Sustainable Processes Connect
ISSN: 3079-1421
2025, Vol. 1, Cite as: doi:10.x/journal.x.x.x

SCIFINITI PUBLISHING

OPEN ACCESS

Research Article

Risk Assessment of Heavy Metal Contamination in Soil for Sustainable Environmental Management in Urban and Rural Areas of Gujrat District, Pakistan

Muhammad Nadeem[1], Bhagat Suberi[1], Mujahid Farid✉[2]

[1]College of Natural Resources, Lobesa, Punakha Royal University of Bhutan, Bhutan
nadeemjarral460@gamil.com (M.N.) ORCID: 0009-0002-7075-1734; Bsuberi.cnr@rub.edu.bt (B.S.) ORCID:0000-0001-8568-9086

[2]Department of Environmental Science, University of Gujrat, Hafiz Hayat Campus, Gujrat,50700, Pakistan
mujahid.farid@uog.edu.pk (M.F.) ORCID; 0000-0003-0092-6666

Abstract

This study was conducted to assess the risk of heavy metal contamination in soil from the sample collection areas. The study aimed to determine whether soil properties such as electrical conductivity (EC), pH, and organic matter (OM) affect heavy metal concentrations in soil. Composite soil samples were collected and analyzed using Atomic Absorption Spectroscopy (AAS) for heavy metal concentrations at a depth of 0-15 cm following the order of Zn > Pb > Cd > Cu. In addition, human health risk assessments with Average Daily Dose (ADD), Hazard Index (HI), Total Hazard Quotient (THQ), and Carcinogenic Risk Assessment (CRA) were conducted for adults and children using dermal ingestion and inhalation paths. The results showed no significant correlation between heavy metal concentrations and soil physicochemical properties. Although Zn and Cu ($r = 0.62$, $p < 0.01$) and Cu and Pb ($r = 0.57$, $p < 0.01$) showed a moderately positive relation, representing common contamination sources probably from industrial actions and vehicular emissions. In addition, Zinc exhibited a low negative correlation with pH ($r = -0.28$, $p < 0.01$), signifying reduced metal availability in alkaline soils. However, the health risk assessment revealed that children in urban areas face higher contamination risks, with a Hazard Index (HI) of 0.06, compared to 0.01 in rural children. Carcinogenic risk assessment revealed that lead (Pb) and Cadmium (Cd) pose the highest risks, with cumulative risk for urban children ($CR = 1.99 \times 10^{-4}$) reaching the upper threshold of the acceptable range. These results emphasize the urgent need for pollution control measures in urban environments. Future studies could explore specific contamination pathways and remediation strategies to minimize human health risks**.** This study contributes to sustainability by identifying soil contamination risks and providing baseline data for safer land use planning. Findings support sustainable agricultural practices and informed policy decisions to protect ecosystems and human health.

Keywords

carcinogenic risk; hazard index; health risk assessment; heavy metals; soil contamination; soil properties; urban pollution

Highlights

- First comparative study assessing heavy metal contamination in both industrial estate soils and rural soils of Gujrat District Pakistan
- Integration of soil physicochemical properties (pH, EC, OM) with heavy metal concentrations to better understand contamination dynamics

- Application of statistical tools (correlation ANOVA Tukey's test) to identify significant variations and relationships in contamination patterns
- Assessment of potential health and environmental risks providing a baseline for sustainable soil and land use management
- Contribution to sustainable development goals by addressing soil quality environmental safety and long-term ecosystem health

1. Introduction

Soil pollution has become a persistent environmental concern worldwide due to rapid industrialization, urbanization, and inadequate waste management practices [1]. Additionally, heavy metal contamination has become a significant concern due to its long-lasting environmental and health impacts [2]. Heavy metals are naturally occurring elements that, in small concentrations, are important for biological processes [3]. However, when present in high concentrations, they become toxic and pose a significant threats to the environment and human health. Soil acts as a sink for these metals, accumulating pollutants over time [2]. The contamination of soil with heavy metals can have detrimental effects on cultivation, as yields grown in polluted soil absorb these metals, which then enter the food chain [4]. Long-term exposure to heavy metals can lead to chronic health consequences, including neurological disorders, cardiac diseases, and kidney loss [5]. Furthermore, once these metals are present in the soil, they are challenging to eradicate, resulting in soil contamination and persistent environmental issues [6].

In Pakistan, industrial activities have increased significantly over the past few years, contributing to economic growth but also leading to severe environmental deterioration. Gujrat, a major industrial hub in Punjab province of Pakistan, is home to a diverse range of industries, including textiles, ceramics, electrical machinery, and steelwork. These industries, although important to residents economically, are the primary sources of contaminants containing heavy metals such as cadmium (Cd), lead (Pb), nickel (Ni), and chromium (Cr) [7]. These metals enter soil through several pathways, including atmospheric deposition solid waste disposal, and irrigation with contaminated water [8]. As a result, the soil in nearby areas, primarily in the city's peripheral regions, has become gradually polluted [9]. Although the Kalra Kalan and River Garden Housing Scheme are two peripheral regions situated near the industrial estate of Gujrat, these areas are in proximity to both agricultural lands and an industrial zone. Numerous people in these zones rely on locally grown crops for their livelihood and daily subsistence, raising concerns about the accumulation of heavy metals in their food chain [10].

Investigating the level of contamination in the study area is vital for improving effective mitigation plans. Thus, this study aimed to evaluate the level of heavy metal contamination in the soil of these two peripheral regions and assess the related hazards to human health and the surrounding environment. Additionally, the present study focuses on concentration levels of definite heavy metals in the soil and comparing them to internationally recognized safety thresholds, such as those established by the US Environmental Protection Agency (EPA) and the World Health Organization (WHO). Permissible limits of WHO in soil for selected metals Lead (Pb) 10mg/kg, Cadmium (Cd) 0.8 mg/kg, Zinc (Zn) 300 mg/kg, Copper (Cu) 100 mg/kg. Cd and Pb are highly limited due to toxicity [11]. This is not only aimed at resident representatives and environmental agencies but also global frameworks concerned with environmental sustainability and public health.

Although the country is facing numerous challenges in treating its industrial waste, many industrial units lack adequate handling facilities. As a result, hazardous unused chemicals are frequently discharged directly into the environment, leading to contamination of nearby soil, water, and air [12]. Thus, the present study of Kalra Kalan and the River Garden Housing Scheme has greater importance mainly because these regions are illustrative of several other peripheral areas located near industrial estates across Pakistan.

This study aimed to fill that gap by providing valuable information on the concentration of heavy metals in soil, as well as the possible risks posed at the local level. Evaluating soil samples for heavy metal concentrations also aligns with worldwide protection standards and study goals to assess the level of pollution and its potential effects. The findings offer profound insights for environmental representatives of industrial shareholders, as well as local groups, enabling them to take necessary actions to mitigate threats of heavy metal contamination while protecting both environment and human health.

The differentiation of this research is its comparative evaluation of the heavy metal contamination in urban as well as rural soils which is in surrounding of industrial estate area of Gujrat. By the incorporation of health risk assessments in different exposure pathways, the study provides complete understanding of pollution dynamics. The findings are focused to deliver specific contextual guidance for the sustainable soil management and to support the effective pollution control strategies in the affected industrial areas of Pakistan.

2. Materials and methods

2.1 Study area

The study was conducted in two peripheral areas of the industrial estate in Gujrat, Pakistan: Kalra Kalan agricultural land (rural) and the River Garden Housing Scheme (urban) (Figure 1). The district lies at an intersection of 74.07° E and 32.57° N, where the study areas extend between 32.57° N and 32.54° N; 74.01° E and 74.08° E. The temperature ranges between 20 °C and 50 °C, where the average annual precipitation of the study area is 670 mm. The urban study area (River Garden) is located 22.1 km from the central city of Gujrat, while the rural area (Kalra Kalan) is 16.4 km away.

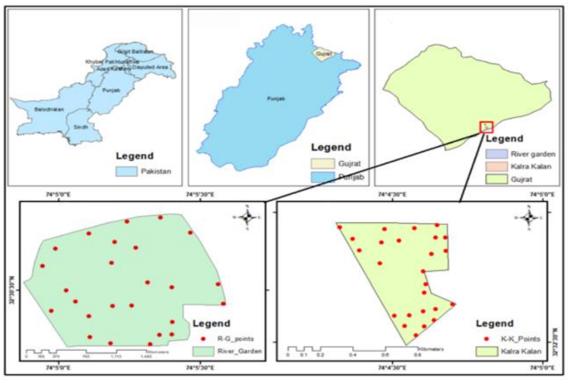

Figure 1: Study area to accurately describe the rural (Kalra Kalan) and urban (River Garden) sampling sites.

2.2 Sampling design

A total of 597 ha of sampling area was considered for the study, consisting of 331 ha from the urban area and 266 ha from the rural area. The areas were divided into 50 quadrants. A systematic random grid composite soil sampling technique comprising 50 composite samples, each from two areas (rural = 25 and urban = 25), was considered using ArcGIS.

2.3Collection of soil samples

Each quadrant of 50 samples was further divided into five smaller units for the sample collection. The soil samples were collected using a stainless-steel auger from 0-15 cm depth of soil [13]. Samples from five quadrats were mixed to make a composite. A total of 50 composite samples were collected and analyzed for heavy metal concentrations. The soil samples werestored in sealed plastic bags and transported to the laboratory for further analysis. All soil samples were air dried before chemical analysis [14].

2.4 Analytical techniques for heavy metal detection (Cd, Cu, Zn, and Pb)

One gram of each air-dried and sieved soil sample was ashed in a muffle furnace at 460 °C for 24 hours. The ash was digested in 10 mL of Aqua regia (1:3 conc. HNO_3:HCl) on a heating block following a sequential temperature program: 2 hours at 25°C, 2 hours at 60°C, and 5 hours at 125°C . The process took a total of nine hours to complete. However, after digestion, the digests were first centrifuged and then made up to volume with 10% HNO_3. Additionally, standard solutions for each element were prepared in 10% HNO_3. The concentrations of different heavy metals in diluted digests were measured by an atomic absorption spectrophotometer (Model No. AA-6300 SHIMADZU) [15]. Furthermore, the rest of the soil samples were taken for physicochemical analyses after the removal of coarse soil components. All samples were run in triplicate to ensure reliability, accuracy, and representativeness of results, thereby minimizing random errors and accounting for small-scale heterogeneity within the sample [16].

2.5 Statistical analysis

All statistical analyses were performed using SPSS (Version 20 Inc, Chicago, IL, USA), and Microsoft Excel (Version 16). The normality of data distribution was tested using Shapiro-Wilk test, which is more appropriate for small to medium sample sizes ($n < 200$). As dataset satisfied assumption of normality parametric tests were applied for subsequent analyses [17]. Descriptive statistics (mean and standard deviation) were calculated to summarize heavy metal concentrations and soil properties. To compare mean differences in metal concentrations across different sampling points a one-way Analysis of Variance (ANOVA) was conducted followed by Tukey's post hoc test to identify pairwise differences [18]. To examine relationships between soil properties substances, and heavy metal contents we used Pearson's correlation coefficient which is a parametric measure suitable for normally distributed data. For each correlation, statistical significance (p-value) was computed to test null hypothesis that $r = 0$ [19]. Non-parametric tests (such as the Mann-Whitney U test) were initially considered as alternatives if normality assumptions were not met. However, since data met assumptions, they were not applied in final analyses.

2.6 Extraction of soil physicochemical properties

The pH of the soil was tested using a calibrated pH meter (HANNA PH Meter Hi98106). A 10 g of air-dried soil and 25 ml of deionized water were combined in a soil-to-water ratio (1:2.5) for every composite sample [20]. Soil organic matter (SOM) content was determined using the Loss on Ignition (LOI) method. This procedure involved weighing around 5 g of dry dirt and then heating it to 550 °C for 4 hr in a muffle furnace. The weight loss after combustion represented the amount of organic matter burned off. The percentage of Soil Organic Matter (SOM) was calculated by;

SOM%= ((Wcs-Wf)/ Wcs –Wc)) ×100…………………………………………………………1

Where, Wcs = The weight of oven-dried soil as well as the crucible

Wf = The weight of the fire sample of the furnace and crucible

Wc = The weight of the crucible

All samples were run in triplicate to ensure the reliability, accuracy, and representativeness of the results, thereby minimizing random errors and accounting for small-scale heterogeneity within the sample [16]. An EC meter (WTW inoLab Cond 720) was used to evaluate the Electrical Conductivity (EC) of soil samples to determine the salinity levels of the soil, which affect the mobility of heavy metals. Thus, 10 g of dirt and 50 ml of deionised water were combined to create a (1:5) soil-to-water suspension to measure the electrical conductivity (EC). After stirring, the mixture was left to settle for half an hour. The conductivity (dS/m) was then recorded by submerging the EC meter probe in the solution [20]. However, the hand texture method was used to assess the soil texture of samples collected from urban and rural areas [21].

2.7 Human health risk assessment

The human health risk was assessed for both rural and urban areas by calculating the Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI), and Lifetime Carcinogenic Risk (LCR) [22,23,24].

2.8 Average Daily Dose

The average daily dose for three phases was calculated, which includes Ingestion (ADDing), Inhalation (ADDinh), and Dermal Contact (ADDderm) in mg/kg/day of heavy metals (Cu, Zn, Pd, and Cd).

$ADDing=C\times(IR \times EF \times ED)/(BW \times AT) \times 10^{-6}$……………2

$ADDinh=C\times(InhR \times EF \times ED)/(PEF \times BW \times AT)$…………….3

$ADDderm=C\times(SA \times AF \times ABF \times EF \times ED)/(BW \times AT) \times 10^{-6}$………4

Where, C = The concentrations of heavy metals (mg/kg)

IngR = The rate of Ingestion in mg/day (100 for adults also 200 for children)

ED = A duration of exposure (24 years for adults and 6 years for children)

Bw = The average body weight (children 15 kg and adult 70 kg)

AT = The average time (365 × ED)

InhR = The inhalation rate in mg/cm2 (20 for both adults and children)

PEF = The particles emission factor in m3/kg (1.36 × 109; both for adult and children)

SA = The surface area of exposed skin in cm2 (2145 for adult and 1150 for children)

AF = The skin adherence factor for soil in mg/cm2 (0.007 for children and 0.20 for adults)

ABF = The dermal absorption factor (As = 0.03 and 0.001 for other metals)

EF Exposure frequency (days per year)
IR Inhalation Rate

CSF Cancer slope factor
THQ Total hazard quotient

Pb, Cd, Zn, and Cu were designed by using the formula mentioned above for soil.

However, the Ingestion Rate (IngR) of water was 2.2 l/day for adults and 1.5 l/day for children, where EF was 365 days/year, and SA was 5700 cm^2 [25,24]. The rest of the parameters were the same as mentioned in the above equation.

2.9 Total Hazard Quotient and Index

THQ=(ADD (Ingestion,Inhalation or Dermal))/RfD…………5

The ratio of THQ represented the ADD in all three phases of exposure. The Chronic Reference Dose (RfD) for each metal, expressed in mg/kg/day, was used to estimate the no carcinogenic risk. A Hazard Quotient (HQ) value > 1 indicates a potential health risk.

The Hazard Index (HI), calculated as the sum of all HQs, was used to assess the total non-carcinogenic risk potential of different contaminants by the three phases. However, there was a chance of carcinogenic effects happening if the (HI > 1), and chance increased with an increasing value of HI. Rfd in mg/kg body weight (BW)/day for Cu, Pd, Cd, and Zn, whereas a significant THQ > 1 health risk (Table 1).

Table 1: Standard reference dose factor and cancer slope factor for both study areas

Metals	Rfd (mg/kg/day)	CSF (mg/kg/day)
Zn	0.3	N/A
Pb	0.0035	0.0085
Cd	0.001	0.38
Cu	0.04	1.7
Metals	**Urban**	**Rural**
Zn	13.54	1.24
Pb	23.47	5.63
Cd	1.91	0.06
Cu	16.99	4.36

HI= ∑ HQ (HQing + HQinh + HQderm)·······6

2.10 Risk assessment of carcinogenic

LCR = ADD (Ingestion,inhalation,or dermal) × CSF…7

LCR= ∑ Cancer RISK (CANCER RISKing1 + CANCER RISKing2 + CANCER RISKier3)···8

Lifetime exposure to cancer risk from Cd, Cu, Pd, and Zn was calculated as a health risk through the cumulative life cancer risk rating, using a formula for each phase's exposure. The CSF cancer risk slope factor is (Table 1) for each metal, corresponding to the three phases of exposure pathways. Whereas LCR < 10^{-6} indicates a negligible carcinogenic risk; LCR > 1 × 10^{-4} indicates a high risk; and a value between 1 × 10^{-6} and 1 × 10^{-4} is generally considered an acceptable or tolerable risk [26].

The average of three replicates of the data collected from each treatment in experiment was calculated. Using the Statistics 10.0 version, an Analysis of Variance (ANOVA) was used and data were generated using Tukey's post hoc test among mean values of treatments to identify significant variation (Table 2 & Table 3).

3. Results

Table 2: Urban River Garden (average concentration of heavy metals (mg/kg).

Site	Zn	Pb	Cd	Cu
1	7.23 p	17.88p	0.42b	7.05u
2	7.55 p	18.45o	1.02ab	7.79uv
3	8.37 o	19.04n	1.61ab	8.62tu
4	9.22 n	19.69m	2.15ab	9.45st
5	9.53 n	20.15m	2.81ab	10.28rs
6	10.54 m	20.92l	2.61ab	11.11qr
7	11.12 l	21.59k	1.27ab	11.94pq
8	11.54 l	22.34j	2.17ab	12.77op
9	12.29 k	22.72j	1.78ab	13.60no
10	13.03 j	23.56i	2.09ab	14.43mn
11	13.55 ij	24.28h	2.41ab	15.27lm
12	14.11 i	24.85g	2.15ab	16.10kl
13	14.70 h	25.42f	2.02ab	16.93jk
14	15.31g	26.13e	2.57ab	17.76ij
15	15.81 fg	26.39e	2.05ab	18.59hi
16	16.37 f	27.30d	2.06ab	19.42gh
17	17.10e	28.0c	2.10ab	20.25fg
18	17.62 e	28.18bc	3.01a	21.08ef
19	18.35 d	28.66ab	2.07ab	21.91de
20	18.85 cd	29.02a	2.05ab	22.74cd
21	19.36 bc	17.96op	2.03ab	23.58c
22	19.72 ab	19.15n	1.76ab	23.74c
23	20.00 a	21.45k	1.07ab	25.24b
24	7.64 p	24.99fg	0.37b	26.29b
25	9.51 n	28.75a	2.04ab	28.80a

Representing the means of three replicates (HSD) of the urban area at (0-15 cm soil depth); small letters indicating significance ($p < 0.05$) level

Table 3: Rural Kalra Kalan (average concentration of heavy metals (mg/kg).

Site	Zn	Pb	Cd	Cu
1	1.53a	4.27a	0.03c	0.23p
2	1.45a	4.25a	0.04bc	0.59op
3	0.88a	4.51a	0.04bc	1.05no
4	1.66a	4.86a	0.06abc	1.53mn
5	0.68a	5.29a	0.07abc	2.05lm
6	0.53a	5.14a	0.08abc	2.65jkl

7	0.68a	5.60a	0.09abc	3.35hij
8	1.06a	5.87a	0.07abc	3.43hi
9	1.89a	6.10a	0.08abc	4.05gh
10	1.78a	6.34a	0.09ab	4.48g
11	1.05a	6.29a	0.06abc	5.45f
12	1.04a	6.93a	0.03c	5.60f
13	1.26a	6.17a	0.04bc	6.05ef
14	2.40a	4.46a	0.03bc	6.52de
15	0.85a	5.01a	0.04bc	7.05d
16	1.35a	5.65a	0.05abc	7.25d
17	1.55a	5.03a	0.05abc	8.04c
18	1.27a	5.45a	0.06abc	8.68bc
19	1.36a	5.97a	0.08abc	9.05ab
20	1.66a	7.21a	0.08abc	9.42a
21	1.99a	6.58a	0.07abc	0.56op
22	1.05a	5.86a	0.11a	1.43mn
23	0.96a	6.57a	0.03bc	2.60kl
24	0.61a	6.12a	0.04bc	3.25ijk
25	0.59a	5.27a	0.06abc	4.57g

Representing the means of three replicates (HSD) of the rural area at (0-15 cm soil depth); small letters indicating significance ($p < 0.05$) level

The soil of urban areas had a pH of 7.70 ± 0.25 SD. In contrast, the pH level in rural soil was 6.87 ± 0.30 SD, which is close to the neutral pH level. . In addition, the Electrical Conductivity (EC) value in urban soil was 2.20 dS/m ± 0.08 SD. Rural soils had a slightly lower EC (2.06 dS/m ± 0.08 SD. The Soil Organic Matter (SOM) in urban soil showed 3.71% ± 0.05 SD, and the rural soils displayed 3.43% ± 0.08 SD, which is slightly lower than in urban regions (Table 4).

Table 4**: Soil physicochemical properties of the two study areas**

Depth	**Test**	**Urban (N = 25) (Mean ± SD)**	**Rural (N = 25) (Mean ± SD)**
0-15 cm	pH	7.70 ± 0.25	6.87 ± 0.30
	EC (dS/m)	2.20 ± 0.08	2.06 ± 0.11
	SOM (%)	3.71 ± 0.05	3.43 ± 0.08

The variances in soil texture distribution differed as well between urban and rural regions at 0-15 cm depths (Figure 2). Urban soils exhibited a higher frequency of clay loam and silt loam compared to rural soils, as silt loam was three times more common, and clay loam appeared twice as often in urban samples. Similarly, in rural areas, both soil types occurred at approximately the same frequency.

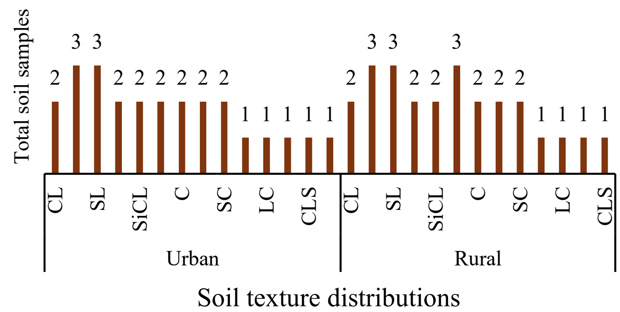

Figure 2: Count of soil texture in urban and rural areas within 0-15 cm depth; (SL = Sandy loam, SiCL = Silt clay loam, CL = Clay loam, CLS = Sandy clay loam)

The same order of average metal concentrations was observed in both rural and urban areas (Zn > Pb > Cd > Cu); however, the concentrations in urban areas were significantly higher-ranging from at least (13.53 mg/kg ± 4.19 SD,)-(Zinc (Zn)) up to (23.47 mg/kg ± 3.72 SD, 16.98 mg/kg ± 6.23 SD) (Pb (Lead, Cu, Copper) the mean Cadmium (Cd) showed similar concentration in urban soils (urban = 1.90 mg/kg ± 0.65 SD and rural = 0.06 mg/kg ± 0.02 SD) compared to rural areas (Cu,4.35 mg/kg ± 2.83 SD, , 5.63 mg/kg ± 0.82 SD) (Table 5).

Table 5: Concentration of heavy metals in the soil in both rural and urban areas (mg/kg)

Depth	**Test**	**Urban (N = 25) (Mean ± SD)**	**Rural (N = 25) (Mean ± SD)**
0-15 cm	Zn	13.53 ± 4.19	1.24 ± 0.48
	Pb	23.47 ± 3.72	5.63 ± 0.82
	Cd	1.90 ± 0.65	0.06 ± 0.02
	Cu	16.98 ± 6.23	4.35 ± 2.83

An independent samples t-test showed that the total heavy metal concentration in urban soil (M = 138.03±13.02) was significantly higher than in rural soil (M = 62.97±6.51), $p < .001$ (Table 6).

Table 6: Comparison of heavy metal concentration in urban and rural areas

Area	***Mean***	***p***
Rural	62.97±6.51	.00
Urban	138.03±13.02	

* Correlation is significant at the 0.05 level (2-tailed)

The correlation analysis revealed a significant moderate positive relation (r = .46, p < .05) between Cu and SOM content in rural areas (Table 7). However, Pb and Zn showed a weak positive relation (r = .18, p = .00). In addition, Soil Organic Matter and Electrical Conductivity indicated a weak positive relation (r = .33, p = .00). A significant moderate positive correlation was observed between Cu and Zn (r = .62, p < .01). Similarly, a significant positive relation was found between Cu and Pb (r = .57, p < .01). While pH indicated a weak relation compared to other variables, a positive relation between EC and pH (r = .28, p = .00) was observed, showing that regions with high salinity typically have slightly more alkaline soils. Zinc and pH showed a weak negative relation (r = -.28, p = .00), indicating that the concentration of heavy metals decreases in more alkaline soils. However, the relation between Zinc and Soil Organic Matter was observed to be weak negative (r = -.29, p = .00), indicating organic matter limits the availability or mobility of Zinc in rural soil. Similarly, Cu and Cd (r = .36, p = .00) Pb and Cd (r = .34, p = .00) showed a weak positive relation.

Table 7: Correlation matrix between soil physicochemical properties and heavy metal concentration of rural areas (N = 25)

Parameters	pH	EC	SOM	Zn	Cd	Cu
pH	1					
EC	0.05	1				
SOM	.33	0	1			
Zn	.18	.18	-.19	1		
Pb	0.05	.31	.29	0	1	
Cd	.126	.14	-.14	-.03	.33	1
Cu	.11	.30	0. 46*	.16	.31	.02

* Correlation is significant at *.05* level (2-tailed)

Correlation between heavy metal concentration and soil physicochemical properties was observed in the urban area (Table 8). A significant moderate positive correlation was found between Cu concentration and Zn (r = .62, p < .01) in the urban soil of Gujrat. In addition, a significant positive moderate relation was observed between Cu concentration and Pb (r = .57, p < .01) in the study area.

2025, Vol. 1, Issue 1
doi:10.x/journal.x.x.x

Table 8: Correlation matrix between soil physicochemical properties and heavy metal concentration of urban areas (N = 25)

Parameters	pH	EC	SOM	Zn	Cd	Cu
pH	1					
EC	.28	1				
SOM	.27	.07	1			
Zn	-.28	.00	-.30	1		
Pb	-.03	.04	.22	.39	1	
Cd	-.19	-.20	-.05	.34	.36	1
Cu	.10	.18	.08	.62**	.57**	.02

* Correlation is significant at *.05* level (2-tailed)

The calculated Hazard Index (HI), which represented the cumulative non-carcinogenic risk, was found to be 0.06 for children and 0.01 for adults (Table 9).

Table 9: The Reference Doses (RfD) and Cancer Slope Factors (CSF) for various heavy metals, along with values for urban and rural areas

Metal	RfD	CSF	Urban	Rural
Zn	0.3	N/A	13.54	1.24
Pb	0.0035	0.0085	23.47	5.63
Cd	0.001	0.38	1.91	0.06
Cu	0.04	1.7	16.99	4.36

The human health risks associated with heavy metal pollution were measured in both rural and urban areas The contact risks for adults and children were assessed by calculating the Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI), and the Carcinogenic Risk calculation (CR). The ADD for metals was estimated using three phases of exposure, expressed in mg/kg/day HI values for any assumed metal overall soil contact pathways were less than 1, indicating significant health risks. However, urban children (0.0606) exhibited a markedly higher HI value compared to rural children (0.0119) (Table 10).

Table 10: Referene Doses (RfD) and Cancer Slope Factors (CSF) of heavy metals usedin the risk assessment study of (Zn, Pb, Cd, and Cu).

Zn	Pb	Cd	Cu
Average Daily Dose (for children)			
9.03×10-05	0.00015654	1.27E-05	0.00011332
8.27E-06	3.76E-05	4.00E-07	2.91E-05
Average Daily Dose (for adult)			
9.48E-06	1.64E-05	1.34E-06	1.19E-05
8.68E-07	3.94E-06	4.20E-08	3.05E-06
Total Hazard Quotient (for children)			
0.00030104	0.04472711	0.0127397	0.00283308
2.76E-05	0.01072917	0.0004002	0.00072703
Total Hazard Quotient (for adult)			
3.16E-05	0.004694	0.001337	0.00029733
2.89E-06	0.001126	0.000042	0.0000763
Carcinogenic Risk Assessment (for children)			
N/A	1.33E-06	4.84E-06	0.00019265
N/A	3.19E-07	1.52E-07	4.94E-05
Carcinogenic Risk Assessment (for adult)			
N/A	1.40E-07	5.08E-07	2.02E-05
N/A	3.35E-08	1.60E-08	5.19E-06
Hazard Index		Cancer Risk	
HI (for children)	HI (for adult)	CR (for children)	CR (for adult)
0.06060094	0.00635992	0.00019882	2.09E-05
0.01188397	0.00124719	4.99E-05	5.24E-06

4. Discussion

4.1 Soil physicochemical properties

Overall, the pH level in the urban area was slightly alkaline. However, the pH of rural soil was slightly lower than in urban zones at the same depth. The pH levels showed a notable difference between urban and rural regions, representing potential variations in soil chemistry. In alkaline soils, the availability of heavy metals like lead (Pb) typically decreases, which reduces their mobility and potential for bioaccumulation. However, the near-neutral pH of rural area soils may promote a balanced nutrient profile, enhancing agricultural yield and biodiversity [27]. The lower pH in rural soil may be attributed to reduced human influence, allowing natural soil-forming processes to prevail [28]. However, a relatively high pH in urban soil may also impact the solubility and mobility of heavy metals [29].

Furthermore, higher EC levels were observed in urban soils, which could be attributed to various urban activities, including road construction, industrial waste, and atmospheric deposition of pollutants. Thus, greater EC may affect soil bacterial groups, inducing nutrient cycling and the breakdown of organic matter [30]. Additionally, the higher EC in the soil can influence the availability and mobility of heavy metals, and these can induce osmotic stress in plants, thereby inhibiting their growth [31]. High EC measurements revealed that soil salinity has adverse effects on plants and soil fertility [32]. Furthermore, urban lands, due to their lower vegetation and increased impermeable surfaces, hinder the natural leaching of salts, which can lead to increased soil salinity. Conversely, elevated SOM in polluted urban soils can form soluble complexes with heavy metals, potentially increasing their mobility and bioavailability to plant roots [33].

Urban soils exhibited higher soil organic matter (SOM), which may be attributed to the accumulation of organic waste and reduced microbial decay in compacted soils. Organic matter can also enhance metal mobility in contaminated soils, raising concerns in urban settings with heavy metal pollution [34]. In rural soils, adequate organic matter supports sustainable agricultural practices by improving soil fertility and stability. In rural areas, soils with a suitable amount of soil organic matter (SOM) maintain agricultural soil fertility, enhance plant growth, and support microbial communities [24]. The urban soil texture is characterised by a higher proportion of sand, resulting in quicker drainage and lower water-holding capacity [35]. Rural soils exhibited a higher content of silt and clay, thereby enhancing their water-retaining and nutrient-holding capacity [36]. Several soil surveys in Gujrat have revealed that the soil texture is predominantly clay loam across both rural and urban landscapes. Thus, soil physicochemical properties provided valuable information for understanding the soil texture in the study area.

4.2 Heavy metal concentration in the soil

The selection of Zn Pb Cd and Cu was based on their prevalence in industrial emissions persistence in soils and well documented toxicity. In Gujrat district industries such as ceramics metal plating and battery manufacturing are major sources of these metals. While Zn and Cu are essential micronutrients, they become toxic at elevated levels whereas Pb and Cd are highly toxic even at low concentrations and pose serious risks to human health. Their persistence and potential transfer into food chain further justify their inclusion for assessing ecological and human health risks. Thus straight supporting study's aim.

These results demonstrated transparent urban-rural gradients, with both Cd and Cu showing their highest concentrations in urban soil. However, the rural soil samples were collected from areas where dominant agricultural practices and agricultural runoff were prevalent; levels of concentrations of each heavy metal were higher in urban soil [37]. The high concentration of these metals in urban soil is likely due to proximity to industrial sites and high traffic, with pollutants originating from sources such as automobile tire wear and brake lining degradation [38]. Rural soil samples showed lower Zn levels, probably because of less contact with primary Zn sources [39]. However, Zinc (Zn) may only be available from natural soil resources or in small quantities presented through fertilisers in rural soil [40]. Although, Zn is a crucial element for flora, fauna, and environmental effects, it is also associated with health effects. Thus, many concentrations can be poisonous, such as high Zn levels, which disrupt nutrient cycling and alter soil microbial communities, affecting ecosystem sustainability [41,42]. Reported a Zn concentration (0.07 to 5.60 mg/kg) in the area, which is significantly lower compared to the present study.

Lead (Pb) contamination in urban areas was often linked to vehicular emissions, particularly from older automobiles that had used leaded gasoline, as well as emissions from industrial activities. In addition, Pb can be found in urban dust, construction debris, and waste disposal areas, all of which contribute to soil contamination [43]. In rural soils, the concentration of Pb was observed to be comparatively low, which may be due to the use of agricultural fertilisers or minor atmospheric deposition. Lead (Pb) is highly toxic, posing significant environmental and health risks, especially to children and pregnant women. Additionally, the accumulation of heavy metals in plants and animals that enter the food chain leads to long-term health effects [44].

The high Cadmium (Cd) concentration observed in urban soil is likely associated with manufacturing activities in the metal refining and battery industries, as well as the disposal of waste [45]. Although Cd is usually introduced into the soil through industrial processes and the use of several fertilisers [46]. Cd concentration in rural areas is less compared to urban soil. Plants can absorb Cd, particularly leafy vegetables, where the human body accumulates Cd from plants, which affects sensitive parts of the human body, such as kidneys and bone [47,48]. The impacts of Cd are very toxic and possibly lead to health effects for humans by consuming untreated products and commodities.

The concentration of Copper (Cu) in urban zones, observed to be higher, could be due to industrial effluents, as well as automobile brake wear. Although rural soils have low concentrations, over time, copper can be added to agriculture through certain fungicides and fertilisers. However, copper (Cu) is a vital micronutrient for both plants and animals; excessive concentrations can become toxic and have adverse effects on plant growth as well as soil organisms [49]. Excessive levels of Cu in human body intake through impure soil production substances cause kidney and liver damage [50].

4.3 Comparison of heavy metal concentration

The normality tests of the data revealed a more substantial deviation from normality (p = .00) in rural samples compared to urban samples. Although urban areas showed less variability due to more evenly distributed sources (vehicular releases and construction activities), the rural areas exhibited greater variability due to inconsistent application of fertilisers or pesticides [51].

4.4 Concentration of heavy metals between urban and rural areas

A gradual increase in variation among Zn, Pb, Cd, and Cu is observed at soil depths of 0-15 cm in urban areas. However, Zn, Pb, Cd, and Cu in rural soil showed less variation at the same soil depths of 0-15 cm in urban areas [52].

4.5 Correlation between soil physicochemical properties and heavy metal concentration of rural area

Although organic matter plays a vital role in retaining heavy metals and binding them, thereby increasing their bioavailability and reducing metal movement in the soil [53]. The results suggested that high content of Organic Matter in the rural soil was associated with high salinity levels [54]. Also reported that high EC values affect soil fertility and water retention capacity. However, the pH of rural soil had no significant impact on the behaviour of heavy metals. Due to the stability of pH remaining in the region, it produced a direct limiting effect on the mobility and solubility of metals [55]. In rural areas, Zinc, Lead, and Cadmium appear less influenced by soil properties than organic matter. The overall effect of pH and EC is not stronger on heavy metals than on other soil properties. In the urban area, it was suggested that there is no significant relation, but rather a weak relation, between OM and EC. It also showed that organic content has a limited influence on metal mobility or retention in urban areas [56].

4.6 Correlation between soil physicochemical properties and heavy metal concentration of urban area

However, Cadmium concentration was found to be highly apparent compared to other soil chemical properties, which could be due to urban area contamination sources having a greater influence on Cadmium. It was indicated that there was a weak influence of pH and organic matter on heavy metal concentration. On the other hand, there was a notable relation between Zinc and lead, which possibly shared the same sources of contamination, such as industrial automobile pollution.

4.7 Risk Index Assessment of heavy metals in the rural and urban areas

The Assessment of non-carcinogenic health risks indicated that studied areas are currently somewhat safe from adverse effects stemming from the combined exposure to Cu, Cd, Pb, and Zn. Both of these values are substantially below the safety threshold of 1.0, a limit established by regulatory bodies [57]. Suggesting that non-carcinogenic health impacts are unlikely for either population group [58]. The individual Total Hazard Quotients further support this conclusion for each metal, which also remained below the risk threshold, indicating a low probability of harm from any single contaminant.

4.8 Human health risk assessment in rural and urban areas

The contact risks for adults and children were assessed by calculating the Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI), and the Carcinogenic Risk calculation (CR). The ADD for metals was estimated using three phases of exposure, expressed in mg/kg/day. For both children and adults, the average daily dose (ADD) followed the order of ingestion > dermal contact > inhalation. However, among children, the highest dose of all metals in the soil was found in Ingestion and Dermal Absorption, whereas Ingestion was greater in adults. This may be a result of children's unique behaviour through skin contact, notably hand-to-mouth contact [24].

4.9 Total Hazard Quotient and Index

The HQ tendency was detected in children as well as in adults in same order: HQ ingestion> HQ dermal> HQ inhalation. For all exposure pathways, the HI values for both children and adults were less than 1, indicating that significant non-carcinogenic health risks are unlikely. However, urban children (0.0606) exhibited a markedly higher HI value compared to rural children (0.0119). The HI for adults remains below hazardous levels but is relatively higher in urban locations.

4.10 Assessment and comparison of Carcinogenic Risk in urban and rural areas

Lifetime exposure to cancer risk from Cd, Cu, Pd, and Zn was calculated using cumulative lifetime cancer risk calculations, which presented valuable information from a health perspective. The Cancer Slope Factor (CSF) for each metal generated valuable insight, covering the three phases of exposure pathways.

In contrast, the carcinogenic risk assessment revealed a notable concern, particularly for children. While the lifetime cancer risk for adults was calculated to be 4.99×10^{-5}, falling within the generally acceptable risk range of 10^{-6} to 10^{-4}, the risk for children was significantly higher [59]. This could be due to industrial development, road traffic discharges, and waste removal practices in urban environments. In addition, Children in urban areas showed a higher cancer risk, particularly from Lead and Cadmium [26]. The cumulative Cancer Risk (CR) for children reached 1.99×10^{-4}, a value that lies at the upper boundary of the acceptable range. This elevated risk, which translates to approximately two potential additional cancer cases per 10,000 children, underscores their heightened vulnerability to carcinogenic substances and highlights a possible public health issue that may require preventative action, a finding consistent with global child health concerns [60].

5. Conclusions

This study provided a critical risk assessment of heavy metal contamination in the soil of two peripheral areas of Gujrat, Pakistan, revealing a significant disparity between urban and rural environments. The research confirmed that urban soil in the River Garden Housing Scheme is significantly more polluted than the agricultural soil in Kalra Kalan, with markedly higher concentrations of Zinc (Zn), Lead (Pb), Cadmium (Cd), and Copper (Cu). The contamination pattern for both areas followed the sequence Zn > Pb > Cd > Cu, with urban concentrations of Pb and Cd being approximately four times and three times higher, respectively than those in rural areas. These results suggest that industrial activities and vehicular emissions are the primary contributors to the contamination gradient, as evidenced by correlations between specific metals.

The human health risk assessment yielded divergent outcomes for non-carcinogenic and carcinogenic risks. The non-carcinogenic Hazard Index (HI) for the studied metals was found to be 0.06 for children and 0.01 for adults, both of which are well below the safety threshold of 1.0, suggesting adverse non-carcinogenic health effects are unlikely for the population. However, the Carcinogenic risk (CR) assessment reveals a significant public health concern, particularly for children, whose cumulative risk ($CR = 1.99 \times 10^{-4}$) reached an unacceptable level. This elevated risk, equivalent to two potential cancer cases per 10,000 children, is predominantly driven by exposure to Pb and Cd in the urban environment, with Ingestion being the primary exposure pathway. In conclusion, while immediate non-carcinogenic threats appear minimal, the unacceptable level of carcinogenic risk for children highlights the urgent need for targeted interventions to control pollution sources and mitigate human exposure in the urban periphery of Gujrat.

Given the significantly higher heavy metal concentrations in urban areas attributed to industrial and traffic sources, it is recommended that local and national environmental protection agencies enforce stricter regulations on industrial waste disposal and emissions in Gujrat. Continuous monitoring of soil quality in areas adjacent to industrial estates and high-traffic roads should be institutionalised to track pollution trends and ensure compliance. Due to the elevated carcinogenic risk for children, particularly through Ingestion, public health initiatives are crucial. It is recommended to develop awareness programs for communities in high-risk areas, such as the River Garden Housing Scheme, to educate them on dangers of heavy metal exposure and promote simple mitigation practices including washing hands, cleaning vegetables grown in local soil, and reducing children's direct contact with contaminated soil. The study identified Lead (Pb) and Cadmium (Cd) as the primary drivers of carcinogenic risk. Therefore, it is recommended that site-specific remediation strategies be explored for hotspots within the urban area. Techniques such as phytoremediation, which uses plants to extract or stabilise metals, could be investigated as a cost-effective and environmentally friendly approach to reduce the bioavailability of these toxic elements in the soil. To develop more effective mitigation plans, further research is recommended to precisely identify the specific contamination pathways from industrial and urban sources to the soil. Future studies should also analyse the concentration of heavy metals in locally grown food crops to quantify the dietary risk to residents, as this is a primary route for heavy metals to enter the human food chain. The results highlight importance of sustainable soil management and pollution control in industrial and rural areas. By guiding policymakers and communities, this research contributes to achieving long-term environmental sustainability and public health protection.

Limitations of Study

- Only four heavy metals (Zn, Pb, Cd, Cu) were analyzed excluding others.
- Dietary exposure through crops and water was not included.
- Sampling was limited to surface soils (0–15 cm) and selected sites.
- Seasonal and temporal variations in contamination were not considered.
- Risk assessment relied on standard models not fully capturing local conditions.

Practical Implications

- Provides baseline data to guide soil quality monitoring and management in industrial and rural areas.
- Helps policymakers design effective regulations to control industrial heavy metal emissions.
- Supports development of targeted soil remediation and risk reduction strategies.
- Informs local communities and farmers about potential health risks, promoting safer agricultural practices.

Future Recommendations

- The findings highlight urgent need for stricter regulatory monitoring of heavy metal emissions from industrial estates.
- Results can guide policymakers in developing soil remediation and waste management strategies.
- Awareness campaigns and community engagement are essential to reduce human exposure risks.
- Future research should explore crop uptake pathways and long-term ecological impacts to support sustainable land use planning.

List of abbreviations

AAS	Atomic Absorption Spectroscopy
THQ	Total Hazard Quotient
ADD:	Average Daily Dose
CR:	Carcinogenic Risk
EC:	Electrical Conductivity
EPA:	Environmental Protection Agency
HI:	Hazard Index
HQ:	Hazard Quotient
IR	Integrated Risk
SOM:	Soil Organic Matter
pH:	Potential of Hydrogen
SPSS:	Statistical Package for the Social Sciences
WHO:	World Health Organization
SD:	Standard Deviation
HSD:	Honestly Significant Difference
CSF:	Cancer Slope Factor
RFD:	Reference Dose Factor

Author Contributions

All authors contribute equally to the research paper. Nadeem, M.: Experimental Design, Formal Analysis, Data Curation, Data Validation, Writing original Draft, Visualization. Suberi, B.: Supervision, Data Validation, Review of Write-up of Draft. Farid, M.: Supervision, Statistical Analysis, Review and Write-up of Draft. All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

The data will be made available on request.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

Not Applicable

Acknowledgments

The authors are highly thankful to the Department of Environmental Sciences, University of Gujrat, Pakistan for technical and research support during research work.

References

1. Tripathi, A. K., Rana, S., Devika, S., Nafees, S., & Ahirwar, R. (2019). *Gene-Environment Interactions: Implications for Environmental Health.* In Recent Trends and Advances in Environmental Health (pp. 313–332).
2. Mishra, S., Bharagava, R.N., More, N., Yadav, A., Zainith, S., Mani, S., and Chowdhary, P. Heavy metal contamination: an alarming threat to environment and human health. In Environmental biotechnology: For sustainable future. Springer Singapore. 2019;103-125.
3. Rai, R., Sharma, S., Gurung, D.B., and Sitaula, B.K. Heavy metal contamination in sediments from vehicle washing: a case study of Olarong Chhu Stream and Paa Chhu River, Bhutan. International Journal of Environmental Studies, 2019;76: 66-83.
4. Goel, R., Debbarma, P., Kumari, P., Suyal, D.C., Kumar, S., and Mahapatra, B.S. Assessment of soil chemical quality, soil microbial population, and plant growth parameters under organic and conventional rice-wheat cropping systems. *Agricultural Research*, 2021;10: 193-204. https://doi.org/10.1007/s40003-020-00499-8
5. Alissa, E.M., and Ferns, G.A. Heavy metal poisoning and cardiovascular disease. Journal of Toxicology, 2011; 870125.
6. Khalid, S., Shahid, M., Bibi, I., Shah, A.H., and Niazi, N.K. A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-incomecountries. International Journal of Environmental Research and Public Health 2017;1-36. https://doi.org/10.3390/ijerph15050895.
7. . Rehman, Z. U., Javed, H., Shahid, K., Javed, K., Hussain, S., Malik, S., Javed, K., & Niaz, A. (2023). Assessment and management strategies for soil pollution in Pakistan: A review. Journal of Pure and Applied Agriculture, 8(4), 69-89.

8. Mahfooz, Y., Yasar, A., Guijian, L., and Islam, Q.U. Critical risk analysis of metals toxicity in wastewater irrigated soil and crops: a study of a semi-arid developing region. *Scientific Reports, 2020 Jul 30;10(1):12845*. https://doi.org/10.1038/s41598-020-69815-0
9. Tang, R., Ma, K., Zhang, Y., and Mao, Q. Applied Geochemistry: The spatial characteristics and pollution levels of metals in urban street dust of Beijing, China. *Applied Geochemistry*, 2013;35: 88-98. https://doi.org/10.1016/j.apgeochem.2013.03.016
10. Masood, N., Farooqi, A., and Zafar, M.I. Health risk assessment of arsenic and other potentially toxic elements in drinking water from an industrial zone of Gujrat, Pakistan: a case study. *Environmental Monitoring and Assessment*, 2019;191. https://doi.org/10.1007/s10661-019-7223-8
11. Escobedo, F.J., Kroeger, T., and Wagner, J.E. Urban forests and pollution mitigation: Analysing ecosystem services and disservices. Environmental Pollution, 2011;159(8-9): 2078-2087. https://doi.org/10.1016/j.envpol.2011.01.010.
12. Mishra, R.K., Mohammad, N., and Roychoudhury, N. Soil pollution: Causes, effects and control. Van Sangyan, 2016;3: 1-14.
13. Ukpong, E.C., Antigha, R.E., and Moses, E.O. Assessment Of Heavy Metals Content in Soils and Plants Around Waste Dumpsites in Uyo Metropolis, Akwa Ibom State. The International Journal of Engineering and Sciences, 2013;2: 75-86.
14. Akbar, K.F., Hale, W.H., Headley, A.D., and Athar, M. Heavy metal contamination of roadside soils of Northern England. Soil & Water Res., 2006, 1(4):158-163 | DOI: 10.17221/6517-SWR.
15. Tüzen, M. Determination of heavy metals in soil, mushroom, and plant samples by atomic absorption spectrometry. Microchemical Journal, 2003;74: 289-297. https://doi.org/10.1016/S0026-265X(03)00035-3.
16. Gerenfes, D., Giorgis, A., and Negasa, G. Comparison of organic matter determination methods in soil by loss on ignition and potassium dichromate method. *International Journal of Horticulture and Food Science*, 2022;4: 49-53.
17. Orcan, F Parametric or non-parametric: Skewness to test normality for mean comparison. International Journal of Assessment Tools in Education, 2020;7: 255-265.
18. Nourbakhsh, N.S. Calculation of the correlation coefficient of heavy metals of chromium and cadmium around the Qayen Cement Plant. World Journal of Environmental Biosciences, 2020;9: 40-47.
19. Ali, M.U., Liu, G., Yousaf, B., Ullah, H., Abbas, Q., and Munir, M.A.M. A systematic review on global pollution status of particulate matter-associated potential toxic elements and health perspectives in urban environment. Environmental geochemistry and health, 2019;41: 1131-1162.
20. Sulaiman, M.B., and Maigari, A.U. Physico-chemical properties and heavy metals content of groundwater around a municipal dumpsite in Gombe, Nigeria. International Journal of Science and Research, 2016;5: 1299-1304.
21. Ritchey, E.L., McGrath, J.M., and Gehring, D. Determining soil texture by feel. Agriculture and Natural Resources Publication, 2015;139: AGR219.
22. Kamunda, C., Mathuthu, M., and Madhuku, M. Health risk assessment of heavy metals in soils from Witwatersrand gold mining basin, South Africa. International Journal of Environmental Research and Public Health, 2016;13(7). https://doi.org/10.3390/ijerph13070663.
23. Boateng, T.K., Opoku, F., and Akoto, O. Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi. Applied Water Science, 2019;9: 1-15. https://doi.org/10.1007/s13201-019-0915-y.
24. Mohammadi, A.A., Zarei, A., Esmaeilzadeh, M., Taghavi, M., Yousefi, M., Yousefi, Z., Sedighi, F., and Javan, S. Assessment of Heavy Metal Pollution and Human Health Risks in Soils Around an Industrial Zone in Neyshabur, Iran. Biological Trace Element Research, 2020;195: 343-352. https://doi.org/10.1007/s12011-019-01816-1.
25. Hanfi, M.Y., and Yarmoshenko, I.V. Health risk assessment quantification from heavy metal contamination in the urban soil and urban surface deposited sediment. Journal of Taibah University for Science, 2020;14:285293.https://doi.org/10.1080/16583655.2020.1735735.
26. Ahmad, W., Zubair, M., Ahmed, M., Ahmad, M., Latif, S., Hameed, A., Kanwal, Q., and Iqbal, D. N. Correction to: Assessment of potentially toxic metalloid contamination in soil near the industrial landfill and impact on human health: an evaluation of risk. Environmental Geochemistry and Health, 2023;45: 4371. https://doi.org/10.1007/s10653-023-01581-0.
27. Yang, J.L., and Zhang, G.L. Formation, characteristics and eco-environmental implications of urban soils: A review. Soil science and plant nutrition, 2015;61: 30-46.
28. Nieder, R., Benbi, D.K., Reichl, F.X.,. Soil quality and human health. In Soil Components and Human Health, 2018;1-34.
29. Zubair, M., Anwar, U., Ashfaq, M., Zafar, M.N., Farid, M., Ahmad, F., Ahmad, W., Ali, S., Rizwan, M., Alsahli, A.A., Alyemeni, M.N., and Wijaya, L. Heavy metals occurrence, seasonal variation, and enr ichment in urban soils augmented with industrial waste. Polish Journal of Environmental Studies, 2021;30: 4871-4886. https://doi.org/10.15244/pjoes/132627.
30. Rashid, A., Schutte, B.J., Ulery, A., Deyholos, M.K., Sanogo, S., Lehnhoff, E.A., and Beck, L. Heavy

metal contamination in agricultural soil: environmental pollutants affecting crop health. Agronomy, 2023;13(6): 1-30. https://doi.org/10.3390/agronomy13061521.
31. Ludwiczak, A., Osiak, M., Cárdenas-Pérez, S., Lubińska-Mielińska, S., and Piernik, A. Osmotic stress or ionic composition: Which affects the early growth of crop species more? Agronomy, 2021;11. https://doi.org/10.3390/agronomy11030435.
32. (a). Zhang, H., Mao, Z., Huang, K., Wang, X., Cheng, L., and Zeng, L. Multiple exposure pathways and health risk assessment of heavy metals for children living in fourth-tier cities in Hubei Province. Environment International, 129 (January): 2018;517-524.
(b).Zio, E. The future of risk assessment. Reliability Engineering & System Safety, 2019;177: 176-190. https://doi.org/10.1016/j.envint.2019.04.031.
33. Luo, X. san, Yu, S., and Li, X. Dong. The mobility, bioavailability, and human bioaccessibility of trace metals in urban soils of Hong Kong. Applied Geochemistry, 2012;27: 995-1004. https://doi.org/10.1016/j.apgeochem.2011.07.001.
34. Barson, W.J. Probable actinic Rocky Mountain spotted fever (2). Pediatric Infectious Disease Journal, 1998;17: 850-852. https://doi.org/10.1097/00006454-199809000-00028.
35. Wang, D., Wang, Z., Zhang, J., Zhou, B., Lv, T., and Li, W. Effects of soil texture on soil leaching and cotton (Gossypium hirsutum L.) growth under combined irrigation and drainage. Water (Switzerland), 2021;13: 1-17. https://doi.org/10.3390/w13243614.
36. Belayneh, M., Yirgu, T., and Tsegaye, D. Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile Basin, Ethiopia. Ecological Processes, 2019;8. https://doi.org/10.1186/s13717-019-0188-2.
37. Huang, Y., Chen, Q., Deng, M., Japenga, J., Li, T., Yang, X., and He, Z. Heavy metal pollution and health risk assessment of agricultural soils in a typical peri-urban area in southeast China. Journal of Environmental Management, 2018;207: 159-168. https://doi.org/10.1016/j.jenvman.2017.10.072.
38. Gupta, V. Vehicle-generated heavy metal pollution in an urban environment and its distribution into various environmental components. Environmental Concerns and Sustainable Development, 2020;113-127. https://doi.org/10.1007/978-981-13-5889-0_5.
39. Argyraki, A., Kelepertzis, E., Botsou, F., Paraskevopoulou, V., Katsikis, I., and Trigoni, M. Environmental availability of trace elements (Pb, Cd, Zn, Cu) in soil from urban, suburban, rural, and mining areas of Attica, Hellas. Journal of Geochemical Exploration, 2018;187 201-213. https://doi.org/10.1016/j.gexplo.2017.09.004.
40. Wissuwa, M., and Ismail, A.M. Rice grain zinc concentrations as affected by genotype, native soil-zinc availability, and zinc fertilization. Improving Crop Production and Human Health, 2008;306: 37-48.
41. Van, H.T., Hoang, V.H., Nga, L.T.Q., and Nguyen, V.Q. Effects of Zn pollution on soil: Pollution sources, impacts and solutions. Results in Surfaces and Interfaces,2024;100360. https://doi.org/10.1016/j.rsurfi.2024.100360.
42. Tarar, Z.H., Khan, M.S.A., Mehdi, S.M., Salim, R., Saleem, I.A., Nazar, S., David, M., Majeed, T., Mughal, M.S., Saleem, M., Iqbal, U., Iqbal, M.M., and Shaheen, M.K. Quantification of Plant Available Zinc, Copper, Iron, Manganese, Boron, and Visualisation of their Spatial Distribution through GIS in District Mandi Bahauddin, Punjab, Pakistan. Pakistan Journal of Agricultural Research, 2020;33: 609-618. https://doi.org/10.17582/journal.pjar/2020/33.3.609.618.
43. Levin, R., Zilli Vieira, C.L., Rosenbaum, M.H., Bischoff, K., Mordarski, D.C., and Brown, M.J.The urban lead (Pb) burden in humans, animals, and the natural environment. Environmental Research, 2021;193: 110377. https://doi.org/10.1016/j.envres.2020.110377.
44. Kumar, A., Kumar, A., Cabral-Pinto, M., Chaturvedi, A.K., Shabnam, A.A., Subrahmanyam, G., Mondal, R., Gupta, D.K., Malyan, S.K., Kumar, S.S., Khan, S.A., and Yadav, K.K. Lead toxicity: Health hazards, influence on the food Chain, and sustainable remediation approaches. International Journal of Environmental Research and Public Health, 2020;17. https://doi.org/10.3390/ijerph17072179.
45. Sager, M Urban soils and road dust-civilisation effects and metal pollution: A review. Environments - MDPI, 2020;7: 1-65. https://doi.org/10.3390/environments7110098.
46. Wang, L., Cui, X., Cheng, H., Chen, F., Wang, J., Zhao, X., Lin, C., and Pu, X. A review of soil cadmium contamination in China, including a health risk assessment. Environmental Science and Pollution Research, 22: 2015;16441-16452. https://doi.org/10.1007/s11356-015-5273-1.
47. Huang, Y., He, C., Shen, C., Guo, J., Mubeen, S., Yuan, J., ans Yang, Z. Toxicity of cadmium and its health risks from leafy vegetable consumption. Food and Function, 2017;8: 1373-1401. https://doi.org/10.1039/c6fo01580h.
48. Genchi, G., Graziantono, L., Carocci, A., and Catalano, A. The Effects of Cadmium Toxicity. International Journal of Environmental Research and Public Health, 2020;17: -24. DOI: 10.3390/ijerph17113782

49. Mir, A.R., Pichtel, J., and Hayat, S. Copper: uptake, toxicity and tolerance in plants and management of Cu-contaminated soil. BioMetals, 2021;34: 737-759. https://doi.org/10.1007/s10534-021-00306-z.
50. Munir, N., Jahangeer, M., Bouyahya, A., El Omari, N., Ghchime, R., Balahbib, A., Aboulaghras, S., Mahmood, Z., Akram, M., Ali Shah, S. M., Mikolaychik, I. N., Derkho, M., Rebezov, M., Venkidasamy, B., Thiruvengadam, M., & Shariati, M. A. (2022). Heavy Metal Contamination of Natural Foods Is a Serious Health Issue: A Review. Sustainability,14(1),161. https://doi.org/10.3390/su14010161
51. Soriano, A., Pallarés, S., Pardo, F., Vicente, A.B., Sanfeliu, T., and Bech, J. Deposition of heavy metals from particulate settleable matter in soils of an industrialised area. Journal of Geochemical Exploration, 2012;113: 36-44. https://doi.org/10.1016/j.gexplo.2011.006.
52. AL-Huqail, A.A., Alsudays, I.M., Alghanem, S.M.S., Anwar, R., Farid, M., Sarfraz, W., Zubair, M., Asam, Z.U.Z., Abbas, M., and Rizwan, M. Treatment of marble industry wastewater by Brassica napus (L.) under oxalic acid amendment: efficacy as fodder and carcinogenic risk assessment. Environmental Science and Pollution Research, 2024;31: 35038-35054. https://doi.org/10.1007/s11356-024-33528-y.
53. Stefanowicz, A.M., Kapusta, P., Zubek, S., Stanek, M., and Woch, M.W. Soil organic matter prevails over heavy metal pollution and vegetation as a factor shaping soil microbial communities at historical Zn-Pb mining sites. Chemosphere, 2020;240: 124922.
54. Sharma, S.B. Trend-setting impacts of organic matter on soil physico-chemical properties in traditional vis-à-vis chemical-based amendment practices. PLOS Sustainability and Transformation, 2022;1: e0000007. https://doi.org/10.1371/journal.pstr.0000007.
55. Naz, M., Dai, Z., Hussain, S., Tariq, M., Danish, S., Khan, I.U., Qi, S., and Du, D. The soil pH and heavy metals revealed their impact on the soil microbial community. Journal of Environmental Management, 2022;321: 115770. https://doi.org/10.1016/j.jenvman.2022.115770.
56. Gunawardana, C., Egodawatta, P., and Goonetilleke, A. Adsorption and mobility of metals in build-up on road surfaces. Chemosphere, 2015;119: 1391-1398. https://doi.org/10.1016/j.chemosphere.2014.02.048.
57. US EPA. Risk Assessment Guidance for Superfund (RAGS) Volume I: Human Health Evaluation Manual (Part A). United States Environmental Protection Agency. Note: This is a foundational document and is regularly updated.
58. Buckley, T.J., Egeghy, P.P., Isaacs, K., Richard, A.M., Ring, C., Sayre, R.R., and Williams, A.J. Cutting-edge computational chemical exposure research at the US Environmental Protection Agency. Environment International, 2023;178: 108097.
59. Wu, W., Wu, P., Yang, F., Sun, D., Zhang, D., and Zhou, Y. Assessment of heavy metal pollution and human health risks in the urban soils of a typical old industrial city, Northeast China. Environmental Geochemistry and Health, 2022;44: 865-881.
60. WHO. Children's environmental health. World Health Organization 2021. https://www.who.int/health-topics/children-environmental-health#tab=tab_1