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Article

Health Risk Assessment of Hazardous Heavy Metals in Two Varieties of Mango Fruit (*Mangifera indica* L. var. Dasheri and Langra)

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Abstract: The spatial assessment of four heavy metals (Cd, Cr, Pb, and As) in two mango fruit (*Mangifera indica* L.) varieties (Dasheri and Langra) collected from the Saharanpur district, Uttar Pradesh, India, was investigated in this study. The samples of ripe mango fruits were collected from the orchards of 12 major towns in the Saharanpur district from May to June 2022. Heavy metal analysis using atomic absorption spectroscopy (AAS) showed the presence of all selected heavy metals. Specifically, the concentration (mg/kg dry weight basis) range of Cd (0.01–0.08), Cr (0.11–0.82), Pb (0.02–0.15), and As (0.01–0.14) did not exceed the safe limits. The geospatial variation in the heavy metal concentration was significantly ($p < 0.05$) different as indicated by the inverse distance weighting (IDW) interpolation and analysis of variance (ANOVA) results. The multivariate statistical analysis using principal component (PC) and agglomerative hierarchical cluster (AHC) analyses revealed that the Saharanpur city location had the highest levels of selected heavy metals out of the 12 sampling locations. In this, the Dasheri variety was identified to have higher heavy metal concentrations in comparison to the Langra variety. Moreover, the health risk study using the target hazard quotient (THQ) confirmed that the levels did not exceed the safe health risk index (HRI) limit of 1. However, the health risk assessment for the child group showed relatively high HRI values (<0.35) compared to those of the adult group (<0.09). Therefore, considering the importance of the Saharanpur district in massive mango fruit production, this study provides vital information regarding the biomonitoring of heavy metals in the two most consumed varieties.

Keywords: health risk assessment; horticulture crops; mango fruits; safe consumption limits; toxic elements

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1. Introduction

Mango is a fruit rich in vitamins with high marketability owing to its high versatility, sweetness, and richness in minerals and fiber. The fruit's richness encouraged people to increase its consumption (besides other tropical fruits) during the COVID-19 pandemic based on the World Health Organization's (WHO) recommendations [1]. Mango cultivation is native to South and Southeast Asia and its production amounted to 54.8 million tons in 2020, which was a 1.9% decrease compared to 2019 [2] due to the COVID-19 pandemic. On a market basis, the term mango includes mangosteens and guavas. The global mango market was estimated at USD 2.4 billion in 2021 and has been forecasted to grow at a 7% compound annual growth rate between 2022 and 2031, with the market estimated to reach approximately USD 4.4 billion [3]. India is the leading producer of mangoes, with a production estimate of 24.7 million tons in 2020 (around 45.1% of the world's mango production) [4]. The gross benefits to India from the mango market were estimated at INR 439.0 billion (USD 5.5 billion) in 2019 [5]. Despite the large production of mangoes in India, only 1% (247 thousand tons) of the total amount is exported. Forbes mentioned that the Indian population is obsessed with mango consumption and considers this fruit a matter of national pride and identity [6].

Besides pests and diseases, the main problems associated with mango production are postharvest losses and huge waste generation [7–9]. These issues lead to huge losses (30–80%) in global production in Africa and India during the harvesting, packing, distribution, and marketing of mangoes [10]. Although mangoes are rich in dietary fiber, vitamins (A, C, and E), potassium, magnesium, and folates [11], fruit processing directly affects their nutritional composition and health benefits. Besides raw consumption, the main products of mangoes include natural and concentrated juices, enriched juices with prebiotics, jams, nectars, canned slices, powders, and flavorings for ice cream, yogurts, and soft drinks [9]. It is noteworthy that the minimal processing of mango fruits is considered among the healthiest postharvest production processes. Mango fruits provide essential nutrition for the human body, including minerals, i.e., copper (Cu: 0.04–0.32 mg/100 g), iron (Fe: 0.09–0.41 mg/100 g), manganese (Mn: 0.03–0.12 mg/100 g), phosphorus (P: 10.0–18.0 mg/100 g), selenium (Se: 0.0–0.6 mg/100 g), and zinc (Zn: 0.06–0.15 mg/100 g) [12], in accordance with recommended daily allowances. Although these minerals are important, their increased concentrations make them potentially toxic elements. Besides soil pollution from various sources, fertilizers, pesticides, and other chemicals directly impact mangoes' hazardous heavy metal uptake such as cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As), etc., from soil and/or fixation from the air [13]. The presence of heavy metals in mango fruits, especially in high quantities, can lead to chronic diseases. These diseases could therefore result in mutagenesis, carcinogenesis, and teratogenesis, especially in vulnerable populations such as children [14].

Mango orchard soils contaminated by neighboring mines, industrial effluents, and untreated sewage sludge may contain dangerous amounts of heavy metals. These amounts should not exceed the daily intake levels set by the FAO/WHO [15], which amount to 60 μg (Cd), 3 mg (Cu), 214 μg (Pb), and 60 mg (Zn). A previous study reported that the concentrations of metals, including heavy metals, in mangoes were in a decreasing order of Ca > K > Mg > Na > Fe > Mn > Zn > Cu [16]. The analysis of fresh mango fruits originating from different orchards in Brazil and Ecuador revealed trace concentrations of cobalt (Co) (< 0.001 mg/100 g) and low concentrations of Cr (0.001–0.003 mg/100 g), Cu (0.02–0.06 mg/100 g), Fe (0.32–1.01 mg/100 g), Mn (0.09–1.32 mg/100 g), nickel (Ni: 0.002–0.01 mg/100 g), P (12.8–13.9 mg/100 g), and Zn (0.08–0.12 mg/100 g) [17]. Therefore, the biomonitoring of the accumulation of hazardous heavy metals in fruits has become an important researchable area.

Health risk assessments of fruits and vegetables targeted for human consumption are attracting increasing interest from researchers, governments, and international health organizations. In this context, several studies have aimed to assess the spatial distribution of heavy metals in consumed fruits, fruit juices, and vegetables [14,18,19]; these studies all concluded that the analyzed samples were safe for human consumption. However, the spatial assessment of heavy metals in mango fruits from South and Southeast Asia, and especially the Indian subcontinent, is limited. Therefore, the current study aimed to assess the health risks of heavy metals in two mango fruit varieties (*Mangifera indica* L.) collected from the Saharanpur district, Uttar Pradesh, India.

2. Materials and Methods

2.1. Description of Study Area and Sampling Sites

The current study was carried out in the Saharanpur district of Uttar Pradesh, India. The administrative boundaries of the Saharanpur district border three different Indian states, i.e., Uttarakhand, Himachal Pradesh, and Haryana, thus playing a crucial role in connecting them. The district is located between the Ganges and Yamuna Rivers (Doab region) just below the Shivalik foothills of the Himalayas; thus, the soil is highly fertile and suitable for rice, sugarcane, and mango crops. Saharanpur district is well known for its mass production of several mango varieties such as Dasheri, Langra, Chausa, and Bombay Green [20]. The district has 25,946 hectares of mango cultivation land, contributing to an annual production of 259,460 metric tons (10 tons/ha), which are distributed nationally and exported internationally [21]. Therefore, the Saharanpur district is famous for being the leading mango producer in western Uttar Pradesh.

2.2. Sample Collection and Processing

In the present study, mango samples were obtained from twelve major towns, i.e., Nakur, Gangoh, Sarsawa, Deoband, Saharanpur, Chhutmalpur, Behat, Biharigarh, Chilkana, Nagal, Rampur Maniharan, and Nanauta (Table 1 and Figure 1). A total of five ripe fruit samples (n = 5 from each site) for each variety (Dasheri and Langra) were collected from the orchards from May to June 2022, which is the peak harvesting time for mango crops. The samples were immediately placed in a polyurethane foam-insulated ice cooler box (11 L, PinnacleThermo, Ahmedabad, Gujrat, India) and transported to a laboratory for further analysis. The mango fruits were cut and the pulp was extracted using a juicer mixture (3345, Usha International Ltd., New Delhi, India), whereas the seeds and fruit peel were discarded. Afterward, the extracted pulp sample was oven-dried at 60 °C until a constant weight was achieved. The oven-dried biomass was further converted into a fine powder using a mechanical grinder to be used for heavy metal analysis.

Table 1. Description of sites selected for the mango fruit (*M. indica*) sample collection from Saharanpur district, Uttar Pradesh, India.

Sampling Sites	Code	Latitude (N) ^	Longitude (E) ^	Elevation (m)
Nakur	NK	29°91.8268′	77°30.6753′	270.97
Gangoh	GH	29°77.8732′	77°26.4657′	262.23
Sarsawa	SS	30°01.3546′	77°40.0800′	275.71
Deoband	DB	29°68.6884′	77°67.6232′	255.97
Saharanpur	SP	29°97.2043′	77°53.9220′	280.04
Chhutmalpur	CP	30°03.5793′	77°74.9424′	298.34
Behat	BT	30°16.7336′	77°61.7344′	300.64
Biharigarh	BG	30°09.8690′	77°82.4043′	311.96
Chilkana	CK	30°08.5917′	77°48.3862′	279.47
Nagal	NL	29°84.0134′	77°63.0569′	270.80
Rampur Maniharan	RM	29°80.7656′	77°45.5417′	268.50
Nanauta	NT	29°71.5787′	77°41.9474′	258.61

^: Coordinates and referencing system (CRS) are rendered as EPSG:4326—WGS 84 projection; Source: Google Earth.

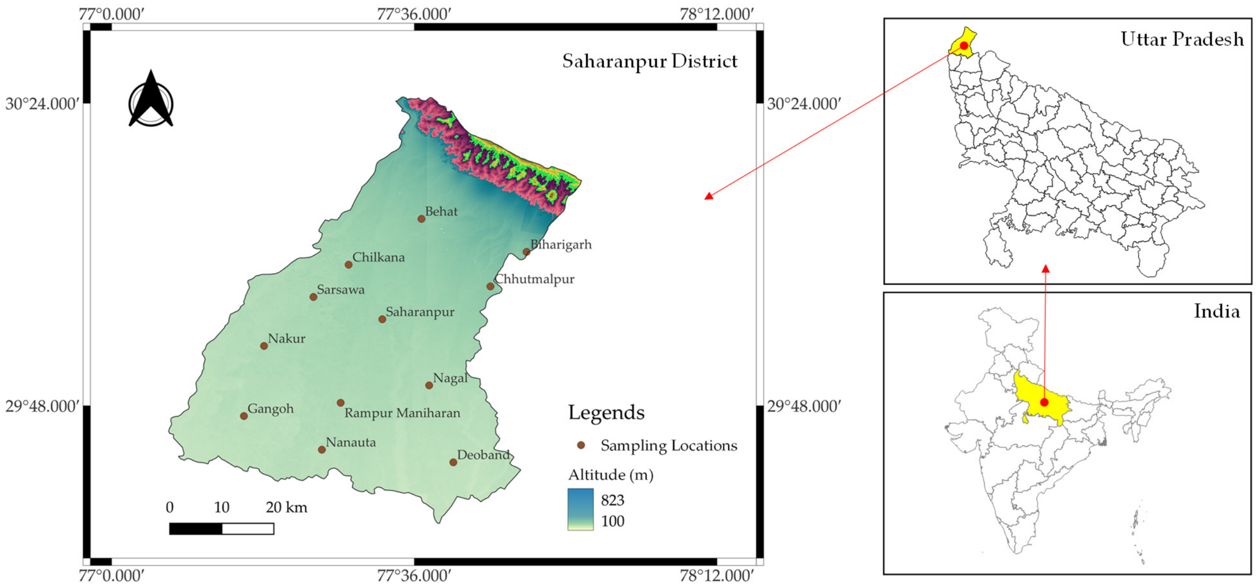

Figure 1. Map showing mango fruit (*M. indica*) sampling locations and digital elevation model (DEM) of Saharanpur district, Uttar Pradesh, India.

2.3. Analysis of Heavy Metals

For this, a total of 1 g of powdered biomass of mango pulp was placed in a 250 mL capacity conical flask, mixed with 10 mL of the di-acid mixture (HNO_3 + $HClO_4$; 3:1), and left for overnight (12 h) self-digestion. Then, the volume of the mixture was adjusted to 50 mL with the addition of a 3% HNO_3 solution, followed by hot-plate-based digestion at 150 °C for 1 h. Finally, more HNO_3 solution was added to increase the contents to 50 mL and filtered through Whatman filter paper number 41. The supernatant was used for heavy metal analysis using atomic absorption spectroscopy (AAS; Analyst 800, PerkinElmer, Waltham, MA, USA). The AAS instrument had a background detection limit of 0.001, 0.003, 0.001, and 0.002 mg/kg for Cd, Cr, Pb, and As, respectively. The instrument was pre-calibrated using analytical grade standard solutions. All chemicals and reagents used in this study were procured from Merck Ltd. (Mumbai, India). The slit length, lamp current (A), and wavelength of the instrument for the determination of Cd, Cr, Pb, and As were adjusted as previously described by Elbagermi et al. [22].

2.4. Data Analysis and Software

Health risk studies are useful tools that provide information about toxicity limits and safety concerns regarding the consumption of contaminated foods [19,23]. In this study, the health risks associated with heavy metal-containing mango fruits collected from selected locations in the Saharanpur district, Uttar Pradesh, India were calculated based on the target hazard quotient (THQ) index. THQ is a standardized index that derives the specific toxicity levels of heavy metals present in foods. Herein, the THQ sum of four selected heavy metals (Cd, Cr, Pb, and As) was used to present the health risk index (HRI) value to determine the cumulative hazard for the mango fruit consumer. The following Equations (1)–(2) were used to calculate the THQ and HRI, respectively:

$$\text{THQ} = 10^{-3} \times \frac{Ef \times Ed \times Ir \times HMc}{Bw \times Cp \times Rd} \quad (1)$$

$$\text{HRI} = \text{THQ}_{\text{Cd}} + \text{THQ}_{\text{Cr}} + \text{THQ}_{\text{Pb}} + \text{THQ}_{\text{As}} \quad (2)$$

where Ef is the exposure frequency of heavy metals, Ed is exposure duration (350 days), Ir is the mango ingestion rate, HMc is the heavy metal concentration in mangoes (mg/kg), Bw is the average body weight, Cp is the consumption period (25,550 days), Rd is the reference doses (Cd: 5.0×10^{-4}; Cr: 3.0×10^{-3}; Pb: 2.0×10^{-2}; As: 4.0×10^{-4}), and 10^{-3} is the conversion factor, respectively.

On the other hand, the heavy metal data collected from the selected location were used to create spatial distribution maps [24]. For this, the inverse distance weight (IDW) method was used to predict the point values within the finite distance using 60 observations. The model can be represented by Equation (3):

$$\mathrm{R}(x) = \frac{\sum_{j=1}^{m} Z(x_i) d_{ij}^{-r}}{\sum_{j=1}^{m} d_{ij}^{-r}} \quad (3)$$

where r and d_{ij} are the weight and distance between the measured points, whereas m shows the number of neighboring estimates used for the point value simulation, respectively.

Moreover, the data were analyzed using principal component analysis (PCA) and agglomerative hierarchical clustering (AHC) to derive the significant relationship between the heavy metal concentration in mango fruits and their sampling locations. The data were tested using a one-way analysis of variance (ANOVA). The level of statistical significance was adjusted as the probability (p) < 0.05. MS Excel 2019 (Microsoft, Redmond, WA, USA), OriginPro 2022b (OriginLab, Northampton, MA, USA), and QGIS (3.22.3-Białowieza, Open Source, Gispo Ltd., Helsinki, Finland) software packages were used for the data analysis and visualization.

3. Results and Discussion

3.1. Concentrations of Heavy Metals in Mango Fruits

The concentrations of heavy metals in two mango fruit varieties (Dasheri and Langra) collected from the Saharanpur district of Uttar Pradesh, India, are given in Table 2. There were significant differences ($p < 0.05$) in the heavy metal concentrations reported from the selected sampling locations. The results indicated that the mango variety samples showed the presence of the selected heavy metals (Cd, Cr, Pb, and As) from most sampling locations except for Pb in the samples from three sites (Langra: Nakur; Dasheri: Biharigarh and Rampur Maniharan) and As in the samples from two sites (Langra: Rampur Maniharan; Dasheri: Behat), where they were reported to be below the detectable limits. The highest contents of Cd (0.08 ± 0.03 mg/kg) were reported in the samples from the Saharanpur site for the Dasheri variety of mango, whereas the maximum Cr was reported in the samples from Saharanpur (0.80 ± 0.09 mg/kg). On the other hand, the maximum values of Pb (0.15 ± 0.05 mg/kg) and As (0.14 ± 0.02 mg/kg) were observed in the samples from the Saharanpur site for the Langra and Dasheri mango varieties, respectively. Overall, the decreasing order of the presence of the four selected heavy metals in both mango varieties was observed as Cr > Pb > As > Cd. Moreover, the levels of Cr in the mango fruit samples were found to be below the safe limit of 2.30 mg/kg, as recommended by USEPA [25]. The other heavy metals, such as Cd and Pb, almost approached the safe limits in the samples from a few sites. Usually, mango crops are sprayed with different insecticides to avoid early damage to the flowers and fruits. There are certain diseases, such as powdery mildew, anthracnose, dieback, phoma blight, bacterial canker, red rust, sooty mold, mango malformation, gummosis, root rot, damping off, scab, etc., that could cause significant damage to mango crops [26]. Thus, the sources of heavy metal accumulation in mango fruits could be due to excessive use of fertilizers and pesticides applied in the earlier stages of their cultivation. Among the selected sampling locations, Saharanpur is an urban area with numerous industrial units and heavy-duty vehicular transportation [27–29], which could be the reason behind the highest levels of heavy metals in the mango fruit samples collected from this site.

Table 2. Heavy metal concentration (mean ± SD; $n = 5$) in two mango fruit (*M. indica*) variety samples collected from Saharanpur district, Uttar Pradesh, India.

Sampling Sites	Mango Varieties	Heavy Metals (mg/kg dwt.)			
		Cd	Cr	Pb	As
Nakur	Dasheri	0.02 ± 0.01 a	0.27 ± 0.02 b	0.13 ± 0.05 d	0.12 ± 0.03 c
	Langra	0.03 ± 0.01 a	0.11 ± 0.04 a	*Bdl*	0.11 ± 0.02 c
Gangoh	Dasheri	0.05 ± 0.02 ab	0.80 ± 0.06 c	0.06 ± 0.02 b	0.08 ± 0.03 b
	Langra	0.04 ± 0.01 b	0.77 ± 0.10 c	0.14 ± 0.05 d	0.05 ± 0.02 a
Sarsawa	Dasheri	0.03 ± 0.01 a	0.53 ± 0.07 c	0.03 ± 0.01 a	0.12 ± 0.02 c
	Langra	0.04 ± 0.02 b	0.72 ± 0.10 c	0.10 ± 0.03 d	0.02 ± 0.01 a
Deoband	Dasheri	0.03 ± 0.01 a	0.66 ± 0.04 d	0.03 ± 0.01 a	0.06 ± 0.02 b
	Langra	0.02 ± 0.01 a	0.18 ± 0.03 a	0.02 ± 0.00 a	0.12 ± 0.01 c
Saharanpur	Dasheri	0.08 ± 0.03 c	0.80 ± 0.09 c	0.07 ± 0.03 b	0.14 ± 0.02 c
	Langra	0.05 ± 0.02 bc	0.50 ± 0.06 d	0.15 ± 0.05 d	0.10 ± 0.01 b
Chhutmalpur	Dasheri	0.06 ± 0.02 b	0.69 ± 0.05 c	0.03 ± 0.01 a	0.02 ± 0.01 a
	Langra	0.05 ± 0.01 b	0.41 ± 0.01 a	0.02 ± 0.01 a	0.01 ± 0.00 a
Behat	Dasheri	0.04 ± 0.01 b	0.65 ± 0.08 c	0.02 ± 0.00 a	*Bdl*
	Langra	0.02 ± 0.01 a	0.70 ± 0.04 d	0.02 ± 0.01 a	0.05 ± 0.02 b
Biharigarh	Dasheri	0.01 ± 0.00 a	0.60 ± 0.06 c	*Bdl*	0.10 ± 0.04 b
	Langra	0.02 ± 0.01 a	0.19 ± 0.03 a	0.12 ± 0.04 d	0.02 ± 0.00 a
Chilkana	Dasheri	0.06 ± 0.02 ab	0.53 ± 0.08 c	0.03 ± 0.01 a	0.05 ± 0.02 a
	Langra	0.03 ± 0.01 a	0.34 ± 0.02 b	0.02 ± 0.00 a	0.02 ± 0.01 a
Nagal	Dasheri	0.04 ± 0.02 ab	0.38 ± 0.07 b	0.09 ± 0.03 c	0.07 ± 0.02 b
	Langra	0.02 ± 0.00 a	0.13 ± 0.03 a	0.04 ± 0.01 a	0.03 ± 0.01 a
Rampur Maniharan	Dasheri	0.05 ± 0.01 ab	0.55 ± 0.03 c	*Bdl*	0.09 ± 0.04 b
	Langra	0.03 ± 0.01 a	0.27 ± 0.04 a	0.06 ± 0.02 b	*Bdl*
Nanauta	Dasheri	0.06 ± 0.02 b	0.60 ± 0.08 d	0.13 ± 0.03 d	0.04 ± 0.02 a
	Langra	0.04 ± 0.01 ab	0.16 ± 0.01 a	0.07 ± 0.02 b	0.03 ± 0.01 a
Safe Limits [25,30,31]		0.10	2.30	0.30	0.50

Bdl: below detectable limits. a–d: indicate no significant difference among values from sampling locations or mango varieties at $p < 0.05$.

As shown in Figure 2a–h, the IDW method was useful for predicting the spatial distribution of heavy metal concentrations throughout the Saharanpur district. The sampling locations at higher altitudes showed relatively lower concentrations of heavy metals, except for Cr. This could be because higher elevation zones are not suitable for mango cultivation, thus anthropogenic activities were also reduced. However, the sampling locations situated within the middle region of the Saharanpur district contained plains lands, which showed the highest occurrence of heavy metals. Notably, the IDW interpolation showed that the Saharanpur, Deoband, and Nanauta sites were mostly characterized by high levels of heavy metals. This suggests that heavy metal concentrations in mango fruits were significantly affected by the type of cultivation land and ease of accessibility to the resources.

Recent studies have reported considerable levels of heavy metals that could affect the edibility of mango fruits. Among these studies, Shareef et al. [32] investigated the contents of heavy metals (Cd, Ni, Pb, and Cr) in mango fruit samples collected from Perlis, Malaysia. They reported that soils having high concentrations of the selected heavy metals showed higher accumulation in mango fruits. Moreover, Tari et al. [29] found that orchards contaminated with excessive pesticide and chemical fertilizer applications were responsible for the accumulation of heavy metals (Al, Ba, Pb, Zn, As, and Hg) in mango fruits collected from Ratnagiri district, Maharashtra, India. They suggested that mangoes grown by farmers who used organic fertilizers had relatively lower contents of the studied heavy metals and were safe for human consumption. Similarly, Anjum et al. [33] detected two heavy metals and concluded that mango fruits irrigated with sewage wastewater sources near urban areas had higher accumulations (i.e., 6.74 and 21.16 mg/kg for Cu and Ni, respectively) compared to those irrigated with tube-well water.

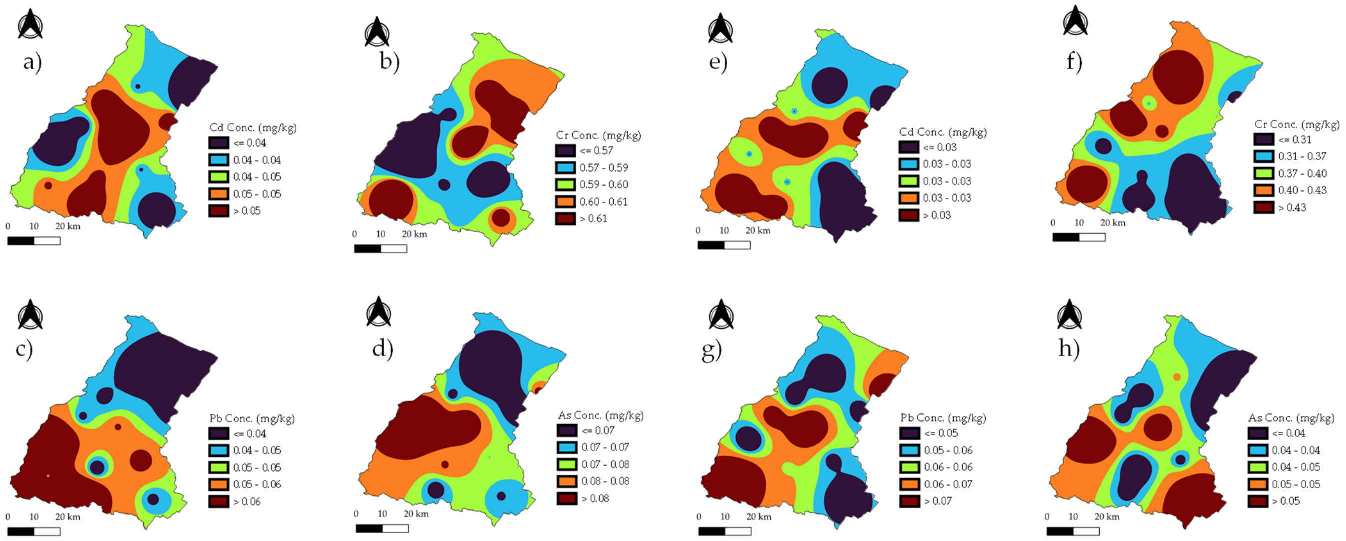

Figure 2. Spatial concentrations of heavy metals (Cd, Cr, Pb, and As) in (**a**–**d**) Dasheri and (**e**–**h**) Langra varieties of mango fruit (*M. indica*) samples collected from Saharanpur district, Uttar Pradesh, India.

3.2. Multivariate Analysis Results of Heavy Metals in Mango Fruits

Multivariate analysis is a helpful statistical technique for transforming large data sets into smaller ones and analyzing them effectively [19]. In this study, PCA and AHC techniques were adopted to derive the interrelationship between heavy metal contents in mango fruits and their sampling locations. Table 3 shows the results of the PCA matrix representing the eigenvalues, variances, and loading values for two mango fruit varieties collected from different sampling locations in the Saharanpur district. Herein, it was evidenced that the data were orthogonally transformed onto two principal components, i.e., PC1 and PC2. For the Dasheri mango fruit variety, the eigenvalues for PC1 and PC2 were identified as 0.06 and 0.01, with variances of 93.80 and 3.49%, respectively. On the other hand, the Langra mango fruit variety exhibited eigenvalues for PC1 and PC2 of 0.02 and 0.01, with variances of 86.83 and 6.75%, respectively. Higher eigenvalues in the case of the Langra variety showed a higher accumulation of selected heavy metals compared to the Dasheri variety. As per the loading biplot shown in Figure 3a–b, Cr had the highest levels, with maximum positive values dominating in PC1 followed by Pb, As, and Cd. The heavy metal concentrations in mango fruits from the sampling locations corresponded to their axial vector lengths. In this, the higher vector lengths for the Langra variety depicted higher levels of the selected heavy metals in the fruit samples, except for Cr. On the other hand, the AHC analysis was used to derive the similarities among the sampling locations in terms of the heavy metal contents in two mango fruit varieties. The AHC showed that the four selected heavy metals formed two major clusters of Cd–Cr and Pb–As for Dasheri, whereas Cd–Cr–Pb and As for Langra were seen in separate groups. The cluster heatmap plots shown in Figure 3c–d verified that all the sampling locations had high variabilities for both the Dasheri and Langra mango fruit varieties. However, several sampling locations depicted similar levels of heavy metal concentrations for Dasheri, whereas for Langra, only Rampur Maniharan, Chilkana, Gangoh, Sarsawa, Deoband, and Nakur depicted similar levels. Thus, there were significant similarities between the nearby sampling locations.

Table 3. PCA results of heavy metal contents in two mango fruit (*M. indica*) variety samples collected from Saharanpur district, Uttar Pradesh, India.

Variables ^	Dasheri		Langra	
	Principle Components		Principle Components	
	PC1	PC2	PC1	PC2
Eigenvalues	0.06	<0.01	0.02	<0.01
Variance (%)	93.80	3.49	86.83	6.75
Nakur	–1.09	–0.89	–2.08	1.16
Gangoh	1.63	0.81	1.43	0.79
Sarsawa	1.42	0.12	–0.37	0.13
Deoband	–0.80	–0.64	0.45	–0.44
Saharanpur	0.54	1.50	1.29	1.87
Chhutmalpur	0.13	–0.90	0.66	–0.88
Behat	1.30	–1.58	0.41	–1.49
Biharigarh	–0.71	1.57	0.07	–0.54
Chilkana	–0.14	–0.80	–0.34	–0.82
Nagal	–0.99	0.01	–1.34	0.06
Rampur Maniharan	–0.41	0.20	–0.21	–0.71
Nanauta	–0.85	0.60	0.02	0.87
Cd	0.01	0.06	0.06	0.11
Cr	0.99	–0.09	0.99	0.10
Pb	0.09	0.99	–0.10	0.74
As	–0.02	–0.07	–0.04	0.65

^: Refer to Table 1 for the location abbreviations.

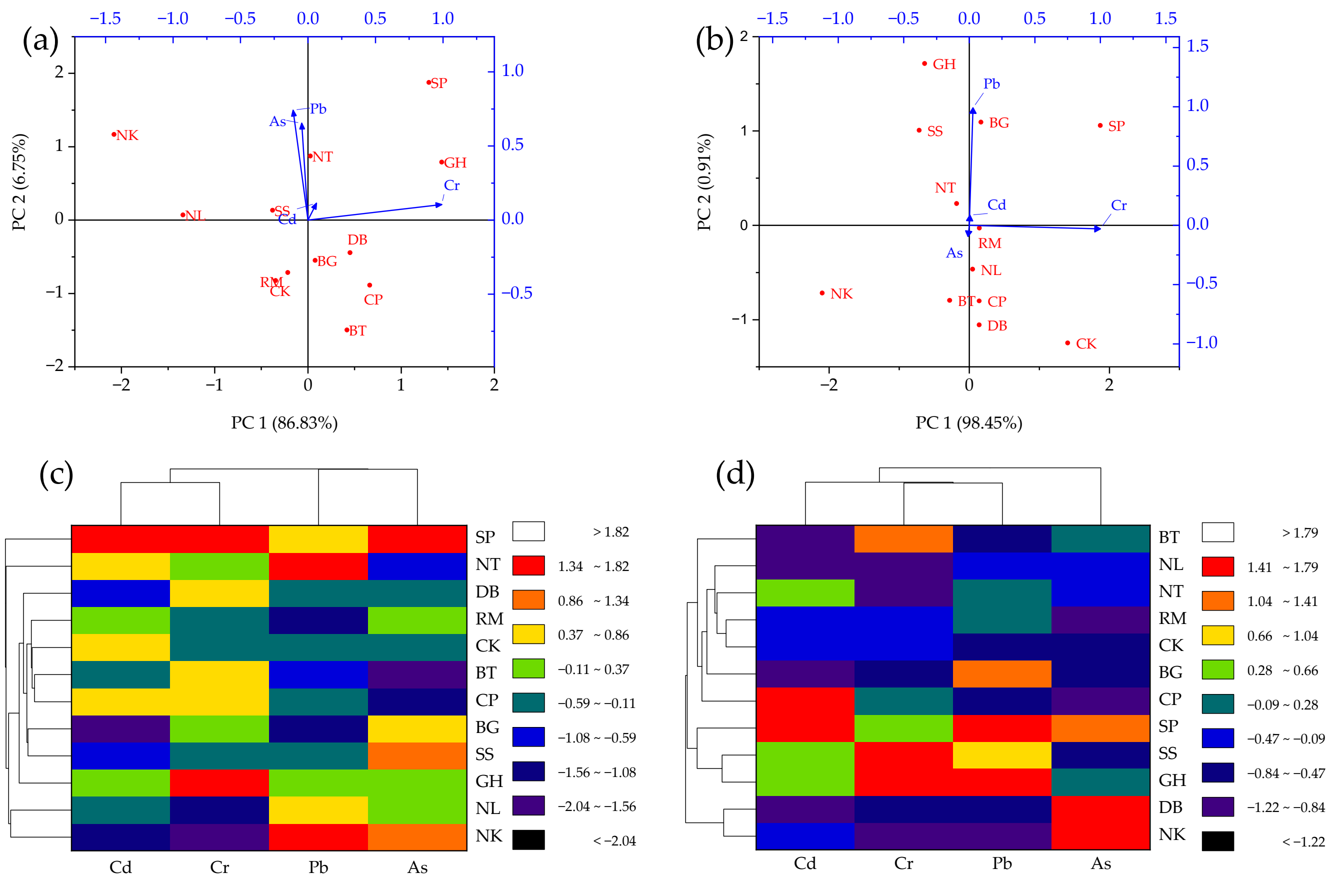

Figure 3. PCA and HCA plots for heavy metals in Dasheri (**a**,**c**) and Langra (**b**,**d**) varieties of mango fruits (*M. indica*) as collected from Saharanpur district, Uttar Pradesh, India (refer to Table 1 for the location abbreviations).

Previously, PCA and AHC tools have been widely adopted to study the heavy metal levels in fruits and vegetables [34]. However, no study in India has been reported concerning the application of multivariate statistical tools for the heavy metal analysis of mango fruits. Among them, Kormoker et al. [35] analyzed the concentration of heavy metals (Cr, Ni, Cu, As, Cd, and Pb) in mango fruits and found that the rotated component matrix method of PCA was useful for deriving the critical parameters including the source apportionment. They reported that the heavy metal concentrations in mango fruits were proportionate to their availability in soils. Similarly, Islam et al. [36] also assessed the concentrations of selected heavy metals (Cr, Ni, Cu, As, Cd, and Pb) in mango fruit samples collected from different locations in Bangladesh. They concluded that PC placed on a rotated space provided better results to identify the most dominant heavy metals. However, the levels of Cd, As, Pb, and As were much higher than in the current study. Another study by Grembecka and Szefer [17] presented the successful application of AHC for the determination of heavy metals in mango fruits from different geographical origins around the world. They suggested that mango fruits cultivated in organic environments had lower levels of Ni and Zn compared to those cultivated using conventional farming practices. Thus, the above reports supported the findings of the current study on the usefulness of the PCA and AHC tools for determining the interactions and similarities between heavy metals in mango fruits and their respective sampling locations across Saharanpur district, Uttar Pradesh, India.

3.3. Health Risk Study Results of Heavy Metals in Mango Fruits

The excessive intake of fruits and vegetables contaminated with heavy metals can lead to serious health problems such as cancer, organ dysfunction, nervous disorders, etc. [37]. However, the health impact widely depends on the consumer's age, weight, intake amount, and frequency of particular heavy metals. The health hazards are generally determined using health risk studies that utilize all these factors and the maximum permissible limits of heavy metal intake provided by various organizations [38]. In this present investigation, the health risks associated with the consumption of selected mango fruit varieties (Dasheri and Langra) contaminated with four heavy metals viz., Cd, Cr, Pb, and As, were assessed using the THQ and HRI methods. HRI is computed using the THQ of the sum of the participating heavy metals, where an HRI value below 1 indicates no potential health hazard. However, if the HRI value exceeds the limit of 1, it indicates that serious health problems could occur in humans [39]. The results presented in Table 4 show that the child group had relatively higher THQ and HRI values for all heavy metals compared to the adult group. However, the decreasing order of the THQ values for the specific heavy metals was Cr > As > Cd > Pb, suggesting that Cr had the largest contribution to the HRI computation. Moreover, the HRI did not exceed the upper threshold limit of 1, where the highest value was observed at the Saharanpur site, i.e., 0.362 (child) and 0.083 (adult) for Dasheri, and 0.256 (child) and 0.058 (adult) for the Langra mango fruit varieties. Although the Dasheri variety showed greater HRI values among all the sampling locations, they were still lower than those for the Langra variety from two locations viz., Deoband and Behat. Overall, the safest sampling location was identified as Behat for Dasheri (HRI = 0.118 for the child group and 0.027 for the adult group) and Rampur Maniharan (HRI = 0.066 for the child group and 0.015 for the adult group) had minimal HRI values. Therefore, the results of the health risk study were consistent with the IDW interpolation results, as shown in the comparable distribution maps.

Table 4. Health risk index of heavy metal contents in selected mango fruit (*M. indica*) variety samples collected from Saharanpur district, Uttar Pradesh, India.

Sampling Sites	Mango Variety	Target Hazard Quotient (THQ)								Health Risk Index (HRI) ^	
		Cd		Cr		Pb		As			
		Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Nakur	Dasheri	0.016	0.004	0.035	0.008	0.013	0.003	0.161	0.037	0.224	0.051
	Langra	0.024	0.006	0.015	0.003	0.000	0.000	0.147	0.034	0.186	0.043
Gangoh	Dasheri	0.040	0.009	0.106	0.024	0.006	0.001	0.107	0.024	0.259	0.059
	Langra	0.032	0.007	0.103	0.024	0.014	0.003	0.067	0.015	0.216	0.049
Sarsawa	Dasheri	0.024	0.006	0.068	0.016	0.003	0.001	0.161	0.037	0.256	0.059
	Langra	0.032	0.007	0.096	0.022	0.010	0.002	0.027	0.006	0.165	0.038
Deoband	Dasheri	0.024	0.006	0.085	0.019	0.003	0.001	0.080	0.018	0.193	0.044
	Langra	0.016	0.004	0.024	0.006	0.002	0.000	0.161	0.037	0.203	0.046
Saharanpur	Dasheri	0.064	0.015	0.103	0.024	0.007	0.002	0.187	0.043	0.362	0.083
	Langra	0.040	0.009	0.067	0.015	0.015	0.003	0.134	0.031	0.256	0.058
Chhutmalpur	Dasheri	0.048	0.011	0.089	0.020	0.003	0.001	0.027	0.006	0.167	0.038
	Langra	0.040	0.009	0.055	0.013	0.002	0.000	0.013	0.003	0.110	0.025
Behat	Dasheri	0.032	0.007	0.084	0.019	0.002	0.000	0.000	0.000	0.118	0.027
	Langra	0.016	0.004	0.094	0.021	0.002	0.000	0.067	0.015	0.179	0.041
Biharigarh	Dasheri	0.008	0.002	0.077	0.018	0.000	0.000	0.134	0.031	0.219	0.050
	Langra	0.016	0.004	0.025	0.006	0.012	0.003	0.027	0.006	0.080	0.018
Chilkana	Dasheri	0.048	0.011	0.068	0.016	0.003	0.001	0.067	0.015	0.186	0.043
	Langra	0.024	0.006	0.045	0.010	0.002	0.000	0.027	0.006	0.098	0.022
Nagal	Dasheri	0.032	0.007	0.049	0.011	0.009	0.002	0.094	0.021	0.184	0.042
	Langra	0.016	0.004	0.017	0.004	0.004	0.001	0.040	0.009	0.078	0.018
Rampur Maniharan	Dasheri	0.040	0.009	0.071	0.016	0.000	0.000	0.120	0.028	0.231	0.053
	Langra	0.024	0.006	0.036	0.008	0.006	0.001	0.000	0.000	0.066	0.015
Nanauta	Dasheri	0.048	0.011	0.077	0.018	0.013	0.003	0.054	0.012	0.192	0.044
	Langra	0.032	0.007	0.021	0.005	0.007	0.002	0.040	0.009	0.101	0.023

^: HRI > 1 indicates a potential health hazard.

In recent studies, the THQ and HRI tools have been successfully used to compute the critical health hazards of heavy-metal-contaminated fruits and vegetables. A study carried out by Kumar et al. [40] found that the HRI tool had good performance in determining the health hazards of six heavy metals present in white button (*Agaricus bisporus*) mushrooms cultivated on sewage-sludge-amended compost. The HRI value was below 1 for the child and adult groups, which demonstrated the safe consumption of harvested mushrooms. Similarly, Islam et al. [36] performed health risk studies of heavy metals (Cr, Ni, Cu, As, Cd, Pb, As, and Pb) in selected vegetables and fruits collected from the Bogra district of Bangladesh. They revealed that the THQ and HRI values almost reached elevated levels of As and Pb, indicating a potential health hazard. Similarly, Qureshi et al. [41] conducted a study to determine the health risks of heavy metal accumulations in mango fruits cultivated using treated wastewater as an irrigation source in Dubai, UAE. They reported that the arable soils irrigated with wastewater retained significant loads of heavy metals (Cu, Fe, Zn, Cr), which later accumulated in the cultivated fruits and vegetables. The health risk study confirmed that the heavy metal absorption rate (bioaccumulation factor) was positively correlated with the estimated daily intake (EDI), which again depends on the type of fruit or vegetable grown in the contaminated soils. As confirmed from the above-discussed reports, the findings of the current study are in strong agreement with the fact that the heavy metals accumulated by mango fruits could have been associated with several anthropogenic activities that occurred in and around the mango orchards.

4. Conclusions

The findings of this study concluded that the two mango fruit (*M. indica*) varieties (Dasheri and Langra) collected from selected locations in the Saharanpur district, Uttar

Pradesh, India, had considerable levels of the selected heavy metals (Cd, Cr, Pb, and As). The decreasing levels of heavy metals in mango fruit varieties followed the order of Cr > Pb > As > Cd. However, the Dasheri variety showed significantly ($p < 0.05$) elevated levels of all heavy metals. The multivariate analysis confirmed that the most polluted location was Saharanpur city. Although the health risk studies showed that there were no potential health risks associated with the consumption of both mango varieties, the child group showed high-risk index values compared to the adult group. The study found that the heavy metal contamination of mango fruits in the Saharanpur district could be due to the excessive use of chemical substances (fertilizers, pesticides, and insecticides) and certain anthropogenic activities near the urban settlements, which ultimately pollute the orchard soils. Further studies on the biomonitoring of additional hazardous heavy metals in soils and other mango varieties are highly recommended.

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