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Research Article

Assessment of ecological and public health risks associated with heavy metals on farmland in Wonosobo Regency, Indonesia

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Abstract

The deposition of metallic substances on farmland is of critical importance owing to its possible detrimental impacts on the surroundings and human wellness. Heavy metals can adversely affect the physicochemical properties of soil and plant health. Prolonged exposure to heavy metals in humans can lead to both carcinogenic and non-carcinogenic effects. The present research intended to determine the dispersion condition of toxic metals on cropland and assess the attendant environmental and health dangers in the Wonosobo Regency. This study used a soil sample survey encompassing 312 soil sampling sites. The completed analyses comprise geographical analysis, index of geo-accumulation (IG), contamination index (CI), Nemerow comprehensive contamination index (NCCI), risk analysis, and health risk analysis. The research findings reveal that cadmium material is the primary contributor to contamination from heavy metals in farmland in Wonosobo Regency, as shown by IG analysis. The CI and environmental hazards assessments suggest considerable pollution levels. Kids are more prone to illnesses than adults due to their daily intake amount, so it is necessary to pay more attention to the daily intake sources in children to minimize exposure to heavy metals.

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Introduction

Agricultural land is a resource for human survival and food production (Viana et al., 2022). Currently, the rapid development of industry and population, mining activities, exhaust gas from motor vehicles, and intensive agricultural activities have caused various problems on farmland (Akoto et al., 2023; Cao et al., 2023; Hansa et al., 2023; Istanbullu et al., 2023; Wan et al., 2024). Heavy metals deposits on agricultural land are one of the issues generated by the discharge of metals from numerous anthropogenic activities into the environment (Xia et al., 2024).

Heavy metals on agricultural land can reduce soil physicochemical properties and plant health (Rehman et al., 2021). Consumption of toxic substances in crops can generate oxidative stress due to forming reactive substances, thereby altering the morphophysiological and biochemical systems at the cellular and tissue levels (Noor et al., 2022). Plants growing in soil polluted with toxic metals show lower growth and development and reduced crop yields (Sharma and Archana, 2016). Prolonged contact with cadmium in plants can lead roots to become necrotic, rotting, and mucilaginous, restricting the elongation of plant roots and shoots and inducing leaf rolling and chlorosis (Haider et al., 2021).

Trace element accumulation on agricultural land can also impair public health (Faraji et al., 2023). Channels of exposure to toxins may get into human beings through three channels, including inhalation, intake of food and drink, and cutaneous exposure

(Chen et al., 2022). Prolonged and continuous exposure affects humans and generates carcinogenic and non-carcinogenic effects (Zhao et al., 2022).

Wonosobo Regency has intensive agricultural production, mainly on horticultural produce land. P and K fertilization and extensive addition of organic materials to cropland create significant quantities of accessible P, K, and organic C (Gani et al., 2021). Intensive fertilization can also cause the deposition of heavy metals on agricultural land (Chen et al., 2020), such as phosphate fertilizer, which can accumulate Cd metal on cultivated land (Suciu et al., 2022). Previous research has shown the accumulation of heavy metals Pb, Co, Ni, Cr, As, and Cd in agricultural land in Wonosobo Regency, with respective concentrations of 11.00±2.80 mg kg^{-1}, 10.83±3.19 mg kg^{-1}, 6.04±2.86 mg kg^{-1}, 3.56±2.31 mg kg^{-1}, 2.02±1.17 mg kg^{-1}, and 1.23±0.43 mg kg^{-1} (Dewi et al., 2023).

Based on the description above regarding the magnitude of the effect of contaminants on agricultural land for the natural world and the general people, this study attempted to deliver data about the assessment of ecological and public health risks that can arise from an increase in toxic element on agricultural land in Wonosobo Regency.

Materials and Methods

Research site

The research was conducted in Wonosobo Regency, Central Java Province. This region is situated between 7.183° and 7.600° latitude North, and 109.717° and 110.067° longitude East. Wonosobo Regency is a highland territory with heights varying from 275-2,250 meters above sea level. The area of Wonosobo Regency is 984.68 km^2. The maximum rainfall was measured in February, with 25 mm, while the minimum occurred in July, with 6 mm. Wonosobo Regency engages in intensive agricultural cultivation, particularly in horticultural fields, with flagship products such as potatoes, cabbage, and scallions. Regular assessment is necessary for horticultural production due to the probable accumulation of heavy metals in the soil resulting from the excessive use of fertilizers and pesticides.

Soil sample collection and analysis techniques

Soil sampling spots were determined using the grid method based on the land use units of the land use map. Soil samples were collected at 312 geographic locations (Figure 1) using a survey method. One sampling point consisted of 5-10 separate samples (subsamples), with a distance of 25-50 m for each subsample in the field. The parameters observed included the trace elements of lead, cadmium, copper, chromium, nickel, cobalt, manganese, zinc, and arsenic. Soil samples were collected from topsoil (0-20 cm). Examination of the soil samples for trace element concentration took place at the IAERI Laboratory, the Ministry of Agriculture. The method for evaluating toxic metals in soil samples, which involved modifying the specimen volume, the amount of diluted solution of nitric acid, and digestion phases, was based on the procedures outlined by Eviati and Sulaeman (2009) and Sisay et al. (2019), and used an Atomic Absorption Spectrophotometer.

Index of Geo-accumulation (IG)

The evaluation of IG to determine the extent of metal contamination over baseline followed this method (Zhang et al., 2023):

$$\mathrm{IG} = \log_2 \left[\frac{\mathrm{Ci}}{1.5 \text{ x } \mathrm{Cb}}\right] \text{ ……….. (1)}$$

where: Ci is the number of metallic element-i in the substrate specimen, Cb is a reference quantity of the associated metal, and multiplier 1.5 is the baseline matrix adjustment ratio. IG is classified into seven categories: not contaminated (IG<0), not contaminated to slightly contaminated (0<IG<1), slightly contaminated (1<IG<2), slight to severely contaminated (2<IG<3), severely contaminated (3<IG<4), severely to extreme contaminated (4<IG<5) and extremely contaminated (5<IG).

Contamination Index (CI) and the Nemerow Comprehensive Contamination Index (NCCI)

The computation of the pollution rate for every metal substance and the determination of the integrated contamination for every observed pollutant CI and NCCI followed the equation developed by Dong et al. (2024):

$$\mathrm{CI} = \frac{\mathrm{Ci}}{\mathrm{Si}} \text{ …….. (2)}$$

where: Ci is the quantity of trace element-i of an earth specimen, while Si is the critical limit of the related heavy metal (Yang et al., 2022).

$$\mathrm{NCCI} = \sqrt{\frac{(\mathrm{Pi})^2 + (\mathrm{Pmax})^2}{2}} \text{ …….. (3)}$$

where: Pmax is the greatest individual CI level for all measured contaminants, and Pi is the mean level. Liu et al. (2021) categorized CI and NCCI levels under five categories, namely: unpolluted (CI, NCCI<0.7), alerting limit (0.7<CI, NCCI<1), mild polluted (1<CI, NCCI<2), medium polluted (2<CI, NCCI<3) and heavy pollution (CI, NCCI>3).

Ecological risk

The prospective environmental risk index (RI) is an evaluation tool for the possible harm of heavy metals to the ecosystem. Calculation of RI involved the use of the following equation (Mitran et al., 2024):

$$\mathrm{EI_i} = \frac{\mathrm{Ci}}{\mathrm{Cb}} \text{ x } \mathrm{CFi} \text{ …….. (4)}$$

$$\mathrm{RI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{EIi} \text{ ……… (5)}$$

The environmental risk factor of element-i is represented as EIi, and the corresponding metal response factor is CFi. The values for CFi are given below: arsenic = 10, cadmium = 30, chromium = 2, copper = 5, nickel = 5, lead = 5, cobalt = 5, manganese = 1, and zinc = 1. The EI levels are categorized into five groups: low (EI<40), moderate (40<EI<80), high (80<EI<160), very high (160<EI<320), and dangerous (EI>320). The overall possible environmental risk for all trace elements is represented by RI, which is classified into four levels: low (RI<150), medium (150<RI<300), high (300<RI<600), and very high (RI>600).

Health risks

The exposure measurement approach established by USEPA is used to assess the detrimental effects of pollutants on soil. The following model calculates the mean daily dosage (MDD) of polluted topsoil fragments for kids and grownups alike by food and skin contact (Liu et al., 2022):

$$\mathrm{MDD_{ingestion}} = \frac{\mathrm{Ci\ x\ IngR\ x\ EF\ x\ ED}}{\mathrm{BW\ x\ AT}}\ \mathrm{x}\ 10^{-6}\ \ldots\ldots\ldots(6)$$

$$\mathrm{MDD_{dermal}} = \frac{\mathrm{Ci\ x\ SA\ x\ AF\ x\ ABS\ x\ EF\ x\ ED}}{\mathrm{BW\ x\ AT}}\ \mathrm{x}\ 10^{-6}\ \ldots(7)$$

$\mathrm{MDD_{ingestion}}$ and $\mathrm{MDD_{dermal}}$ refer to MDD via consumption and skin absorption, respectively, whereas Ci indicates the amount of trace elements in the topsoil. Hazard quotient (HQ) is a standard metric used to quantify noncarcinogenic hazards to determine the proportion of long-term daily consumption:

$$\mathrm{HQ} = \frac{\mathrm{MDD}}{\mathrm{RfD}}\ \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

while RfD denotes a long-term benchmark dosage, the Hazard Index (HI) is a method to quantify the possible noncarcinogenic implications of all trace elements based on the above formula:

$$\mathrm{HI} = \sum_{\mathrm{n=i}}^{\infty} \mathrm{HQ_i}\ \ldots\ldots\ldots\ldots(9)$$

When the HI is below one, there is no likelihood of significant adverse health effects; however, if it is above one, health problems may occur. The estimated carcinogenic risk (CR) for acquiring cancers from trace elements exposure was evaluated by the subsequent formula.

$$\mathrm{CR} = \mathrm{ADD\ x\ SF}\ \ldots\ldots\ldots\ldots(10)$$

In this equation, SF is the slope factor. The CR values are divided into three categories according to Men et al. (2018): no significant risk ($<10^{-6}$), acceptable risk (10^{-6}-10^{-4}), and unacceptable risk ($>10^{-4}$).

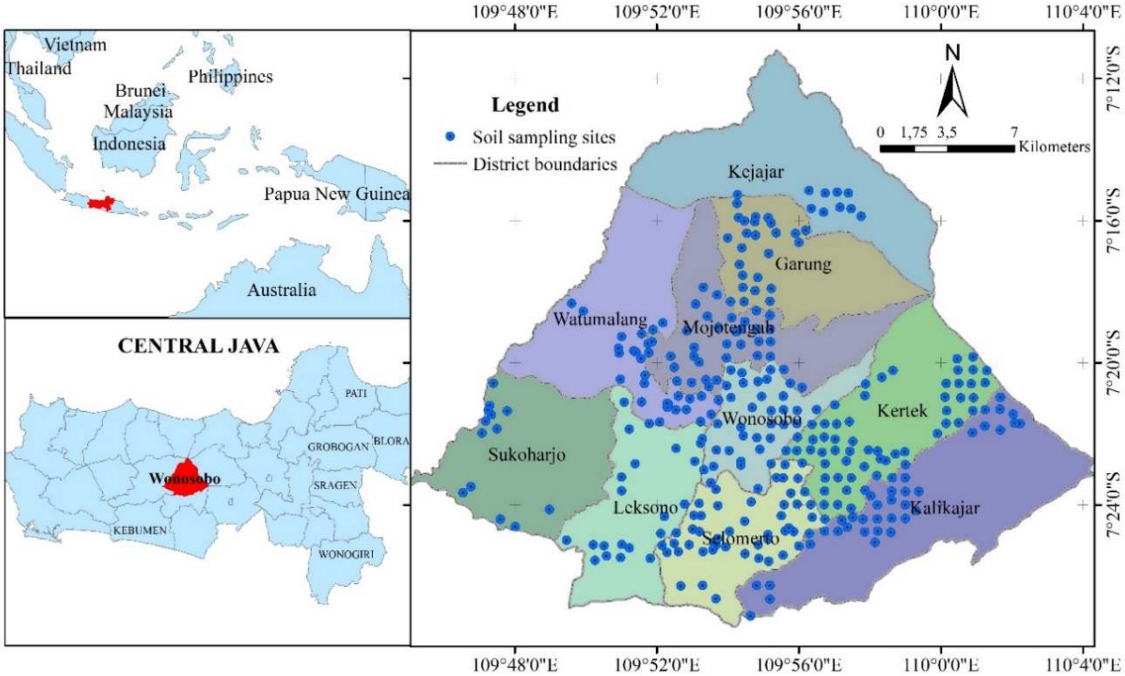


Figure 1. Site of soil collection in Wonosobo Regency.

Results and Discussion

Quantities of all metals were identified in almost all soil sample locations in the agricultural land in Wonosobo Regency. The maximum values of the metal content of lead, cadmium, cobalt, nickel, chromium, arsenic, manganese, copper, and zinc recorded were 40.84 mg kg^{-1}, 2.40 mg kg^{-1}, 20.76 mg kg^{-1}, 23.60 mg kg^{-1}, 122.02 mg kg^{-1}, 6.22 mg kg^{-1}, 372.17 mg kg^{-1}, 9.18 mg kg^{-1}, and 68.94 mg kg^{-1}, respectively (Table 1). According to these maximum quantities, none of the maximum metal concentrations exceed the threshold level for heavy metals in the environment.

The distribution and spatial variation of toxic substances in farmland in Wonosobo Regency were indirectly determined using coefficient variance (CV) values. The CV values of Pb, Cd, Co, Ni, Cr, As, Mn, Cu, and Zn metals were 34.55%, 34.96%, 29.46%, 47.35%, 64.89%, 57.92%, 105.27%, 63.11%, and 113.70%, respectively. A CV value of <15% reflects the level of variation of the metals, which is classed into three groups, namely low with a CV value of <15%, medium between 15%-35%, and high CV>35% (Song et al., 2022). The more significant the CV value, the stronger the repercussions of human activities and vice versa (Wu et al., 2021). The CV numbers for Pb, Cd, and Co range between 29.46% and 34.96%. It shows that the degree of variations of Pb, Cd, and Co is in the medium variation group, and the spread of metallic substances is quite varied, showing the impact of human behaviors on the material concentration. The CV value of Ni, Cr, As, Mn, Cu, and Zn is >35%. This suggests a high degree of variation, and the distribution of contaminants is quite variable, reflecting the detrimental effects of high human activities on the levels of pollutants in farmland (Zhang et al., 2022).

Figure 2 shows the geographic pattern of contaminants in cropland in Wonosobo Regency. The metals Pb, Cr, Ni, and Zn dominate the geographic distribution in the low-value group, while the metals As, Mn, Co, and Cu are evenly dispersed. The distribution of Cd metal features the high-value group (>1.92 mg kg^{-1}). This suggests that Cd metal, with a concentration of >1.92 mg kg^{-1}, dominates and is widely distributed across the agricultural land of Wonosobo Regency.

Table 1. Characterization data of metallic substances in soils of farms of the research region.

Descriptive statistics	Pb	Cd	Co	Ni	Cr	As	Mn	Cu	Zn
Mean	11.00	1.23	10.83	6.04	3.56	2.02	70.34	2.25	8.03
Standard Error	0.22	0.02	0.18	0.16	0.13	0.07	4.19	0.08	0.52
Median	10.40	1.26	10.70	5.75	3.05	1.69	44.60	2.09	4.31
Standard Deviation	3.80	0.43	3.19	2.86	2.31	1.17	74.05	1.42	9.13
Sample Variance	14.46	0.19	10.15	8.15	5.33	1.36	5484.08	2.03	83.40
Range	38.54	2.38	19.67	22.81	21.10	6.22	371.49	9.16	68.75
Minimum	2.30	0.02	1.08	0.80	0.91	0.00	0.68	0.02	0.19
Maximum	40.84	2.40	20.76	23.60	22.02	6.22	372.17	9.18	68.94
Count	312	312	312	312	312	312	312	312	312
Confidence Level (95%)	0.42	0.05	0.35	0.32	0.26	0.13	8.25	9.18	1.02
CV (%)	34.55	34.96	29.46	47.35	64.89	57.92	105.27	63.11	113.70
Critical limit (Alloway, 1995)	100-400	3-8	25-50	100	75-100	20	1500-3000	60-125	70-400

Index of Geo-accumulation (IG)

Figure 3 displays the IG ratings on farmland in Wonosobo Regency. The IG average values in the series are as follows: Cd (2.89) > As (-0.47) > Pb (-1.09) > Co (-1.81) > Ni (-3.91) > Cu (-4.36) > Zn (-4.38) > Cr (-5.88) > Mn (-10.67). Upon assessing the average IG of all the metals investigated, it was found that cadmium has an IG value of primarily over one, while the other metals have values below zero. Except for cadmium, the agricultural land in Wonosobo Regency is unpolluted by the examined elements. The average index of geo-accumulation of cadmium is 2.89, signifying that cadmium exposure ranges between the medium to severe range.

The accumulation of cadmium elements in cropland may originate from the widespread usage of agricultural chemicals and fertilizers (Yan et al., 2020). Extended application of phosphorus fertilizer, as well as the use of animal manure such as cow, chicken, and pig manure, is thought to serve as the major contributing cause of Cd elements buildup on agricultural land (Sui et al., 2023; Li et al., 2024; Rahim et al., 2024). Cadmium elements can accumulate on agricultural land through numerous causes, including earth-parent materials, mineral extraction, and motorized vehicles (Zhang et al., 2022). Table 2 indicates the percentage of the IG value category. The IG values for the elements lead, cadmium, and arsenic are in the uncontaminated to slightly polluted variety of 0.96%, 1.28%, and 24.36%, respectively. Cadmium metals are in the slightly and slightly severely polluted groups, with 37.82% and 55.13%, respectively. Arsenic is categorized into three groups: uncontaminated (72.76%), uncontaminated to slightly contaminated, and slightly contaminated, with the latter group comprising 2.88%. The remaining metals fall into the unpolluted category.

Contamination Index (CI) and the Nemerow Comprehensive Contamination Index (NCCI)

An investigation into the status of toxic metals on farmland can also be conducted using pollution index analysis. Figure 4 shows the CI values of trace elements in farmland in Wonosobo Regency. The average CI values, in order, are as follows: Co (0.43) > Cd (0.41) > Pb (0.11) > Zn (0.11) > As (0.10) > Ni (0.06) > Cr (0.05) > Mn (0.05) > Cu (0.04). All the metals investigated were not categorized as polluted based on the average CI value because their CI values were below 0.7.

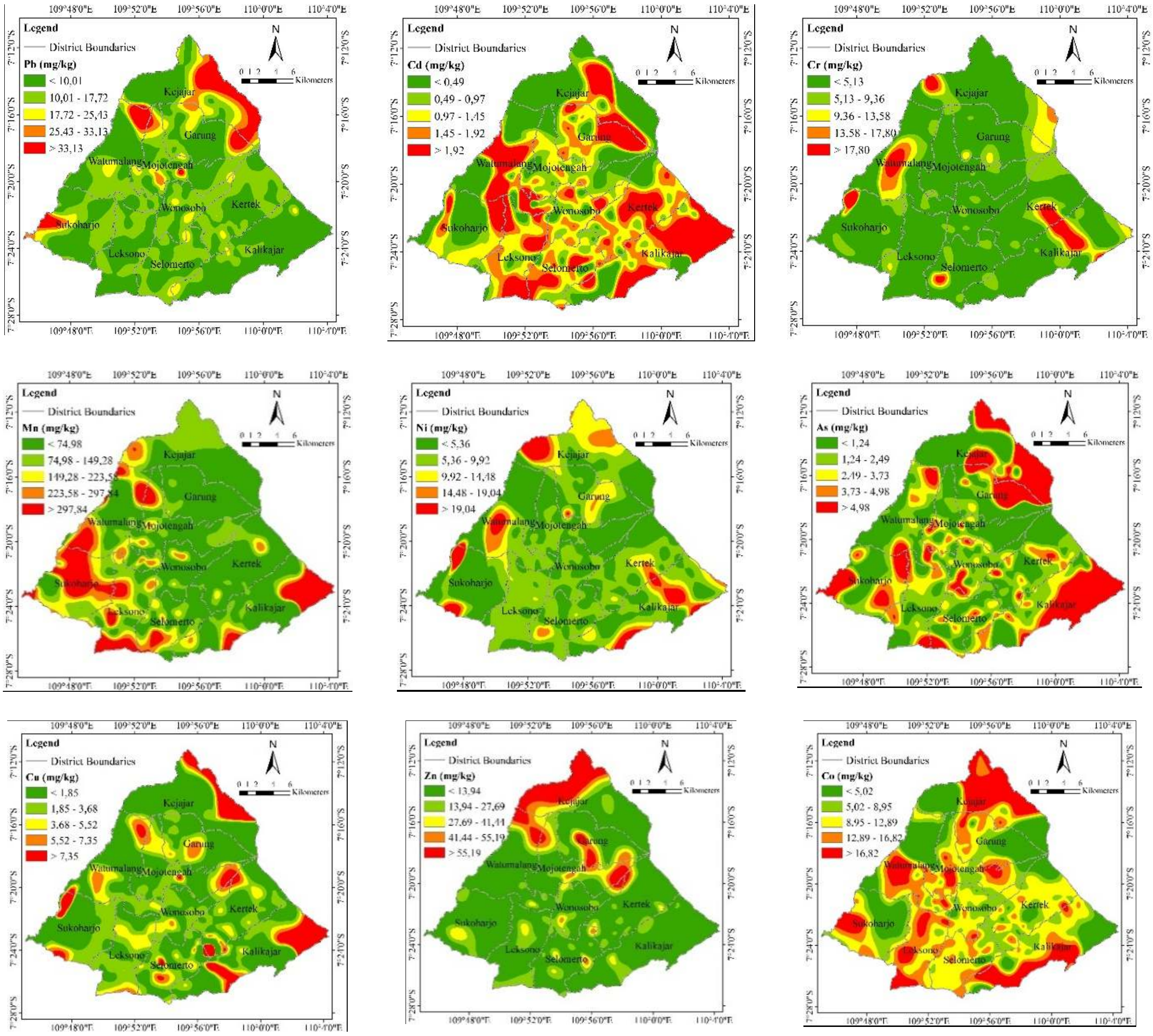
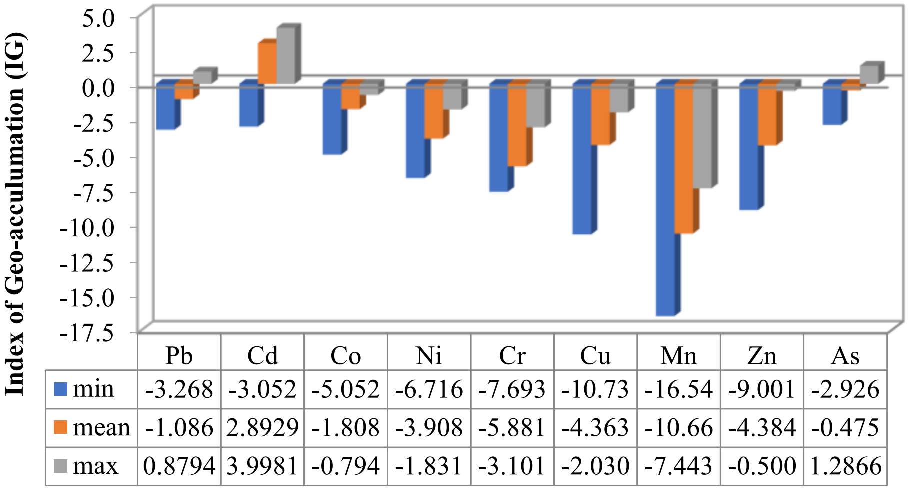


Figure 2. Geographical dispersion of toxic metals in farmland in Wonosobo Regency.

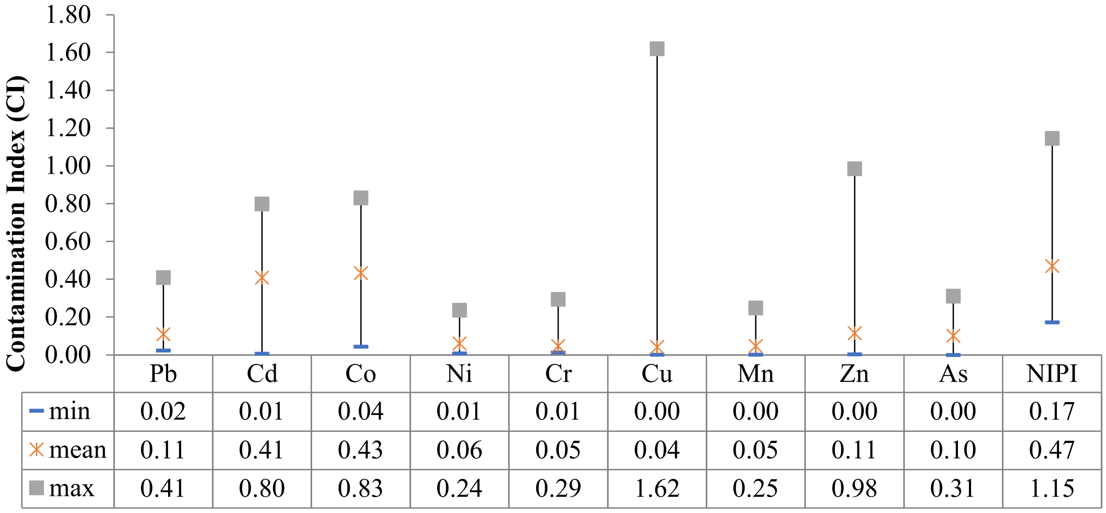


	Pb	Cd	Co	Ni	Cr	Cu	Mn	Zn	As
🟦 min	-3.268	-3.052	-5.052	-6.716	-7.693	-10.73	-16.54	-9.001	-2.926
🟧 mean	-1.086	2.8929	-1.808	-3.908	-5.881	-4.363	-10.66	-4.384	-0.475
⬜ max	0.8794	3.9981	-0.794	-1.831	-3.101	-2.030	-7.443	-0.500	1.2866

Figure 3. Index of Geo-accumulation (IG) value.

Table 2. Proportion (%) of IG result categories.

Heavy Metals	**Unpolluted**	**Unpolluted - Slight**	**Slight**	**Slight-Severe**	**Severe**	**Severe-Sxtreme**	**Extreme**
Pb	99.04%	0.96%	0.00	0.00	0.00	0.00	0.00
Cd	1.28%	1.28%	4.49%	37.82%	55.13%	0.00	0.00
Co	100.00	100.00	0.00	0.00	0.00	0.00	0.00
Ni	100.00	100.00	0.00	0.00	0.00	0.00	0.00
Cr	100.00	100.00	0.00	0.00	0.00	0.00	0.00
Cu	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn	100.00	100.00	0.00	0.00	0.00	0.00	0.00
Zn	100.00	100.00	0.00	0.00	0.00	0.00	0.00
As	72.76%	24.36%	2.88%	0.00	0.00	0.00	0.00



	Pb	Cd	Co	Ni	Cr	Cu	Mn	Zn	As	NIPI
− min	0.02	0.01	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.17
× mean	0.11	0.41	0.43	0.06	0.05	0.04	0.05	0.11	0.10	0.47
■ max	0.41	0.80	0.83	0.24	0.29	1.62	0.25	0.98	0.31	1.15

Figure 4. Contamination index and Nemerow comprehensive contamination index.

Table 3 also shows the percentage CI value based on the pollution status category. The CI % value is defined by all heavy metal readings at all soil sampling locations, not just the average CI value. It indicates that metals like Cd and Co have CI values that fall into groups other than unpolluted. The percentage of CI values for the metals Pb, Ni, Cr, As, Mn, Cu, and Zn is 100% in the unpolluted group. The CI values for Cd and Co metals fall into two categories: the uncontaminated category and the warning threshold. The percentage values for Cd metal are 99.04% and 0.96%, while the percentage values for Co metal are 97.12% and 2.88%. The overall CI value percentage shows that only Cd and Co metals have reached the alert threshold category for heavy metal pollution. This aligns with the results of the IG value for Cd metal, which is the primary driver of contamination in cropland in the Wonosobo Regency. The NCCI value of trace elements in farmland in Wonosobo Regency is depicted in Figure 4.

Table 3. Result analysis of the percentage of contamination index (CI) value categories.

Heavy Metals	**Percentage of CI**				
	Unpolluted	**Alerting Limit**	**Mild**	**Medium**	**Heavy**
Pb	100.00	0.00	0.00	0.00	0.00
Cd	99.04	0.96	0.00	0.00	0.00
Co	97.12	2.88	0.00	0.00	0.00
Ni	100.00	0.00	0.00	0.00	0.00
Cr	100.00	0.00	0.00	0.00	0.00
Cu	100.00	0.00	0.00	0.00	0.00
Mn	100.00	0.00	0.00	0.00	0.00
Zn	100.00	0.00	0.00	0.00	0.00
As	100.00	0.00	0.00	0.00	0.00

The NCCI value is the product of the comprehensive CI values of all observed metals. The average NCCI value for agricultural land in Wonosobo Regency is 0.47, indicating that the value is in the unpolluted category because the value is below 0.7. Based on the average integration value of all measured heavy metals, the agricultural area in Wonosobo Regency is classified as unpolluted.

Ecological risk (Ei)

Table 4 illustrates the harmful effects of metallic substances on farmland in Wonosobo Regency. The environmental risk calculation findings show that the EI value for Cd is over 40, specifically 368.24, which places Cd metal in the severe environmental danger category. This is conceivable because the hazardous response coefficient value is high (30) compared to other metals. The EI value for the Pb, Co, Ni, Cr, As, Mn, Cu, and Zn are below 40, with corresponding values 3.72, 2.26, 0.54, 0.06, 0.51, 0.10, 0.12, and 11.89 respectively.

This indicates that those metals fall into the low-level ecological risk category. The RI value for all metals is 387.43, which suggests that the integrated risk to the environment from all heavy metals found is in the relatively high-level group. This is because of the very high EI value for Cd, resulting in a high RI value. According to the findings of the IG study, the CI and ecological risk suggest that Cd element is the primary contributor to heavy metal contamination in farmland in Wonosobo Regency, with moderate contamination values. Significant amounts of Cd element in cropland can severely impact human health through food consumption (Li et al., 2021) and skin absorption (Chen et al., 2021). Exposure to cadmium is harmful to public health as it can cause various chronic diseases such as coronary artery disease, stroke, and cardiovascular illness (Liu et al., 2021).

Table 4. Ecological risks index and potential ecological risk index values.

Descriptive statistics	**Ecological Risk (EI)**									**RI**
	Pb	**Cd**	**Co**	**Ni**	**Cr**	**Cu**	**Mn**	**Zn**	**As**	
Mean	3.72	368.24	2.26	0.54	0.06	0.51	0.10	0.12	11.89	387.43
Standard Error	0.07	7.33	0.04	0.01	0.00	0.06	0.01	0.01	0.39	7.43
Median	3.51	379.32	2.23	0.51	0.05	0.42	0.06	0.07	9.94	396.35
Standard Deviation	1.28	129.52	0.66	0.25	0.04	1.11	0.10	0.14	6.86	131.16
Sample Variance	1.65	16776.39	0.44	0.06	0.00	1.23	0.01	0.02	47.12	17203.84
Range	13.02	713.65	4.10	2.04	0.33	19.43	0.52	1.06	36.59	714.72
Minimum	0.78	5.43	0.23	0.07	0.01	0.00	0.00	0.00	0.00	21.81
Maximum	13.80	719.08	4.32	2.11	0.35	19.44	0.52	1.06	36.59	736.53
Count	312	312	312	312	312	312	312	312	312	312
Confidence Level (95.0%)	0.14	14.43	0.07	0.03	0.00	0.12	0.01	0.02	0.76	14.61

Health risk

The mean daily dosage (MDD), hazard index (HI), and carcinogenic risk (CR) values were calculated based on exposure to heavy metals on agricultural land via ingesting and skin absorption pathways. Table 5 demonstrates the ADD value for both adults and children. The ADD value for children is significantly higher than that for adults, specifically about four times greater. This is because the weight of children is substantially less than that of adults (Long et al., 2021). Children are at greater risk than adults. Thus, it is vital to consider children's food intake to avoid health hazards linked to exposure to toxic metals (Zhang et al., 2021).

The mean daily dosage value via the ingestion method significantly exceeds that of the skin absorption route. The consumption route contributes to more than 99% of the total MDD of metallic elements. This indicates that the intake of harmful metals via the dietary route is the primary source of metal accumulation in the human body (Nakagawa et al., 2022).

Figure 5 shows HI levels in children and adults via ingestion and skin absorption. HI levels in children are more significant than in adults. The increased risk of exposure in children is related to children's activity patterns and faster metabolism (Jing-yu et al., 2021). An HI number greater than one suggests a non-carcinogenic danger can occur, but if the HI value is less than one, then there is no non-carcinogenic risk. Figure 5 shows that no non-carcinogenic hazards can arise.

Carcinogenic risk

The CR value for adults is 1.7751×10^{-6}, while for children, it is 7.0864×10^{-6} (Figure 6). This implies that children have a CR value seven times greater than adults. The CR values for both children and adults are still within the permissible limit, namely 1×10^{-4}. This means that children and adults are not at risk of developing cancer (Kharazi et al., 2021).

Table 5. Average daily dose and hazard quotient values.

		MDD (mean daily dosage)		**HQ (hazard quotient)**	
		Ingestion (x 10^{-6})	**Dermal (x 10^{-9})**	**Ingestion (x 10^{-3})**	**Dermal (x 10^{-6})**
Pb	Adult	6.417	25.080	1.604	6.270
	Children	25.667	49.280	6.417	12.320
Cd	Adult	0.716	2.799	2.387	9.329
	Children	2.864	5.499	9.547	18.330
Co	Adult	6.315	24.683	6.315	24.683
	Children	25.261	48.500	25.261	48.500
Ni	Adult	3.522	13.765	0.088	0.344
	Children	14.087	27.047	0.352	0.676
Cr	Adult	2.076	8.113	6.919	27.043
	Children	8.302	15.941	27.675	53.136
Cu	Adult	1.477	5.771	0.037	0.144
	Children	5.906	11.340	0.147	0.283
Mn	Adult	41.033	160.380	1.710	6.683
	Children	164.130	315.140	6.839	13.131
Zn	Adult	4.683	18.302	0.016	0.061
	Children	18.731	35.963	0.062	0.120
As	Adult	1.179	4.607	3.929	15.358
	Children	4.715	9.053	15.717	30.178

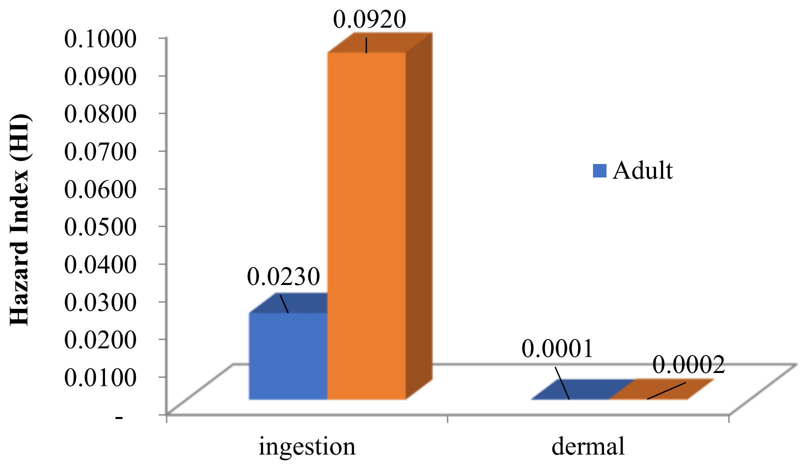


Figure 5. The value of hazard index (HI).

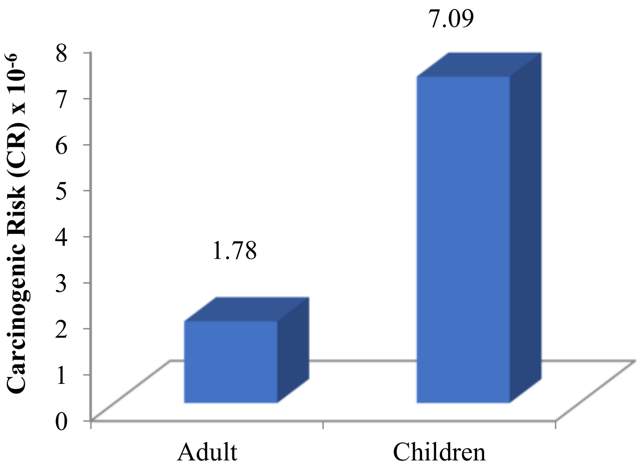


Figure 6. The carcinogenic risk value in children and adults.

Conclusion

All heavy metals tested were identified in almost all soil sampling sites, with maximum metal concentration values below the threshold limit for heavy metallic substances in topsoil. The regional distribution of Cd metal is dominated by the high-value group, namely >1.92 mg kg^{-1}. The results of the IG analysis, the Contamination Index (CI), and environmental risk suggest that cadmium is the principal cause of heavy metal contamination on farmland in Wonosobo Regency, with significant contamination values. Health risk studies demonstrate that children have more significant health risks than adults based on daily intake dose. However, both non-carcinogenic and carcinogenic hazards in both in children and adults show that there is no potential for health hazards. The accumulation of heavy metals in agricultural land in Wonosobo Regency poses significant ecological and health risks. Therefore, efforts are needed to minimize these risks and reduce heavy metal concentrations in agricultural areas.

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