentrations of heavy metals like Cd, Cr, Zn, Pb and Hg in radish spinach (*Raphanus sativus* L.) which were collected in winter (December 2019) exceeded permissible limits of consumptions. Concentrations of heavy metals were compared for red spinach (*Amaranthus dubius* Mart. ex Thell.) which is common leafy vegetable grown in Dhapa. Red spinach has more scavenging capacity of Pb and CD. Maximum concentrations of heavy metals were obtained in monsoon season (September 2019).

2.2.3. Assessment of Level of Soil Pollution

The level of soil pollution resulting from the uncontrolled disposal of MSW at the Dhapa landfill and the migration of leachate can be assessed using the geo-accumulation index (I_{geo}) (Singh et al., 1997; Bello et al., 2016; Aiman et al., 2016; Vaverková et al., 2018). Geo-accumulation index (I_{geo}) can be calculated using Equation (1) proposed by Muller (1969).

$$\text{Geo-accumulation index } (I_{geo}) = \log_2 \frac{Concentration\ of\ heavy\ metal}{1.5 \times geochemical\ background\ of\ the\ heavy\ meta} \quad (1)$$

The classifications of Igeo for soil contamination by heavy metals, as suggested by Yaqin et al. (2008), are outlined in Table 4.

Table 4. Categories of Igeo and the Corresponding Values

I_{geo}Class	Contamination Level	Igeo Value
0	Uncontaminated	$I_{geo} \leq 0$
1	Uncontaminated/moderately contaminated	0<Igeo< 1
2	Moderately contaminated	1<Igeo< 2
3	Moderately/strongly contaminated	2 <Igeo< 3
4	Strongly contaminated	3 <Igeo< 4
5	Strongly/extremely contaminated	4 <Igeo< 5
6	Extremely contaminated	I_{geo}>5

Table 5. Igeo Index Calculation

Parameters	Soil collected under Red Spinach, Mar 20		Soil collected under Radish Spinach, Dec 19		Soil collected under Red Spinach, Sep 19		Soil collected under Red Spinach, June 19	
	I_{geo} Index	Contamination Level	I_{geo} Index	Contamination Level	I_{geo} Index	Contamination Level	I_{geo} Index	Contamination Level
Cd (mg/kg)	12.407	Extremely contaminated	5.464	Extremely contaminated	8.830	Extremely contaminated	7.8	Extremely contaminated
Cr (mg/kg)	0.462	Uncontaminated/ moderately contaminated	-1.932	Uncontaminated	2.594	Moderately/ strongly contaminated	3.304	Strongly contaminated
Zn (mg/kg)	1.463	Moderately contaminated	1.224	Moderately contaminated	0.762	Uncontaminat-ed/moderately contaminated	0.301	Uncontaminat-ed/moderately contaminated
Pb (mg/kg)	3.249	Strongly contaminated	4.826	Strongly/ extremely contaminated	2.067	Moderately/ strongly contaminated	0.696	Uncontaminat-ed/moderately contaminated
Hg (mg/kg)	-0.774	Uncontaminated	2.811	Moderately/ strongly contaminated	-0.774	Uncontaminated	-0.511	Uncontaminated

Note: Geochemical background of Cd=0.035ppm, Cr=90ppm, Zn=95ppm, Pb=20ppm and Hg=0.19ppm. All are Shale Values, Source: Turekian and Wedepohl (1961).

Based on the findings depicted in Table 5, it's evident that the agricultural field exhibits significant contamination with Cd and ranges from moderate to strong contamination with Cr, Zn, and Pb.

2.2.4. Assessment of the Transfer of Metal to Plant from the Soil

To understand transfer of heavy metals from soil to the plant Bioaccumulation concentrationwas assessed using Equation(2) (Vaverková et al., 2018; Sipter et al., 2009; Pachura et al., 2016; Zhang et al., 2020).

$$\text{Bioaccumulation concentration (BAC)} = \frac{Concentration\ of\ heavy\ metal\ in\ plants}{Concentration\ of\ heavy\ metal\ in\ soil} \quad (2)$$

Zhang et al. (2008) established the categories for rising BAC levels, and this evaluation of the computed values was carried out on their recommendations.

Table 6. Category of Plants Based On BAC Values

Category	BAC Values
Non-accumulator plants	BAC<0.01
Low accumulator plants	0.01<BAC<0.1
Moderate accumulator plants	0.1<BAC<1.0
High accumulator plants	1.0<BAC<10.0

From Table 7 it is clear that radish spinach translocate Cd and Cr effectively from soil since bioaccumulation factors corresponding to Cd and Cr are greater than 1. Red spinach is low to moderately accumulator plant of heavy metals while radish spinach is moderate to high accumulator plant for Cd, Cr, Zn, Pb and Hg. Not only type of plants, accumulation of heavy metals also depend on the concentrations of metals in soil on which the vegetables grown. Necessary care should be taken for selection of vegetables to be grown in the heavy metal laden soil since the concentration of heavy metals in vegetables are directly related to health risk.

Table 7. Bioaccumulaion Concentration Values of Vegetables

Vegetables	BACValues				
	Cd	Cr	Zn	Pb	Hg
Red Spinach, Mar 20	0.001	0.003	0.041	0.003	0.2
Radish Spinach, Dec 19	2.158	9.702	0.946	0.034	0.15
Red Spinach, Sep 19	0.297	0.012	0.05	0.202	0.06
Red Spinach, June 19	0.033	0.002	0.115	0.192	0.083

2.2.4. Assessment of Ecological Risk

The potential ecological risk index (PERI), as established by Hakanson (1980), is determined based on the elemental abundance and release capability of pollutants in environment. It is useful in classifying the degree of pollution and ecological danger developing owing to the presence of heavy metals in soil. It can be calculated using Equation (3) (Cao et al., 2009; Zhu et al., 2012; Jiang et al., 2014; Islam et al., 2015).

$$E_r^i = T_r^i \times C_r^i = T_r^i \times \frac{C_n^i}{C_b^i} \quad (3)$$

where:

E^i_r: potential ecological risk factor of a single heavy metal;

T^i_r: toxic response coefficient for a heavy metal i;

C^i_r: the pollution factor for the individual heavy metal;

C^i_n: concentration of heavy metal i in soil sample (mg kg^{-1});

C^i_b: background concentration or maximum permissible limit for i metal (mg kg^{-1}).

On the basis of its severity *PERI* can be classified into 5 grades as presented in Table 8.

Table 8. Classifications of PERI and its Associated Values

PERI Classification	Associated Values
Low risk	$E^i_r \leq 40$
Moderate risk	$40 < E^i_r \leq 80$
High risk	$80 < E^i_r \leq 160$
Very high risk	$160 < E^i_r \leq 320$
Extremely high risk	$E^i_r > 320$

Risk index (*RI*) is the summation of the individual *PERI* for studied metals in the soil contaminated by MSW ans is calculated using Equation 4.

$$RI = \sum_{i=1}^{n} E_r^i \quad (4)$$

RI is classified into4 grades as presented in Table 9.

Table 9. Classifications of RI and its Associated Values

PERI Classification	Associated Values
Low risk	$RI \leq 150$
Moderate risk	$150 < RI \leq 300$
High risk	$300 < RI \leq 600$
Very high risk	$RI > 600$

To assess ecological risk, we considered the highest concentrations of heavy metals detected in soils collected from agricultural fields in March 2020.

Table 10. Ecological Risk Calculation

Element	Indication	Cd	Cr	Zn	Pb	Hg
The concentration of elements in the soils (mg/kg)	C^i_n	285.2	185.89	392.76	285.2	0.1667
The regional background value of elements (mg/Kg)	C^i_b	1	90	175	70	0.25
The contamination factor	C^i_r	285.2	2.065	2.244	4.074	0.667
Toxic Response Factor	T^i_r	30	2	1	5	40
The potential ecological risk	E^i_r	8556	4.131	2.244	20.371	26.672
The sum of all potential ecological risk for elements in the soils	RI	8609.419				

As seen in Table 10, the Eir values for Cr, Zn, Pb, and Hg are below 40, suggesting that the soil in agricultural fields poses a low potential ecological risk associated with these heavy metals. The Eir value for Cd surpassed 320, indicating an extremely high potential ecological risk. The obtained ecological risk index (RI) value for this study was 8609.419, indicating that the soil is under significant ecological risk.

2.2.5. Assessment of Human Exposure

The next stage involved calculating exposure rates, which are primarily dependent on a number of variables including age, gender, body weight, climate, socioeconomic status, and so on. These variables include the amount, frequency, and length of the daily average consumption of contaminated groundwater and crops (Mishra et al., 2018). Potency Factors (PF), Reference Dose (RfD) of heavy metals, body weight, water consumption, and other data have been gathered from several sources in order to assess the inherent uncertainty associated with the hazards to human health. Adult Indian body weight data came from the National Family Health Survey (NFHS, 2024), which is a survey conducted online. Due to the lack of Indian water consumption statistics, the U.S. EPA's water intake recommendations have been adopted. RfD for heavy metals was gathered from a number of databases, including the provisional peer-reviewed toxicity values (PPRTV) database (U.S. EPA, 2022), the health effects assessment summary tables (HEAST) (U.S. EPA, 1997), and the integrated risk information system (IRIS) (U.S. EPA, 2024). Table 12 lists the relative concentrations (RfD) and oral potency factors of heavy metals found in vegetables and groundwater collected from farms and settlements around the Dhapa garbage site.

Average Daily Dose (ADD): is the average amount of contaminant consumed per day through water or vegetables and is calculated using Equation (5) (Sipter et al., 2009; Singh et al., 2010; Nabulo et al., 2010; Tariq, 2021).

$$\text{ADD (mg/kg-day)} = \frac{C \times DI}{BW} \quad (5)$$

where:

C = concentration of heavy metals present in water(mg/L) or vegetables(mg/Kg);

DI = average daily intake of water (mg/L) or vegetables(mg/g);

BW= average body weight (kg) of the consumer.

Chronic Daily Intake (CDI): is defined as mass of a heavy metal consumed per unit body weight per unit time, averaged over a long period of time and is calculated using Equation 6 (Chen et al., 2015; Ametepey et al., 2018; Yuan et al., 2019; Guo et al., 2019).

$$\text{CDI (mg/Kg-day)} = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (6)$$

where:

C = concentration of heavy metal in water (mg/L)or vegetables(mg/g);

IR = ingestion rate of water (L/day) or vegetables (mg/g);

EF = annual exposure frequency (days/year);

ED = exposure duration (years);

BW = average body weight (kg) of the consumer;

AT = averagingtimefor carcinogen (days/year × average life expectancy in year).

Table 11 presents the average body weight, ingestion rate, annual exposure frequency, exposure duration and averaging time of consumption of contaminated groundwater and vegetables for adult persons.

Table 11. Magnitude, Duration and Frequency of Consumption of Heavy metals

Parameter	Unit	Receptor
Body weight (BW)	kg	55
Exposure frequency (EF)	days/year	350
Exposure duration (ED)	Year	30
Average Life Expectancy (Countryeconomy.com, 2022)	Year	69.42 for males: 68.24 for females: 70.69 therefore an average of two extremes have been taken
Averaging time for carcinogen (AT)	days/year × Average Life Expectancy (Year)	365 × 69.2
Ingestion rate of vegetables (IR) [National Sample Survey (2011–2012)]	g/day	160 (Rural India)
		184 (Urban India)
Ingestion rate of water (IR)	L/day	2.2

2.3. Dose Response Assessment

The dose-response connection is essentially a quantitative relationship that shows how hazardous a heavy metal is to the exposed species at different concentrations. Using this approach, the risk resulting from heavy metal exposure is determined by clinical, occupational, and epidemiological investigations. The milligrams of heavy metals consumed or inhaled per kilogram of weight of the person per day (mg/kg-day) is used to equalize dose. The aim of this evaluation is to establish a quantitative correlation between the quantity of heavy metals that a person is exposed to and the likelihood of a dangerous consequence resulting from it. There are two types of responses that can be distinguished: non-carcinogenic and carcinogenic.

Non Carcinogenic Responses

For non-carcinogenic effects it is usually assumed that there is always a threshold dose as represented by Reference Dose (RfD) below which there is no appreciable risk to humans.

Carcinogenic Responses

Regarding the mathematical model for carcinogenic investigations, there are numerous disagreements. The most widely used model for epidemiological investigations is the linear multistage model for carcinogens, which was developed by the EPA. Lifetime incremental risk is calculated using the slope known as potency factor (PF) or slope factor (SF), which is utilized at low doses where the dose response curve is considered to be linear.

Table 12 presents the RfDs and PFs of different heavy metals obtained in groundwater and vegetables collected during the study.

Table 12. Reference Dose and Oral Slope Factor or Potency Factors of Heavy Metals

Heavy Metals	Classification by IARC	RfD ($mgkg^{-1}d^{-1}$)	Oral SF /PF ($(mg/kg\ bw\text{-}day)^{-1}$)	Source
Arsenic (As)	1	3.00E-04	1.5	IRIS
Cadmium (Cd)	1	1.00E-03	0.38	IRIS
Chromium (Cr) (Hexavalent)	1	3.00E-03	0.5	IRIS
Zinc (Zn)	3	3.00E-01	---	IRIS
Lead (Pb)	2B	3.60E-03	8.5E-03	OEHHA 1992
Nickel (Ni)	1	2.00E-02	0.91	IRIS
Mercury (Hg)	3	3.00E-04	---	Dept of Env Affairs, South Africa

Note: IARC- International Agency of Research on Cancer; Group 1 chemicals have been determined to be carcinogenic to humans; Group 2B chemicals may also cause cancer in humans; and Group 3 chemicals are not known to cause cancer in humans. The PPRTV preliminary peer-reviewed toxicity values are part of the IRIS integrated risk information system (ACS, 2024).

Risk Characterisation

The process of risk assessment ends with risk characterization. This method combines dose response and exposure response research to produce probability of effects happening in people under particular exposure situations. Table 11's exposure parameters and Table 12's RfD and PF values are used to determine quantitative risk. Using the risk characterization approach, risk managers can create safety recommendations or classify the research area based on the level of risk that is deemed acceptable. Two types of risk can be distinguished: cancer risk and non-cancer risk.

Non-cancer Risk: Equation 6 is used to determine the Hazard Quotient (HQ), which is a measure of non-cancer risk. When food or water has an HQ value higher than 1, it is unsafe to consume and carries a significant risk of infection. It is clear from Equation 6 that HQ is independent of exposure duration. Note that while HQ indicates the degree of worry, it is not a risk indicator (Nabulo et al., 2010; Ametepey et al., 2018; Enyinna & Nte, 2013; Mohammadi et al., 2022).

$$\text{Hazard Quotient (HQ)} = \frac{Average\ Daily\ Dose\ (ADD)}{Reference\ Dose\ (RfD)} \quad (7)$$

The Hazard Index (HI) represents the overall chronic danger owing to being subjected to any chemicals via a single exposure route, since a receptor may be exposed to several chemicals linked to non-cancer health consequences. HI is calculated using Equation 7 (Nabulo et al., 2010; Chen et al., 2015; Ametepey et al., 2018; Mohammadi et al., 2022).

$$\text{HI} = \sum_{i=1}^{n} HQ_i \quad (8)$$

A HI number of over one suggests the presence of non-carcinogenic effects, whereas an HI value of less than one implies no discernible danger (Gujre et al., 2021).

Cancer Risk: The EPA's linear multi-stage model, which assumes a linear dose-response curve at low pollutant concentrations, is used to assess the cancer risk, as was previously explained. The incremental lifetime risk of cancer can be calculated as:

Incremental lifetime cancer risk (CR) = Chronic Daily Intake (CDI) × Potency Factor (PF)

CR values between 1×10^{-6} and 1×10^{-4} indicate acceptable carcinogenic risk, while values higher than 1×10^{-4} indicates significant health hazard due to carcinogenicity.

3. Results and Discussion

Table 13 and 14 present the HQ values of different heavy metals obtained in groundwater and vegetables collected from villages and agricultural fields adjacent to Dhapa landfill site.

From Table 13 it is clear high non-carcinogenic risks are involved in consumption of heavy metal laden groundwater to the people residing the villages adjacent to landfill site. The risk due to Hg>Pb>As. HI value is greater than 1 indicates the heavy metal pollution may pose a very high non-carcinogenic risk due to consumption of groundwater to the adult.

The results obtained are similar to the study (Vongdala et al., 2019), where also the accumulation of Cd, Cu, Ni and Zn in groundwater was lower than Pb and Cr.

As can be seen from Table 13, cadmium and zinc do not exceed permissible standards and do not pose a health hazard. As other studies conducted in both dry and wet seasons show, no traces of cadmium (Cd) and zinc (Zn) were found in the water of their domestic well, which was located outside the landfill, about 70 m (Vongdala et al., 2019). At the same time, Onwukeme and Okechukwu (2021) did not find high concentrations of arsenic in the soils of the landfill, although the current study revealed a strong excess of arsenic in water samples.

The concentrations of Cd, Cr and Pb identified in the study (Sulistyowati et al., 2023) were found to exceed sediment quality standards at sampling sites outside the landfills, which is associated with leachate discharge and activities at landfills.

From Table 14 it is clear that non-carcinogenic effect of consumption of Radish are very likely due to heavy metals Cd, Cr, Hg, Pb and Zn. For Red spinach Hg and Zn created no non-carcinogenic risk since HQ values are less than 1. HI values show that high non-carcinogenic risks are very likely

Table 13. HQ Values of Different Heavy Metals due to Consumption of Water

Heavy Metals	Concentration in Ground Water (mg/L)	RfD (mg/kg.d)	DI/BW (L/kg)	ADD (mg/kg.d)	HQ	Non Carcino-genic Risk
Arsenic (As)	0.009	0.0003	0.04	0.00036	1.2	Risk
Cadmium (Cd)	0.01	0.001	0.04	0.0004	0.4	No Risk
Chromium (Cr) (Hexavalent)	0.05	0.003	0.04	0.002	0.667	No Risk
Mercury(Hg)	0.19	0.0003	0.04	0.0076	25.333	Risk
Nickel (Ni)	0.03	0.02	0.04	0.0012	0.06	No Risk
Lead (Pb)	0.2	0.0036	0.04	0.008	2.222	Risk
Zinc (Zn)	4.16	0.3	0.04	0.1664	0.555	No Risk
HI					**30.437**	**Risk**

Note: RfD – Reference Dose; DI – average daily intake of water (mg/L) or vegetables(mg/g); BW – average body weight (kg) of the consumer; ADD – Average Daily Dose; HQ – Hazard Quotient.

Table 14. HQ Values of Different Heavy Metals due to Consumption of Vegetables

Heavy Metals	Concentration in (mg/kg)		RfD (mg/kg.d)	DI/BW (kg/kg)	HQ of		Non Carcinogenic Risk
	Radish Spinach, Dec 19	Red Spinach, Sep 19			Radish Spinach, Dec 19	Red Spinach, Sep 19	
Cadmium (Cd)	5	7.1	0.001	0.04	14.545	20.655	Risk
Chromium (Cr) (VI)	343.3	10	0.003	0.04	332.897	9.697	Risk
Mercury (Hg)	0.3	0.01	0.0003	0.04	2.909	0.097	Risk for Radish Spinach
Lead (Pb)	28.8	25.4	0.0036	0.04	23.273	20.525	Risk
Zinc (Zn)	315	11.97	0.3	0.04	3.055	0.116	Risk for Radish Spinach
HI					**376.679**	**51.09**	**Risk**

due to consumption of both radish and red spinach grown in the agricultural fields for adult.

Chromium concentrations pose a health risk. As found by Onwukeme & Okechukwu (2021), chromium concentrations in the landfill soil generally exceeded WHO regulatory limits. Although soil samples were not tested in the current study, results from plant foods also show severely elevated chromium concentrations. The obtained indicators are also consistent with the results of (Vongdala et al., 2019), where in both dry and wet periods the authors found maximum levels of contamination in the stems and roots (but not in the leaves) with metals such as Cd, Cr, Pb and Zn. The excess was 8–56 times higher than WHO norms. The authors suggest that sources of chromium in soil may include waste consisting of lead-chromium batteries, dyed plastic bags, diesel engine residues, treated anti-corrosion agents, and discarded plastic materials (Onwukeme & Okechukwu, 2021).

In an abandoned landfill site, Cr and Zn contents in crop samples were found to be within recommended limits, but Cd contents were higher (Ekere et al., 2020), which is generally consistent with the current results.

Carcinogenic risks were determined for As, Cd, Cr, Pb and Ni for groundwater and for vegetables carcinogenic risks were calculated for Cd, Cr and Pb and are presented in Table 15.

From Table 15 it is clearly visible that significant health hazards due to carcinogenicity are observed for consumption of ground water as well as vegetables grown in the landfill adjacent agricultural fields for adults.

Similar conclusions have been made by other researchers in the vicinity of open or abandoned landfill sites (Akanchise et al., 2020; Sulistyowati et al., 2023).

Thus, the current study scientifically substantiates that uncontrolled and uncontrolled activities such as open waste dumps in this region pose a significant threat to the adult population, and therefore to children (since children are always more vulnerable to negative impacts). That is, the issues of control and sanitary organization of the landfill using special barriers, sorting and rapid processing of recyclable waste components occupy a leading place among environmental problems in this region. Namely, the development and implementation of a regional program to reduce the negative impact of the landfill under study, taking into account the current research results, will help protect the population and new generations of this region.

Table 15. CR Values for Heavy Metals for Ground water and Vegetables

Heavy Metals	Concentration in Ground Water (mg/L)	CR values in Ground Water	Carcinogenic Risk	CR values in		Carcinogenic Risk
				Radish Spinach, Dec19	Red Spinach, Sept19	
As	0.009	2.24 E-04	Risk	---	---	---
Cd	0.01	6.3 E-05	Acceptable Risk	2.29 E-03	3.252 E-03	Risk
Cr (VI)	0.05	4.14 E-04	Risk	2.069 E-01	6.028 E-03	Risk
Ni	0.03	4.53 E-04	Risk	---	---	---
Pb	0.2	1.19 E-05	Acceptable Risk	1.25 E-04	1.1 E-04	Risk

4. Conclusion

The uncontrolled landfill site at Dhapa, Kolkata receives the unsegregated municipal solid waste throughout the year. The generated leachate percolates through the soil without any treatment and ultimately contaminates soil and water resources. High heavy metal concentrations in groundwater above the permissible drinking standards reveal the metal contamination due to leachate migration. The geo-accumulation index values of Cd, Cr, Zn, Pb and Hg support the anthropogenic heavy metal pollution to soil used for agriculture. The potential ecological harm posed by heavy metal contamination to the nearby environment is supported by a significant ecological risk index. When nearby fields are utilized for illicit waste farming, the heavy metals found in the soil are also transported to the vegetables. Natural cadmium enrichment in phosphorous fertilizer, anthropogenic heavy metal contamination of zinc fertilizer also causes heavy metal concentration in vegetables. Heavy metals have an impact on human health in addition to the nutritional value of plants. The transport of heavy metals from soil to plants is supported by a bioaccumulation concentration of veggies larger than one. The current investigation revealed that the adult residing in villages may have high non-carcinogenic risks due to consumption of ground water and both radish and red spinach grown in the agricultural fields. The adult may have carcinogenic risk due to consumption of groundwater for As, Cr and Ni. Cd, Cr and Pb present in both Radish Spinach and Red Spinach have high probability of creating carcinogenic effects. This research area is one of Kolkata's more prolific vegetable growing places. To avoid an excessive accumulation in the food chain, it is crucial to regularly test the levels of these hazardous contaminants in soil and vegetables. In order to protect the ecosystem as well as the soil and vegetables, an appropriate landfill operation system must be in place to stop leachate migration that might further contaminate groundwater. Additionally, compromised water and soil resources must be remedied. Ensuring that the residents have access to clean water requires action.

References

Aiman U., Mahmood A., Waheed S. & Malik R.N., 2016, Enrichment, geo-accumulation and risk surveillance of toxic metals for different environmental compartments from Mehmood Booti dumping site, Lahore city, Pakistan. Chemosphere 144: 2229–2237. https://doi.org/10.1016/j.chemosphere.2015.10.077

Akanchise T., Boakye S., Borquaye L.S., Dodd M. & Darko G., 2020, Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana. Scientific African 10, e00614.

Alao J.O., Fahad A., Abdo H.G., Ayejoto D.A., Almohamad H., Ahmad M.S., … & Joy A.O., 2023, Effects of dumpsite leachate plumes on surface and groundwater and the possible public health risks. Science of The Total Environment 897, 165469.

American Cancer Society (ACS), 2024, Known and Probable Human Carcinogens. https://www.cancer.org/cancer/risk-prevention/understanding-cancer-risk/known-and-probable-human-carcinogens.html

Ametepey S.T., Cobbina S.J., Akpabey F.J., Duwiejuah A.B., Ametepey S.T., Cobbina S.J., Akpabey F.J., Duwiejuah A.B. & Abuntori Z.N., 2018, Health risk assessment and heavy metal contamination levels in vegetables from Tamale Metropolis, Ghana. International Journal of Food Contamination 5(1): 1–8. https://doi.org/10.1186/s40550-018-0067-0

Bello S., Zakari Y.I., Ibeanu I.G.E. & Muhammad B.G., 2016, Characterization and assessment of heavy metal pollution levels in soils of Dana steel limited dumpsite, Katsina state Nigeria using geo-accumulation, ecological risk and hazard indices. American Journal of Engineering Research 5(1): 49–61.

Bhalla B., Saini M.S. & Jha M.K., 2014, Assessment of municipal solid waste landfill leachate treatment efficiency by leachate pollution index. Assessment 3(1): 8447–8454.

Bhatnagar J.P. & Awasthi S.K., 2000, Prevention of food adulteration act (act no. 37 of 1954) alongwith central & state rules (as amended for 1999). Ashoka Law House.

Cao H.C., Luan Z.Q., Wang J.D. & Zhang X.L., 2009, Potential ecological risk of cadmium, lead and arsenic in agricultural black soil in Jilin Province, China. Stochastic Environmental Research and Risk Assessment 23: 57–64. https://doi.org/10.1007/s00477-007-0195-1

Chen H., Teng Y., Lu S., Wang Y. & Wang J., 2015, Contamination features and health risk of soil heavy metals in China. Science of The Total Environment 512: 143–153. https://doi.org/10.1016/j.scitotenv.2015.01.025

Countryeconomy.com, 2022, India – Life expectancy at birth. https://countryeconomy.com/demography/life-expectancy/india

De S., Maiti S.K., Hazra T., Debsarkar A. & Dutta A., 2017, Appraisal of seasonal variation of groundwater quality near an uncontrolled municipal solid waste landfill in Kolkata, India. The Global NEST Journal 9(3): 367–376. https://doi.org/10.30955/gnj.002172.

Ekere N.R., Ugbor M.C.J., Ihedioha J.N., Ukwueze N.N. & Abugu H.O., 2020, Ecological and potential health risk assessment of heavy metals in soils and food crops grown in abandoned urban open waste dumpsite. Journal

of Environmental Health Science and Engineering 18: 711–721.
El Morabet R., Khan R.A., Alsubih M., Khan N.A., Yusuf M., Khan P., … & Lutsak O., 2023, Epidemiology study of Diarrhoea, Cholera, Typhoid, Hepatitis A and Hepatitis E in Middle East and North Africa Region. Ecological Questions 34(4): 1–21. https://doi.org/10.12775/EQ.2023.044
Enyinna P.I. & Nte F.U., 2013, Estimation of Soil Hazard Quotient of Some Identified Heavy Metals from an Abandoned Municipal Waste Disposal Site in Aba, Nigeria. International Journal of Natural Sciences Research 3(8): 89–93.
EPA, 2014, Priority Pollutant List. https://www.epa.gov/sites/default/files/2015-09/documents/priority-pollutant-list-epa.pdf.
FAO/WHO, 1995, General standard for contaminants and toxins in food and feed, CXS 193-1995 (Adopted in 1995; Revised in 1997, 2006, 2008, 2009). https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B193-1995%252FCXS_193e.pdf.
Gujre N., Mitra S., Soni A., Agnihotri R., Rangan L., Rene E.R. & Sharma M.P., 2021, Speciation, contamination, ecological and human health risks assessment of heavy metals in soils dumped with municipal solid wastes. Chemosphere 262, 128013. https://doi.org/10.1016/j.chemosphere.2020.128013
Guo G., Zhang D. & Wang Y., 2019, Probabilistic human health risk assessment of heavy metal intake via vegetable consumption around Pb/Zn smelters in Southwest China. International journal of environmental research and public health 16(18), 3267. https://doi.org/10.3390/ijerph16183267
Hakanson L., 1980, An ecological risk index for aquatic pollution control. A sedimentological approach. Water Research 14(8): 975–1001.
Han Z., Ma H., Shi G., He L., Wei L. & Shi Q., 2016, A review of groundwater contamination near municipal solid waste landfill sites in China. Science of the Total Environment 569: 1255–1264.
Hanoshenko O., Vambol V., Vambol S., Yeremenko S., Fialka M.I., Bodnar I. & Inozemtseva O., 2022, Medical waste generation, handling and crime statistics' analysis in this activity field: a case study of the Poltava region (Ukraine). Ecological Questions 33(3): 79–88. Doi: 10.12775/EQ.2022.026
Hikon B.N. & Yebpella G.G., 2024, Bioavailability of Metals in the Biosphere. Trends in Ecological and Indoor Environment Engineering 2(1): 41–49. https://doi.org/10.62622/TEIEE.024.2.1.41-49
IS 10500, 2012, Indian Standard: DRINKING WATER — SPECIFICATION. https://cpcb.nic.in/wqm/BIS_Drinking_Water_Specification.pdf
Islam S., Ahmed K. & Masunaga S., 2015, Potential ecological risk of hazardous elements in different land-use urban soils of Bangladesh. Science of The Total Environment 512: 94–102. https://doi.org/10.1016/j.scitotenv.2014.12.100
Jiang X., Lu W.X., Zhao H.Q., Yang Q.C. & Yang Z.P., 2014, Potential ecological risk assessment and prediction of soil heavy-metal pollution around coal gangue dump. Natural Hazards and Earth System Sciences 14(6): 1599–1610. https://doi.org/10.5194/nhess-14-1599-2014
Lahori A.H., Ahmad S.R., Afzal A., Mierzwa-Hersztek M., Bano S., Muhammad M.T., Saleem I. & Soomro W.A., 2023, Alone and Combined Application of Press Mud Compost and Fuller Earth for Abating Pb and Cd and Enhance Sorghum Growth in Polluted Soils. Trends in Ecological and Indoor Environment Engineering 1(1): 7–15. https://doi.org/10.62622/TEIEE.023.1.1.07-15
Liu M., Wei Y., Salam M., Yuan X., Liu B., He Q., … & He Y., 2022, Potassium supplement enhanced cadmium removal in a Microcystis aeruginosa photobioreactor: Evidence from actual and simulated wastewater. Journal of Hazardous Materials 424, 127719. https://doi.org/10.1016/j.jhazmat.2021.127719
Mishra H., Karmakar S., Kumar R. & Kadambala P., 2018, A long-term comparative assessment of human health risk to leachate-contaminated groundwater from heavy metal with different liner systems. Environmental Science and Pollution Research 25: 2911–2923. https://doi.org/10.1007/s11356-017-0717-4
Mohammadi A., Mansour S.N., Najafi M.L., Toolabi A., Abdolahnejad A., Faraji M. & Miri M., 2022, Probabilistic risk assessment of soil contamination related to agricultural and industrial activities. Environmental Research 203, 111837. https://doi.org/10.1016/j.envres.2021.111837
Muller G., 1969, Index of geoaccumulation in sediments of the rhine river. Geo Journal 2(3): 108–118. https://sid.ir/paper/618491/en
Nabulo G., Young S.D. & Black C.R., 2010, Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. Science of the Total Environment 408(22): 5338–5351. https://doi.org/10.1016/j.scitotenv.2010.06.034
Nai C., Tang M., Liu Y., Xu Y., Dong L., Liu, J. & Huang Q., 2021, Potentially contamination and health risk to shallow groundwater caused by closed industrial solid waste landfills: Site reclamation evaluation strategies. Journal of Cleaner Production 286, 125402.
NFHS, 2024, National Family Health Survey. http://rchiips.org/nfhs/

Onwukeme V.I. & Okechukwu V.U., 2021, Leaching matrix of selected heavy metals from soil to ground water sources in active dumpsites: A case study of Southern Nigeria. IOSR J Environ Sci, Toxicol Food Technol 15(4): 1–18.

Pachura P., Ociepa-Kubicka A. & Skowron-Grabowska B., 2016, Assessment of the availability of heavy metals to plants based on the translocation index and the bioaccumulation factor. Desalination and Water Treatment 57(3): 1469–1477. https://doi.org/10.1080/19443994.2015.1017330

PFAR, 2004, The Prevention of Food Adulteration Act & Rules (PFAR) (as on 1.10.2004). https://www.fssai.gov.in/upload/uploadfiles/files/pfa-acts-and-rules.pdf

Salam M., Alam F., Dezhi S., Nabi G., Shahzadi A., Hassan S.U., … & Bilal M., 2021, Exploring the role of Black Soldier Fly Larva technology for sustainable management of municipal solid waste in developing countries. Environmental Technology & Innovation 24, 101934. https://doi.org/10.1016/j.eti.2021.101934

Salam M., Zheng L., Shi D., Huaili Z., Vambol V., Chia S.Y., … & Ullah E., 2023, Exploring Insect-based technology for waste management and livestock feeding in selected South and East Asian countries. Environmental Technology & Innovation 32, 103260. https://doi.org/10.1016/j.eti.2023.103260

Sawicka B., Krochmal-Marczak B., Sawicki J., Skiba D., Pszczółkowski P., Barbaś P., … & Farhan A.K., 2023, White Clover (*Trifolium repens* L.) Cultivation as a Means of Soil Regeneration and Pursuit of a Sustainable Food System Model. Land 12(4), 838. https://doi.org/10.3390/land12040838

SASSMR, 2017, Semi-Annual Social Safeguard Monitoring Report IND: Kolkata Environmental Improvement Investment Program (KEIIP) – Tranche 2, Project number: 42266-025. https://www.keiip.in/pdf/42266-025-smr-en_0.pdf

Singh A., Sharma R.K., Agrawal M. & Marshall F.M., 2010, Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. Tropical Ecology 51(2): 375–387.

Singh M., Ansari A.A., Müller G. & Singh I.B., 1997, Heavy metals in freshly deposited sediments of the Gomati River (a tributary of the Ganga River): effects of human activities. Environmental Geology 29: 246–252. https://doi.org/10.1007/s002540050123

Sipter E., Auerbach R., Gruiz K. & Mathe-Gaspar G., 2009, Change of bioaccumulation of toxic metals in vegetables. Communications in soil science and plant analysis 40(1-6): 285–293. https://doi.org/10.1080/00103620802647165

Sulistyowati L., Nurhasanah N., Riani E. & Cordova M.R., 2023, Heavy metals concentration in the sediment of the aquatic environment caused by the leachate discharge from a landfill. Global Journal of Environmental Science and Management 9(2): 323–336.

Tariq F.S., 2021, Heavy metals concentration in vegetables irrigated with municipal wastewater and their human daily intake in Erbil city. Environmental Nanotechnology, Monitoring & Management 16, 100475. https://doi.org/10.1016/j.enmm.2021.100475

Turekian K.K. & Wedepohl K.H., 1961, Distribution of the elements in some major units of the earth's crust. Geological Society of America Bulletin 72(2): 175–192.

U.S. EPA, 1997, Health Effects Assessment Summary Tables (Heast). U.S. Environmental Protection Agency, Washington, D.C., 1997. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2877

U.S. EPA, 2022, Provisional Peer-Reviewed Toxicity Values (PPRTVs). https://www.epa.gov/pprtv

U.S. EPA, 2024, Integrated Risk Information System. https://www.epa.gov/iris

Vambol S., Shakhov Y., Vambol V. & Petukhov I., 2016, A mathematical description of the separation of gas mixtures generated by the thermal utilization of waste. Eastern-European Journal of Enterprise Technologies 1(2(79)): 35–41. https://doi.org/10.15587/1729-4061.2016.60486

Vambol V., 2016, Numerical integration of the process of cooling gas formed by thermal recycling of waste. Eastern-European Journal of Enterprise Technologies 6 (8): 48–53.

Vambol V., Kowalczyk-Juśko A., Vambol S., Khan N.A., Mazur A., Goroneskul M. & Kruzhilko O., 2023, Multi criteria analysis of municipal solid waste management and resource recovery in Poland compared to other EU countries. Scientific Reports 13(1), 22053.

Vaverková M.D., Elbl J., Radziemska M., Adamcová D., Kintl A., Baláková L., … & Brtnický M., 2018, Environmental risk assessment and consequences of municipal solid waste disposal. Chemosphere 208: 569–578. https://doi.org/10.1016/j.chemosphere.2018.06.026

Vongdala N., Tran H.D., Xuan T.D., Teschke R. & Khanh T.D., 2019, Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. International Journal of Environmental Research and POublic Health 16(1), 22.

Wang Y., Wang F., Cheng Z., Su Q. & Cao Y., 2023, Health risk cause of water around landfill in hilly area and prevention and control countermeasures. Journal of Environmental Management 346, 119019.

Yaqin J.I., Yinchang F.E.N.G., Jianhui W.U., Tan Z.H.U., Zhipeng B.A.I. & Chiqing D.U.A.N., 2008, Using geoaccumulation index to study source profiles of soil dust in China. Journal of Environmental Sciences 20(5): 571–578. https://doi.org/10.1016/S1001-0742(08)62096-3

Yuan Y., Xiang M., Liu C. & Theng B.K., 2019, Chronic impact of an accidental wastewater spill from a smelter, China: a study of health risk of heavy metal (loid) s via vegetable intake. Ecotoxicology and Environmental Safety 182, 109401. https://doi.org/10.1016/j.ecoenv.2019.109401

Zahorodniuk K., Voitsekhovsky V., Korobochka A., Hrynzovskyi A. & Averyanov V., 2019, Development of modernized paper filtering materials for water purification, assessment of their properties. Eastern-European Journal of Enterprise Technologies 1(10 (97)): 6–13. https://doi.org/10.15587/1729-4061.2019.156534

Zhang M., Wang P., Lu Y., Lu X., Zhang A., Liu Z., … & Sarvajayakesavalu S., 2020, Bioaccumulation and human exposure of perfluoroalkyl acids (PFAAs) in vegetables from the largest vegetable production base of China. Environment International 135, 105347. https://doi.org/10.1016/j.envint.2019.105347

Zhang M., Wang P., Lu Y., Lu X., Zhang A., Liu Z., … & Sarvajayakesavalu S., 2008, Bioaccumulation and human exposure of perfluoroalkyl acids (PFAAs) in vegetables from the largest vegetable production base of China. Environment International 135, 105347. https://doi.org/10.3923/pjbs.2008.490.492

Zhu H.N., Yuan X.Z., Zeng G.M., Jiang M., Liang J., Zhang C., … & Jiang H.W., 2012, Ecological risk assessment of heavy metals in sediments of Xiawan Port based on modified potential ecological risk index. Transactions of Nonferrous Metals Society of China 22(6): 1470–1477. https://doi.org/10.1016/S1003-6326(11)61343-5