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ECOLOGICAL AND HEALTH RISK ASSESSMENT OF LEAD Pb IN AGRICULTURAL SOIL NEAR THE MUNICIPAL LANDFILL IN THE CITY OF MOSTAR, BOSNIA AND HERZEGOVINA

Jelena KUZMAN KATICA[1], Aida ŠUKALIĆ[2], Aleksandra ŠUPLJEGLAV JUKIĆ[2], Dženita ALIBEGIĆ[2]

[1]Association Dinarica, Mostar, Bosnia and Herzegovina
[2]Dzemal Bijedic University of Mostar, Mostar, Bosnia and Herzegovina

Corresponding author email: aida.sukalic@unmo.ba

Abstract

The research was conducted with the aim of assessing the health risks to people caused by agricultural soil pollution with heavy metals, specifically lead, in agricultural areas near landfills in Mostar, Bosnia and Herzegovina. Soil samples from seven locations were analyzed for lead concentration and chemical characteristics. The results showed high concentrations of lead in the soil at all locations, with the highest values in Buđevci 2 (203.90 mg/kg) and the lowest in Buđevci 4 (51.63 mg/kg).

Using the Human Health Risk Assessment Model of the United States Environmental Protection Agency (US EPA), the carcinogenic and non-carcinogenic risks for children and adults were calculated, considering exposure pathways through ingestion, inhalation, and dermal contact. The results revealed significant potential risks, with hazard quotients exceeding safe values at some locations. The non-carcinogenic hazard for adults is 5.58, while for children, it is 43.83.

Furthermore, the Ecological Risk Index (ERI) was calculated to assess the overall ecological impact of heavy metal pollution in the soil. Based on the contamination factor (CF), moderate contamination was determined at all locations, while significant contamination was found at Buđevci 2. These findings indicate serious potential risks to the health of the population engaged in agriculture in these areas.

Key words: *agricultural soil, lead Pb, ecological risk, health risk.*

INTRODUCTION

Good human health is linked to a healthy environment. Disposed materials with heavy metals in open landfills raise concerns and present a risk to individuals, plants, and animals that encounter contaminated soil, primarily due to inadequate waste management (Ugurlu, 2004).

The creation and disposal of waste have been observed as one of the driving forces of soil pollution with heavy metals.

The improper disposal of waste poses a significant global environmental hazard, leading to the pollution of heavy metals.

WHO (World Health Organization), EFSA (European Food Safety Agency), and US EPA (United States Environmental Protection Agency) define risk assessment methodology for chemical contaminants (Dorne et al., 2011).

The heavy metals Cr (VI), Cd, As, Hg, and Pb are considered non-threshold pollutants due to the effect of their highly toxic nature on organisms. Even at low concentrations, they can be lethal (Jayanthi et al., 2017; Rahman & Singh, 2019).

Since they are not biodegradable, their bioaccumulation through food chains can cause long-term environmental risks. Several authors determined disturbances in the natural biological balance due to contamination with heavy metals originating from landfill leachate and the slowing down of the self-purification process in nature (Gworek et al., 2016; Öman & Junestedt, 2008; Talalaj, 2015).

Investigating soil pollution in landfills is crucial due to the complex interactions of heavy metals with the environment (Vaverková et al., 2018) indicate that untreated landfills can increase metal levels in air, soil, and groundwater. Therefore, continuous monitoring of environmental parameters near the landfill is necessary. Inhaling emitted substances, consuming food grown in a contaminated area, and contaminated water and soil can have harmful effects on the health of residents living near the polluted place (Krčmar et al., 2018). Due to these considerations, it is essential to consistently assess and analyze the affected matrix. If heavy metals infiltrate the food chain, they can endanger the health of both humans and animals. Certain heavy metals, such as mercury, arsenic, nickel, and lead, demonstrate toxic effects when their concentrations exceed the environment's maximum allowable concentration (Šukalić et al., 2018).

According to WHO data (WHO, 1997), lead poisoning in children causes neurological damage that causes a decrease in intelligence, problems in learning and coordination of movements and loss of short-term memory.

According to Iqbal's 2012 research, being exposed to excessive amounts of lead can result in epileptic seizures, mental retardation, and behavioral disorders. The primary ways lead enters the human body include inhaling lead-rich dust, exposure of the skin to lead-contaminated soil and dust, and consumption of lead-contaminated water and food produced in areas contaminated with lead (Kumar et al., 2020).

The Human Health Risk Assessment Model, established by the United States Environmental Protection Agency (US EPA), is a commonly utilized approach for evaluating the potential adverse effects on human health resulting from exposure to contaminants. It aids in mitigating potential risks to human health. Nevertheless, this model has not been employed to evaluate the health risks associated with the consumption of agricultural products contaminated with lead in Bosnia and Herzegovina. The area surrounding the municipal landfill in Mostar is inhabited by people who engage in agricultural production and livestock farming. This population is at risk of negative effects on health due to the consumption of food grown on contaminated land. The negative impacts of solid waste on the soil, especially agricultural soil, can be varied and may cause serious and even permanent consequences. These consequences can be:

- soil infection - entry of harmful microorganisms into the soil (bacteria, viruses) that can later cause infections in humans and animals. Such processes occur in urban and suburban areas where infected animals move or people bury their corpses;
- soil contamination - the introduction of various pollutants into the soil, such as heavy metals, pesticides, and biocides, which reach the soil through the disposal of solid waste and medicines and whose presence in the soil leads to changes in its chemical and biological properties. Also, the physical impact of waste on the ground is reflected in the pressure on the ground, so in theory, high layers of deposited waste can collapse (Waste Management Adaptation Plan for the Uborak-Buđevci regional landfill in Mostar - addition, 2023).

In the process of developing measures and an adaptation plan for the operation of the Uborak municipal waste landfill, a team of experts conducted soil sampling in the vicinity of the landfill and analyzed the content of heavy metals at three locations: Buđevci 1, Buđevci 2, Buđevci 3. The results were published in the document "Waste Management Adaptation Plan for the Uborak-Buđevci regional landfill", noting an elevated concentration of lead in the total form in the soil. Considering the obtained results, the ultimate goal was to expand the research to an additional 4 locations and consolidate the results. Subsequently, a health risk assessment was conducted by incorporating lead intake and the potential ecological risk index from all 7 locations in the area around the landfill. We do not have any data on previous research at these location.

MATERIALS AND METHODS

Research location

The municipal landfill of JP "Deponija" is located in the suburb of Mostar, Gornji Vrapčići, Bosnia and Herzegovina. It started operating in 2014 and borders the old landfill where waste disposal began in 1960 (Figure 1).

Figure 1. Locations of the landfill and sampling sites (B1-Buđevci 1, B2-Buđevci 2, B3-Buđevci 3, B4-Buđevci 4, B5-Buđevci 5, B6-Buđevci 6, B7-Buđevci 7) Mostar, Bosnia and Herzegovina

It is located around 8 kilometers by air north of the city center of Mostar. It is approximately 1.5 kilometers by air from the Neretva river and close to the M-17 highway, which is connected to it by a local asphalt road. It is surrounded by private houses, military barracks, arable agricultural areas, mostly vineyards and orchards. The occasional Sušica groundwater flows next to the landfills. The nearest houses are at a distance of about 80 m from the landfill and are part of the settlements of Buđevci and Rasoja, while the houses of the settlements of Kuti and Livač are at a distance of 100 m by air and more. In addition to the area of the City of Mostar, waste from neighboring municipalities is also deposited at the landfill. With the opening of the new landfill, the plan was to allocate 80% of raw materials that can be recycled or used for other purposes (RDF), after which 20% of the waste would remain for disposal (Kuzman & Hodžić, 2012).

The planned model did not come to life. Only 2% of the waste usable for recycling is separated on-site. Due to the disposal of the remaining amount of waste at the landfill, its capacity was filled in a short period, and the disposal continued above the ground level. The consequences of this method of waste disposal are its spreading, the appearance of rodents, fires, unpleasant odors, dust, and negative consequences for the environment and people living nearby. A frequent occurrence is leachate from the body of an old landfill that was not built according to sanitary measures. The appearance of invasive plant species, an abundance of insects in the vicinity, and the death of cultivated crops are visible indicators of negative environmental impacts.

The new landfill is located adjacent to the old one on a usable surface area of 11.5 hectares, and it is being built in stages. The first phase, covering an area of 2 hectares, concerns the landfill body - the space for municipal waste disposal, and it has been constructed according to sanitary standards. The second phase covers an area of 0.85 hectares. A recycling yard with a capacity of 15 t/h has been installed on the landfill site. For profitability, waste from neighboring municipalities is also deposited at the landfill, besides waste from the city of Mostar. The planned model for recycling and composting has not been successful. Only 2% of recyclable waste is separated on-site. Due to the disposal of the remaining amount of waste at the landfill, its capacity is quickly filled, and disposal continues above the surface level. The consequences of such waste disposal include its scattering, rodent infestations, fires, unpleasant odors, dust, and negative environmental impacts on nearby residents.

Based on the wind data for Mostar in 2022, we can notice that the dominant winds are from the northwest (NW) and west (W) directions (Figures 2 and 3).

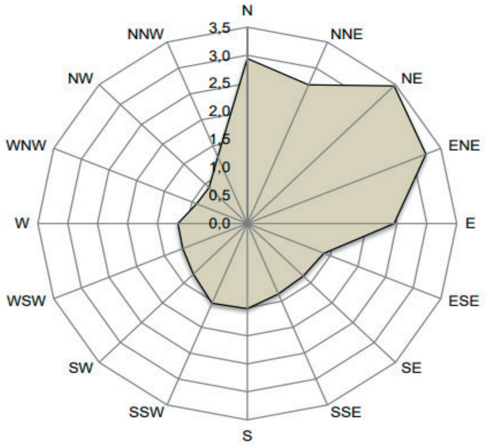

Figure 2. Mean wind speed for each wind direction in m/s (https://www.fhmzbih.gov.ba/podaci/klima/godisnjak/G2022.pdf)

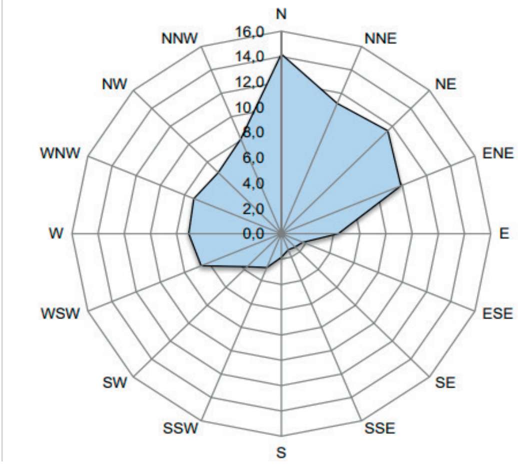

Figure 3. Frequency of individual wind directions in % (https://www.fhmzbih.gov.ba/podaci/klima/godisnjak/G2022.pdf)

In Mostar, the most common winds are from the northwest (NW) and west (W) directions, while the least frequent winds are from the southeast (ESE) and south (S) directions. The highest percentage of winds comes from the northwest direction (NNW), occurring with a frequency of 8.5%. Following are winds from the southwest direction (WSW) with a share of 8.1% and west-northwest (WNW) with a share of 7.3%. Other dominant winds include those from the west (W), southwest (WSW), and south (S), each with a share between 6% and 7%. (https://www.fhmzbih.gov.ba/podaci/klima/godisnjak/G2022.pdf).

In order to develop measures and an adaptation plan for the operation of the Uborak municipal waste landfill, a team of experts conducted soil sampling in the vicinity of the landfill and analyzed the heavy metal content at three locations: Buđevci 1, Buđevci 2, Buđevci 3.

The results were published in the document "Waste Management Adaptation Plan for the Uborak-Buđevci regional landfill", which only noted an elevated concentration of lead in the soil. Based on the results obtained, the ultimate goal was to expand the research to four additional locations and to consolidate the results to calculate the health risk associated with lead intake and the potential ecological risk index from all seven locations around the landfill. We do not have any data on previous research at these sites.

Location Buđevci 1, as well as Buđevci 4, are located north of the new and northwest of the old landfill. Location Buđevci 2 is situated north of the old, northeast of the new landfill. Location Buđevci 6 and 7 are east of both landfill while Buđevci 3 is south of both landfills. Location Buđevci 5 is southwest in relation to both.

Soil sampling

The area around the RD Uborak-Buđevci is covered with brown valley shallow and moderately deep, skeletal soils predominantly formed by anthropogenic processes on gravel. They belong to the IVb soil category and are associated with rendzinas. These soils are highly permeable, well-aerated, and very skeletal. Such a structure results in high permeability, causing rainfall water to quickly penetrate into the deeper layers of the soil. In order to develop measures and an adaptation plan for the operation of the Uborak municipal waste landfill, a team of experts conducted soil sampling and heavy metal content analysis at three locations:

Buđevci 1 - 43°23'19" N 17°52'56" E;
Buđevci 2 - 43°23'11" N 17°53'09" E;
Buđevci 3 - 43°23'04" N 17°52'49" E.

The results were published in the document "Waste Management Adaptation Plan for the Uborak-Buđevci regional landfill," from which we, as the authors of this study, extracted the data and performed an ecological risk assessment. Due to its relevance, the research was expanded to four additional locations where sampling, heavy metal content analysis, and ecological risk assessment were carried out in 2022.

Buđevci 4 - 43°23'18" N 17°52'59" E
Buđevci 5 - 43°23'09" N 17°52'40" E
Buđevci 6 - 43°22'59" N 17°52'56" E
Buđevci 7 - 43°23'02" N 17°53'08" E

All locations are situated at a distance of 200 to 400 m from the old and new landfill, in different directions. The selection of these locations was made to form a circle around the landfill, contributing to the relevance and precision of the research.

Sampling sites were chosen randomly from the agricultural lands, taking into account the distance between the locality and the landfill, as well as the distance between the localities themselves.

The average sample was taken using a shovel from the surface of approximately 1 ha (locations Buđevci 4, Buđevci 6, and Buđevci 7) and approximately 0.5 ha for location Buđevci 5, in the following manner:

At various diagonally placed locations (Figure 1) at approximately equal distances, pits with a depth of 30 cm were excavated. The number of pits per plot was approximately 20.

Along the edge of the pit, soil was extracted at a 90° angle from the surface to a depth of 30 cm using the shovel. The shovel, with the soil adhering to it, was lifted so that the soil remained on the shovel when placed on the ground.

A "belt" of soil, 3-4 cm wide in the middle of the shovel up to its tip, i.e., to a depth of 30 cm, was created with a clean knife. The soil on the shovel to the left and right of the "belt" was discarded, and the soil "belt" was placed on a clean nylon sheet.

The procedure was repeated as many times as there were pits. On the nylon sheet, weeds, roots, stones, and other materials were removed. After removing unwanted materials, individual samples were mixed and homogenized.

An average sample weighing 1.5 kg was then packed into a clean plastic bag, accompanied by a completed data form, and sent to the laboratory.

The process was repeated for each plot, and when moving to a new plot, the shovel was cleaned.

Determination of lead content in samples

Sample preparation for the instrumental analysis of total lead content in soil was conducted using aqua regia in a ratio of 3:1 (v/v). Subsequently, its content was determined in the extract using atomic absorption spectrometry (AAS). The extraction of heavy metals in aqua regia was performed according to the international standard ISO11464. This standard specifies the method for extracting trace elements with aqua regia using an appropriate atomic spectrometric technique. According to this standard, the soil sample is ground to particles smaller than 2 mm for digestion with aqua regia. Such grinding achieves obtaining a more homogeneous sample from which a subsample is taken, increasing the efficiency of acid action by increasing the particle surface area. The dried sample is then extracted with a mixture of hydrochloric/nitric acid by standing for 16 hours at room temperature, followed by two hours of reflux boiling. The extract is clarified (filtered), and the volume is adjusted with nitric acid. International standard ISO11047 specifies the method of atomic absorption spectrometry for determining one or more elements in soil extracts obtained with aqua regia in accordance with ISO11466.

In the Federation of Bosnia and Herzegovina, the research followed the guidelines outlined in the "Instruction on determining the permissible amounts of harmful and dangerous substances in the soil and their testing methods" (Official Gazette of the FBiH, no. 96/22).

This instruction not only sets the limit values for pollutants in agricultural soil but.

Health risk assessment from soil

Considering the diverse negative impacts heavy metals can impose on human health, the non-carcinogenic hazard for both children and adults was computed using the risk assessment model outlined by the US Environmental Protection Agency (US EPA, 1997; US EPA, 2001) (Eq. 1, 2, 3):

$$\boldsymbol{ADI_{inh}} = \frac{\boldsymbol{CxIRairxEFxED}}{\boldsymbol{PEFxBWxAT}} \tag{1}$$

$$\boldsymbol{ADI_{ing}} = \frac{\boldsymbol{CxIRxEFxEDxCF}}{\boldsymbol{BW\ x\ AT}} \tag{2}$$

$$\boldsymbol{ADI_{der}} = \frac{\boldsymbol{CxSAxFExAFxABSxEFxEDxCF}}{\boldsymbol{BWxAT}} \tag{3}$$

ADIing, ADIinh, and ADIderm represent chronic daily intakes or doses administered orally (mg/kg/d), through inhalation (mg/m^3 for non-carcinogenic and g/m^3 for carcinogenic elements), and via dermal route (mg/kg/d). In this formula, C denotes the concentration of heavy metals in mg/kg in the soil, IR is the ingestion factor in mg/d, IRair is the inhalation factor in m^3/d, EF signifies the exposure frequency in days/year, ED represents the exposure duration in years, BW stands for body weight in kg, AT indicates the period over which the average dose is expressed in days, SA is the exposed skin area in cm^2, FE is the fraction of the ratio of dermal exposure to soil, AF is the soil adhesion factor for the skin in mg/cm^2, ABS is the dermal absorption factor, and CF is the chronic conversion factor in kg/mg. PEF is the particle emission factor. For non-carcinogenic hazard assessment, the hazard quotient (HQ) and hazard index (HI) were computed using the formulas (Eq. 4, 5):

$$\boldsymbol{HQ} = \frac{\boldsymbol{ADI}}{\boldsymbol{RfD}} \tag{4}$$

$$\boldsymbol{HI} = \boldsymbol{\sum_1^i HQ} \tag{5}$$

The reference dose (RfD) represents an estimate of the daily exposure to heavy metals that does not result in harmful effects on human health over a lifetime. Each heavy metal has a different RfD value. RfD is necessary for calculating non-carcinogenic risk and is expressed in the same units as ADI. The HQ value below 1 indicates an acceptable level, suggesting a low probability of adverse effects. Conversely, HQ values exceeding 1 signify unacceptable risks, indicating a higher probability of adverse health effects (Lim et al., 2008; Ohajinwa et al., 2019).

HQ values surpassing 1 are considered concerning. The HQ for lead has been computed for ingestion, dermal contact, and inhalation routes. In the case of carcinogens, the risk is assessed as the incremental probability that an individual will develop cancer over their lifetime due to exposure to a potential carcinogen (Šukalić et al., 2020). The equation for calculating the lifetime cancer risk (ILCR) is expressed as equation 6:

$$\boldsymbol{Risk}_{\boldsymbol{path\ of\ entry}} = \sum_{k=1}^{n} \boldsymbol{ADI_k}\ \boldsymbol{CSF_k} \qquad (6)$$

Risk refers to the likelihood of an individual developing cancer over their lifetime due to how lead enters the body. ADI (mg/kg/day) represents the average daily intake, CSF (mg/kg/day) denotes the cancer slope factor, k stands for the heavy metal, and n represents the number of heavy metals. A risk exceeding 1×10^{-4} is generally deemed unacceptable, while a risk below 1×10^{-6} is considered to pose no adverse effects. Calculated risks falling between 1×10^{-4} and 1×10^{-6} are considered within acceptable limits. A risk of 1×10^{-6} indicates that an individual has a 1 in 1,000,000 chance of developing cancer from the estimated exposure (Adamu et al., 2015; Du et al., 2013; Olujimi et al., 2015).

also establishes specific limit values for lead.

The exposure parameters utilized in this study are detailed in Table 1.

Table 1. Exposure parameters used for the health risk assessment through different exposure pathways for soil (Kamunda et al., 2016)

Parameters	Unit	Definition	Value	
			Children	Adult
ABS	--	Dermal absorption factor	0.1	0.1
AF	mg/cm^2	Soil adhesion factor for skin	0.2	0.07
BW	kg	Average body weight	15	70
ED	year	Exposure time	6	30
EF	days/year	Exposure frequency	350	350
FE	--	Dermal exposure ratio to soil	0.61	0.61
Irng	mg/day	Soil ingested factor	200	100
Irair	m^3/day	Inhalation factor	10	20
SA	cm^2/event	Exposed skin surface	2.8	5.7
AT	Day	Average time		
		for non-carcinogens elements	ED x 365	
		for carcinogens elements	70×365	
CF	kg/mg	Chronic calculation factor	10^{-6}	
PEF	kg/mg	Soil particulate emission factor – air	1.36×10^9	
RfD_o Pb	mg/kg/day	Reference Dose for oral intake of lead	3.60E-3	
RfD_d Pb	mg/kg/day	Reference Dose for dermal contact of lead	5.25E-04	
RfD_i	mg/kg/day	Reference dose for lead inhalation	3.52E-03	
CSF_o Pb	mg/kg/day	Chronic Slope Factor for lead oral exposure	8.50E-3	
CSF_i Pb	mg/kg/day	Chronic Slope Factor for lead inhalation	4.20E-2	

The carcinogenic impact of Pb on humans through dermal contact is uncertain due to the lack of precise values provided by most researchers. Values of 8.5×10^{-3} and 8.5×10^{-2} have been mentioned in multiple instances, but the reliability of this data is questionable. (Miletić A. et al., 2023). Therefore, carcinogenic effects through dermal contact were not considered in the study.

Individual and overall index of potential ecological risk from soil

Hakanson (1980) proposed the concept of assessing the Ecological Risk Index (ERI) for heavy metals in sediment.

The ERI evaluates the potential risk that heavy metals pose to organisms by taking into account both their concentrations and toxicological effects. It is derived from the sum of individual potential risk factors (Eir) in the soil, and its computed based on the equation:

$$Ei_r^i = T_r^i x CF \quad (7)$$

Tir represents the toxic response factor of each heavy metal and the value for lead is Pb = 5. CF is the contamination factor calculated by dividing the concentration of heavy metals in soil by the background value of the same metal. The highest permissible value of 50 mg/kg in that soil was used as the background value (Eq.: 8).

$$CF = C_{heavy\ metal} / C_{background} \quad (8)$$

The interpretation of soil contamination based on the contamination factor (CF), Eir values for determining the severity of ecological risk as follows in Table 2.

Table 2. Classification of soil contamination based on the contamination factor (CF) and categorization standard for potential ecological risk in soil

CF values	Contamination level	Eir values	Contamination degree
<1	low contamination	Eir <40	low potential ecological risk
1<CF<3	moderate contamination	40≤ Eir <80	moderate potential ecological risk
3<CF<6	considerable contamination	80≤ Eir <160	considerable ecological potential
CF>6	serious contamination	160≤ Eir <320	high potential ecological risk
<1	low contamination	Eir ≥320	serious ecological risk

RESULTS AND DISCUSSIONS

Results

The results of the research on the concentration of lead at the localities are shown in Table 3.

In Table 4, the subparameters of chemical soil characteristics at the investigated locations are listed. The parameters include pH in water, pH in KCl, carbonate content, humus content, available P_2O_5, and available K_2O.

Table 5 lists the results of the calculation of carcinogenic and non-carcinogenic health risks for adult.

Table 3. Results of the average values of lead (Pb) mg/kg on localities near the landfill

Localities	Heavy metal	Average
	Lead, mg/kg	
Buđevci 1	91.07 ± 100.02	95.4
Buđevci 2	119.2 ± 297.93	203.90
Buđevci 3	48.2 ± 59.6	53.9
Buđevci 4	52.6 ± 61.4	51.63
Buđevci 5	43.1 ± 70.1	57
Buđevci 6	43.6 ± 51.83	48.67
Buđevci 7	49.85 ± 62.75	57.9
Standard Deviation	25.13	
Official Gazette of FBiH (22/96)	50	
WHO (2003)	100	

Table 4. The chemical soil characteristics at the investigated locations

Localities	pH H_2O	pH KCl	Content $CaCO_3$, (%)	Humus content (%)	Available P_2O_5, mg/100 g	Available K_2O, mg/100 g
Buđevci 1	8.03	7.53	60.67	11.34	42.78	21.69
Buđevci 2	8.05	7.62	66.6	10.77	8.37	14.96
Buđevci 3	8.38	7.75	56.53	11.47	14.96	97.07
Buđevci 4	8.06	7.29	14.05	5.08	14.36	26
Buđevci 5	8.09	7.21	11.08	4.13	14.02	48.7
Buđevci 6	7.9	7.43	19.26	5.77	33.04	32.7
Buđevci 7	7.99	7.53	32.75	8.43	4.11	32.3

Table 5. Values of carcinogenic and non-carcinogenic health risk for adults on each locality

Localities	ADI	Pb	ILCR	HQ Pb	HI
Buđevci 1	ingestion	4.74E-06	4.74E-06	0.36	0.97
	inhalation	2.90E-11		5.46E-6	
	dermal	/		0.61	
Buđevci 2	ingestion	1.02-05	1.02E-05	0.78	2.07
	inhalation	6.20E-11		1.17E-5	
	dermal	/		1.29	
Buđevci 3	Ingestion	1.96E-09	1.96E-09	0.21	
	inhalation	1.64E-11		3.08E-6	0.21
	dermal	/		3.42E-01	
Buđevci 4	ingestion	2.58E-06	2.58E-06	7.16E-04	0.33
	inhalation	1.57E-11		2.95E-6	
	dermal	/		0.33	
Buđevci 5	ingestion	2.84E-06	2.85E-06	0.22	0.58
	inhalation	1.73E-11		3.26E-6	
	dermal	/		0.36	
Buđevci 6	ingestion	2.43E-06	2.43E-06	0.19	0.49
	inhalation	1.48E-11		2.79E-06	
	dermal	/		0.31	
Buđevci 7	ingestion	2.89E-06	2.89E-06	0.22	0.59
	inhalation	1.76E-11		3.31E-06	
	dermal	/		0.37	
Total ILCR			2.57E-05	Total HI	5.58

Table 6 lists the results of the calculation of the assessment of carcinogenic and non-carcinogenic health risks for children.

Contamination factor (CF) and potential ecological risk (Eir) values are shown in Table 7.

Table 6. Values of carcinogenic and non-carcinogenic health risk for children on each locality

Localities	ADI	Pb	ILCR	HQ Pb	HI
Buđevci 1	ingestion	1.04E-4	1.04E-4	3.39	7.35
	inhalation	1..58E-10		1.27E-5	
	dermal	/		3.97	
Buđevci 2	ingestion	2.22E-4	2.22E-4	7.24	15.72
	inhalation	3.37E-10		2.72E-5	
	dermal	/		8.48	
Buđevci 3	Ingestion	5.86E-5	5.86E-5	1.91	4.16
	inhalation	8.92E-11		7.20E-06	
	dermal	/		2.24	
Buđevci 4	ingestion	5.61E-5	5.61E-5	1.83	3.98
	inhalation	8.54E-11		6.89E-06	
	dermal	/		2.15	
Buđevci 5	ingestion	6.19E-5	6.19E-5	2.02	4.40
	inhalation	1.41E-9		7.61E-06	
	dermal	/		2.37	
Buđevci 6	ingestion	5.29E-5	5.29E-5	1.73	3.75
	inhalation	8.05E-11		6.50E-6	
	dermal	/		2.02	
Buđevci 7	ingestion	6.29E-5	6.29E-5	2.06	4.46
	inhalation	9.58E-11		7.73E-6	
	dermal	/		2.41	
Total ILCR			6.18E-4	Total HI	43.83

Table 7. Contamination factor and potential ecological risk values on each locality

Localities	CF		Ei_r	
Buđevci1	1.91	Moderate contamination	9.54	low potential ecological risk
Buđevci2	4.07	Considerate contamination	20.39	low potential ecological risk
Buđevci3	1.07	Moderate contamination	5.39	low potential ecological risk
Buđevci6	1.03	Moderate contamination	5.16	low potential ecological risk
Buđevci7	1.14	Moderate contamination	5.70	low potential ecological risk
Buđevci4	0.97	Moderate contamination	4.87	low potential ecological risk
Buđevci5	1.16	Moderate contamination	5.79	low potential ecological risk

Discussions

The concentration of lead (Pb) in the surface layer of the soil varied from 48.67 mg/kg to 203.9 mg/kg in the investigated area. Mičijević et al., in 2020, in their research, stated the measured average values of lead in the area of Mostar as 85.61 mg/kg. Also, they stated that by calculating the HI for children, it was determined that the value of HI for oral intake of Pb from the soil in Mostar is 3.03 and, therefore, represents a health risk. Saha et al. (2023), in their health risk assessment and pollution load for heavy and toxic metal contamination from leachate in soil and groundwater near a landfill in the Middle Brahmaputra Valley, India, report health risk assessment results for lead: HI ing. for children 2.60E-2; HI ing. for adults 1.38E-2; HI inh. for children 6.29E-2; HI inh. for adults 1.77E-1; HI der. for children 3.74E-4; HI der. for adults 6,16E-4. They also report ILCR of 0.000169 for children and 0.0002 for adults. As for lead, in the risk assessment, soil ingestion is the main route for toxic lead to enter the body. In this research, a significant carcinogenic hazard was found for children with the highest measured ILCR values of 1.04E-4 at Buđevci 1 and 2.22E-4 at Buđevci 2. At the other localities, it was within acceptable limits. However, when taking into account the measured values from all the localities, then the possibility of developing cancer in children in this area is high and amounts to 6.18E-4. That means that 1 child out of 1618 children has a risk of developing cancer due to the intake of lead from the soil. Also, the value of HI in all localities was above 1, and in the total sum from all localities, it exceeded 43.83, which indicates a very high risk of non-carcinogenic health risks in children. In adults, ILCR at Buđevci 2 is worrisome and amounts to 1.02E-05, while at the other localities, it is within acceptable limits. However, the sum of all values from other localities is 2.57E-05, which affects the concern for the occurrence of carcinogenic hazard to the health of adults. The HI values did not exceed 1 at any of the localities, although, at Buđevci 2, the measured value was close to 1, more precisely 0.75. In total, the value of HI from all localities is 1.97, indicating a possible occurrence of non-carcinogenic health risks in adults, but much less than in children. According to a study conducted by Chuan Du and Zhapning Li in 2023, the soil of a historical landfill in China contained non-carcinogenic values for Pb greater than 1 at all sites. As a result, the study recommended that regulatory agencies and authorities should relocate nearby residents and prohibit them from engaging in any agricultural activities in the region. The Contamination Factor (CF) serves as a practical and straightforward tool for assessing heavy metal contamination, with a higher value indicating a higher level of pollution at a specific location. The CF values for soil samples in the research area are presented in Table 8, ranging from <0.97 to 4.07 mg/kg. The CF values across all samples suggest a moderate level of contamination, except for sample Buđevci 2, which indicates considerable contamination. Based on physico-chemical research, the soil at locations Buđevci 1 to Buđevci 7 is characterized by slightly alkaline pH in water and pH in KCl, suggesting that the soil is moderately alkaline. The calcium carbonate ($CaCO_3$) content is relatively high, and the humus content is moderate to high. The availability of phosphorus (P_2O_5) and potassium (K_2O) varies but is generally moderate. In such soils, where there are high levels of $CaCO_3$ and humus, lead is expected to tend to bind to soil particles and remain relatively stationary.

The concentration data for Pb in that particular sample were obtained from the Adaptation Plan. The mean values of the ecological risk index (Er) for Pb in the soil samples of the research area ranged from < 4.87 to 20.39 (Table 7). The observed results show there is minimal potential ecological risk at all localities. The lead contamination factor at location Buđevci 2 is CF= 4.07, which is highly polluted due to waste, and represents a considered environmental risk at the same location.

In the research of Fadhel, M. A., Abdulhussein, F. M. 2022 on the assessment of soil Pb contamination in Baghdad, the authors reported that average concentrations ranged from 19507.5, 12.8, and 2.2 mg/kg for soils near industrial facilities.Also, by calculating the potential environmental risk, the authors state that there is a very high environmental risk in industrial locations, while in other investigated locations there is a low environmental risk.

Kolawole T.O. et al. (2023), in their research of potentially toxic elements around municipal solid waste landfills in Southern Nigeria, reported that the ecological risk potential (Er) from Cd and Pb was high within the facility, considerate near the facility, and low at localities 600 - 1000m from the building.

Chen et al. (2022) stated, in their research on the potential ecological risk from heavy metals in the soil, that 76% of the researched area has a low ecological risk (RI < 150); areas with moderate ecological risk ($150 \leq RI < 300$) cover up 20.7%; areas of high ecological risk ($300 \leq RI < 600$) cover up 2.72% of the research area and are intersected by areas of moderate risk; areas of serious ecological risk ($600 \leq RI$) cover up less than 1% of the research area. Table 8 lists the average values of Pb concentration and waste management methods at some landfills in the world.

Table 8. Overview of the average lead concentrations (Pb mg/kg^{-1}) in landfills in other countries with references (Karimian S. et al., 2021)

Country	Pb, mg/kg^{-1}	Waste management method	Reference
Spain	18.6	Waste disposal (60%)	M.Mari et al., 2009
Italy	39.3	Waste disposal (22%)	Bretzel & Calderisi, 2011
Serbia	54.5	Waste disposal	Krčmar et al., 2018
China	26.7	Disposal+ Incineration	Ma et al., 2018
Nigeria	83.4	Open waste disposal	Adelopo et al., 2018
Malaysia	90.4	Incineration	Jayanthi et al., 2017

CONCLUSIONS

The measured lead concentrations in this research ranged from 48.67 mg/kg to 203.9 mg/kg. At six localities, except Buđevci 4, lead concentrations were above the permitted values (Official Gazette of FBiH 22/96).

One sample from the Adaptation Plan even exceeded the values prescribed by the WHO (WHO, 2003).

Based on the contamination factor (CF), moderate contamination was determined at all localities, while considerate contamination was determined at Buđevci 2. Although a low ecological risk has been determined, given that it is an agricultural land near the landfill, all necessary measures and actions should be taken to protect people's health. Research shows that the risk of carcinogenic and non-carcinogenic diseases is much higher in children than in adults. Based on risk assessment calculations, it can be concluded that the data on the risk for children's health are worrisome.

As an extension for future work, this study suggests studying the health effects of toxic heavy metals (loids) on individuals in the landfill area, including adults, the elderly, and children. Further research is planned at this location, with a proposed expansion of the study to include three additional heavy metals in order to obtain more precise and relevant data.

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