Risk Assessment of Heavy Metals in Basmati Rice: Implications for Public Health

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Abstract: Basmati rice is increasingly recognized and consumed in different parts of the world due to its different tastes and nutritional properties. This research focused on determining the cadmium (Cd), cobalt (Co), Copper (Cu), iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn) content in locally grown basmati rice in Pakistan and assessing the risks of these values to human health. Root, shoot and grain samples of basmati rice were taken, along with soil samples from the five regions studied. Metal mean concentrations (mg/kg) in grains fluctuated from 2.70 to 9.80 for Cd, 4.80 to 9.85 for Zn, 1.16 to 1.46 for Cu, 1.84 to 10.86 for Co, 2.05 to 13.07 for Fe, 5.03 to 11.11 for Mn and 3.24 to 13.28 for Ni, respectively. All metal values were within permissible limits except for Cd. The enrichment factor for Cd was highest among all sites. Cobalt and zinc had the highest bioaccumulation factor and translocation factor. The highest enrichment factor was noticed for Cd and the lowest for Cu. The health risk index at all examined sites was less than one. Consistent examination is recommended to limit health hazards instigated by the use of rice polluted with a greater concentration of Cd.

Keywords: Basmati; daily intake of metals; contamination factor; Oryza sativa; trace element

1. Introduction

In Pakistan, rice is the staple food crop that provides a significant amount of nutrition and vitamins [1]. Rice contains 3% nutritive fat and 20% proteins and provides 27% nutritive energy [2]. Rice is characterized by its nature to grow on acidic and alkaline soil. It can also grow in arid areas [3]. Punjab and Sind are renowned for rice production in Pakistan [4]. Approximately 60–70% of individuals in these provinces use rice as food; 6.0 million tons of rice are produced by Pakistan annually and it exports almost 4.0 million tons, with the remaining 2.0 million tons being the approximate annual consumption of
rice. Prices are comparable to those of local competitors, especially India, and therefore Pakistani exporters can maintain their share of the world market [3].

Those elements having a density higher than 4 g/cm$^3$ are considered heavy metals [5]. Elements such as cadmium (Cd), nickel (Ni) and copper (Cu) accumulate in edible and non-edible parts of plants [6,7]. In small amounts, these elements function as micronutrients, while in large amounts they are considered toxic [8]. Growing crops on polluted soil can present a severe danger to human life [9–11]. Industrial effluents and mining are significant causes of toxicity [12,13]. The burning of waste material, the exhaust of vehicles, the application of chemical fertilizers and the treatment of sewage sludge as fertilizer on agronomic land are the primary causes of contamination [14].

Application of pesticides, improper disposal of waste material and distinctive deposition can also cause metals pollution [15]. Growing food crops on polluted soil causes metal toxicity in food crops [16,17]. Elements in the soil diffuse into food chains through bioaccumulation [18]. As a result, these metals affect human beings and plants [19,20].

High metal concentrations can increase the soil’s potential to accumulate these elements [21]. Heavy metals have a mobile structure that can be transported from soil to plants [22]. These elements show mobility between root and shoots, and between shoots and grains. Contaminated crops may expose people to various serious diseases [23–25]. Heavy metals are supported by many studies to be carcinogenic, and also cause blood, bone, heart and kidney diseases [26–29]. Small concentrations of heavy metals can be quite harmful to living things. For example, alveolitis, bronchitis, and emphysema result from ingesting small concentrations of Cd. Kidney problems are also caused by inhalation of Cd [30]. Cd toxicity also causes nerve and bone diseases in humans [31]. While low concentrations of Zn are responsible for many physiological functions in the body, higher concentrations pose a serious threat to life [32]. Excessive Cu concentration causes diarrhoea, nausea and Wilson’s disease [33,34].

As human beings consume contaminated rice, metals accumulate in body parts. Therefore, the aim of this research was to evaluate Ni, Co, Fe, Cd, Zn and Mn content in regionally cultivated rice and assess the nutritive hazards related to the consumption of $Oryza sativa$ among native inhabitants. The objective of the study was to calculate the hazard posed by heavy metals in primarily rice-cultured areas of Jhang. Accumulations of dangerous elements were measured in soil and parts of rice plants to evaluate the bioaccumulation factor and translocation factor.

2. Materials and Methods

2.1. Study Area

Agronomic fields in Jhang district were chosen as a study area (Figure 1). Jhang is located in Punjab province, Pakistan. Most of the land, almost 8809 km$^2$, is agronomic, excluding the area near the Chenab River. The district receives an average of 150 mm (https://jhang.punjab.gov.pk/climate, accessed on 29 July 2021) annual rainfall, with irregular rainfall taking place in winter. Five agricultural sites were carefully selected near the side of Moza Satiana Chiniot road to investigate metal contents in randomly collected basmati rice (grain, root and shoot) and soil samples. All sites were selected to determine the level of contamination in rice crops due to canal water irrigation.

2.2. Soil

From five cultivation sites treated with water from the canal, four samples (each sample with five replicates) of soil and Basmati rice were collected. Soil was taken from a depth of 15 cm from the examined area by using a sterilized augur, applying the method of Sanchez [35]. Samples were first sun-dried then shifted to an oven at a temperature of 105 °C.
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2.3. Roots, Shoots, Grains

By using a sterilized apparatus, four samples of Basmati (rice variety) roots, shoots and grains from five different sites were collected (each sample with five replicates). Distilled water was applied to the samples to eradicate soil particles and then HCl was added for dilution purposes. Sun-dried samples were shifted to an oven for five days’ drying at a temperature of 105 °C.

2.4. Digestion of Soil, Grains, Roots and Shoots Samples

After drying in the oven continuously for five days, the samples were pulverised into powder form via pestle and mortar. By following Vukadinović and Bertić [36]’s “Wet Digestion Method”, 2 g of each powdered sample was digested. After this process, samples were transferred to digestion booths. An amount of 10 mL of 1:3 aqua regia HNO₃:HCl solution was poured into each beaker containing root, shoot, soil and grain samples. Digested samples were left overnight. Subsequently, hot plates containing each sample solution were heated at 70 °C for 4 h. H₂O₂ (2 mL) was continuously added and the solution was then further heated at 70 °C for 4 h until becoming colourless. The solution was filtered through 42 µm filter paper after cooling. Distilled water was added to increase each sample to a volume of 50 mL.

2.5. Metal Analyses

Filtered samples after digestion were run through an atomic absorption spectrophotometer (AAS) (Model: AA-6300, Shimadzu, Kyoto, Japan) to analyze element concentration. For accurate results, the following technique was applied: optical emission immersion was used to find the concentration of the metals under study, for which the instrument operating conditions are given in Table 1.
Table 1. Atomic absorption spectrophotometer operating parameters for determination of heavy metal levels.

| Metal | Cd  | Co  | Zn  | Fe  | Cu  | Mn  | Ni  |
|-------|-----|-----|-----|-----|-----|-----|-----|
| Wave length (nm) | 228.8 | 250.0 | 213.9 | 248.3 | 324.8 | 279.5 | 232.0 |
| Lamp current low (mA) | 8 | 9.5 | 8 | 12 | 6 | 12 | 12 |
| Slit width (nm) | 0.7 | 0.2 | 0.7 | 0.2 | 0.7 | 0.2 | 0.2 |
| Air flow rate (L/min) | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Burner height (mm) | 7 | 10 | 7 | 9 | 7 | 9 | 7 |

2.6. Quality Control

All necessary procedures and precautions were followed during analyses. To obtain precise outcomes from the AAS, chemicals and salts required for digestion were obtained from E. Merck (Germany) with a certified purity of 99%. Standard preparation precautions were sustained during the experiment. Metal absorption in rice and soil was determined on a dry weight basis. Each sample was analysed three times.

2.7. Statistical Analysis

SPSS 20 was employed to find correlation and variance. A one-way ANOVA was used to check variance and correlation (association between rice and soil). The variance between metals for each soil and rice sample was determined to be 0.001, 0.01 and 0.05, according to Steel and Torrie [37].

2.8. Bioaccumulation Factor

Bioaccumulation factor (BAF) was calculated via the equation determined by Cui et al. [38].

\[ \text{BAF} = \frac{\text{Element conc. (mg/kg) at edible part of Oryza sativa}}{\text{Element conc. (mg/kg) in soil}} \]

2.9. Translocation Factor (TF)

Translocation factor (TF) was calculated according to Liu et al. [39].

\[ \text{TF} = \frac{\text{Element conc. (mg/kg) in shoot}}{\text{Element conc. (mg/kg) in root}} \]

2.10. Pollution Load Index (PLI)

The pollution load index (PLI) determines the level of metal pollution in soil by applying the following formula [39]:

\[ \text{PLI} = \frac{\text{Element conc. (mg/kg) in soil}}{\text{Element conc. in referenced soil}} \]

2.11. Enrichment Factor

Enrichment factor (EF) determines metals availability in soil and variance in growth rate [40].

\[ \text{EF} = \frac{\text{Element conc. (mg/kg) at edible part of Oryza sativa}}{\text{Element conc. (mg/kg) in examined soil}} \times \frac{\text{Element conc. (mg/kg) in edible part of Oryza sativa}}{\text{Standard Element conc. (mg/kg) of metal in soil}} \]

2.12. Daily Intake of Metals

The daily intake of metal (DIM) in the human body was evaluated using the following equation [41].

\[ \text{DIM} = C_{\text{metal}} \times \frac{C_{\text{daily food intake}}}{B_{\text{average weight}}} \]

\( C_{\text{metal}} \) designates the concentration of elements, 
\( C_{\text{daily food intake}} \) designates the daily intake of food crops mg/kg/person/day, and 
\( B_{\text{average weight}} \) designates the average body weight of a person. The daily intake of rice and average body weight of a person were assumed as 0.345 mg and 60 kg respectively [42,43].
2.13. Health Risk Index

The health risk index (HRI) indicates the hazard to individuals who consume contaminated food crops. It was determined by applying the equation from [44]:

\[
HRI = \frac{DIM}{RFD}
\]

If HRI is greater than 1 it designates harmfulness whereas if less than 1 it designates harmless conditions for human health.

\(RFD\) refers to an oral reference dose.

3. Results

ANOVA found that site location significantly \((p < 0.05)\) influenced element concentration in the soil of Basmati rice fields (Table 2). At all soil sites, the value of Cd was higher, while the values of Fe and Mn were lower (Figure 2). Significant concentrations of Ni, Co, Fe, Cd, Zn, Cu and Mn content were found at different sites (Table 2). In rice plant roots, the levels of Cu and Co were highest, while Ni was low at all sites (Figure 3).

### Table 2. ANOVA for heavy metals in soil and roots, shoots and grains of Basmati rice.

| Source of Variation | Degree of Freedom | Mean Square          |
|---------------------|-------------------|----------------------|
|                     |                   | Cd       | Zn       | Cu       | Co       | Fe       | Mn       | Ni       |
| Paddy Soil          | 4                 | 0.206    | 0.004    | 0.004    | 0.002    | 0.002    | 0.003    | 0.002    |
|                     | 10                | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    |
| Root                | 4                 | 0.158 ***| 0.073 ***| 0.001 ***| 0.001 ***| 0.124 ***| 0.002 ***| 0.001 ***|
|                     | 10                | 0.002    | 0.001    | 0.001    | 0.001    | 0.002    | 0.001    | 0.001    |
| Shoot               | 4                 | 0.003 ***| 0.002 ***| 0.003 ***| 0.002 ***| 0.002 ***| 0.002 ***| 0.001 ***|
|                     | 10                | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    |
| Grain               | 4                 | 0.004 ***| 0.002 ***| 0.001 ***| 0.002 ***| 0.002 ***| 0.003 ***| 0.002 ***|
|                     | 10                | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    | 0.001    |

***: Significant at 0.001 level.

![Figure 2. Dispersal of heavy metals in paddy soil at the five sites.](image-url)
The outcomes from the ANOVA revealed a significant effect of sites on Ni, Co, Cd, Zn, Cu, Mn and Fe content in rice shoots (Table 2). In these shoots, the values of Cu and Co were highest, while Ni was low at all sites (Figure 4).

Examination of variance indicated significant influence of sites on element concentration (Cu, Ni, Co, Fe, Cd, Zn and Mn content) in Basmati grains (Table 2). In grains, the levels of Cu and Co were the highest, while Ni was low at all sites (Figure 5).

Variance in the degree of contamination between sites was determined using the PLI [45]. Pollution load index values greater than one are considered polluted, while PLI values less than one are considered unpolluted [46]. The value of PLI for all metals at all sites was less than one, indicating that the soil of all sites was safe (Table 3).
Figure 4. Variation in concentration of heavy metals in rice shoots from the five sites.

Examination of variance indicated significant influence of sites on element concentration (Cu, Ni, Co, Fe, Cd, Zn and Mn content) in Basmati grains (Table 2). In grains, the levels of Cu and Co were the highest, while Ni was low at all sites (Figure 5).

Variance in the degree of contamination between sites was determined using the PLI [45]. Pollution load index values greater than one are considered polluted, while PLI values less than one are considered unpolluted [46]. The value of PLI for all metals at all sites was less than one, indicating that the soil of all sites was safe (Table 3).

Figure 5. Variation in concentration of heavy metals in rice grains from the five sites.

At Site-I, BAF of Cd, Mn, Zn and Fe was higher than that of Cu, Co and Ni. At Site-II, BAF of Cu, Fe and Zn was lower than that of Co, Mn, Cd and Ni. At Site-III, BAF of Fe, Ni, Mn and Zn was higher than that of Co, Cu and Cd. At Site-IV, BAF of Ni, Cd and Mn was lower than that of Cu, Zn, Fe and Co. At Site-V, BAF of Mn, Fe, Cu and Zn was higher than that of Co, Ni and Cd. Across the five various sites, Co and Mn displayed the highest BAF while Cd and Cu displayed the lowest BAF (Table 3).

Levels of diffusion of metals from soil to rice grains diverged among sites, as the EF of the tested elements at the five various sites was as follows: Cd (1.7705–7.355), Zn (0.2100–0.6834), Cu (0.2376–2.0131), Co (0.4147–0.9767), Fe (0.2989–0.6309), Mn (0.0577–0.6131), and Ni (0.1418–0.9392).

Table 3. Pollution load index, Bioaccumulation, enrichment and translocation factors for Basmati rice.

| Metal | Site-I | Site-II | Site-III | Site-IV | Site-V |
|-------|--------|---------|----------|---------|--------|
| Cd    | 0.0928 | 0.9732  | 0.1924   | 0.7707  | 0.6510 |
| Zn    | 0.3235 | 0.2779  | 0.3681   | 0.2318  | 0.2763 |
| Cu    | 0.4217 | 0.5389  | 0.2989   | 0.2938  | 0.4114 |
| Co    | 0.4767 | 0.3441  | 0.4845   | 0.6279  | 0.5504 |
| Fe    | 0.3222 | 0.1287  | 0.2338   | 0.3390  | 0.1103 |
| Mn    | 0.3285 | 0.2631  | 0.3491   | 0.3059  | 0.2414 |
| Ni    | 0.7139 | 0.0433  | 0.2624   | 0.9296  | 0.3761 |

Pollution load index

| Site | Cd | Zn | Cu | Co | Fe | Mn | Ni |
|------|----|----|----|----|----|----|----|
| Site-I | 0.0928 | 0.3235 | 0.4217 | 0.4767 | 0.3222 | 0.3285 | 0.7139 |
| Site-II | 0.9732 | 0.2779 | 0.5389 | 0.3441 | 0.1287 | 0.2631 | 0.0433 |
| Site-III | 0.1924 | 0.3681 | 0.2989 | 0.4845 | 0.2338 | 0.3491 | 0.2624 |
| Site-IV | 0.7707 | 0.2318 | 0.2938 | 0.6279 | 0.3390 | 0.3059 | 0.9296 |
| Site-V | 0.6510 | 0.2763 | 0.4114 | 0.5504 | 0.1103 | 0.2414 | 0.3761 |

Bioaccumulation factor

| Site | Cd | Zn | Cu | Co | Fe | Mn | Ni |
|------|----|----|----|----|----|----|----|
| Site-I | 0.8129 | 0.6891 | 0.4147 | 0.4682 | 0.6611 | 0.7237 | 0.6001 |
| Site-II | 0.9873 | 0.4753 | 0.3212 | 0.6309 | 0.4245 | 0.6559 | 0.6105 |
| Site-III | 0.4453 | 0.7264 | 0.4952 | 0.5292 | 0.6834 | 0.6170 | 0.6482 |
| Site-IV | 0.2574 | 0.4688 | 0.5172 | 1.1664 | 0.6779 | 0.4231 | 0.3587 |
| Site-V | 0.2376 | 0.5559 | 0.3380 | 0.2930 | 0.3279 | 0.4462 | 0.2603 |

Enrichment factor

| Site | Cd | Zn | Cu | Co | Fe | Mn | Ni |
|------|----|----|----|----|----|----|----|
| Site-I | 6.0563 | 0.3045 | 0.1731 | 2.0131 | 0.0884 | 0.0677 | 0.5437 |
| Site-II | 7.355 | 0.2100 | 0.1348 | 2.7130 | 0.0568 | 0.0613 | 0.5531 |
| Site-III | 3.3177 | 0.3210 | 0.2077 | 2.2754 | 0.0914 | 0.0577 | 0.5873 |
| Site-IV | 1.9173 | 0.2072 | 0.2161 | 5.0155 | 0.0907 | 0.0396 | 0.3250 |
| Site-V | 1.7705 | 0.2457 | 0.1418 | 1.2601 | 0.0439 | 0.0417 | 0.2358 |

Translocation factor

| Site | Cd | Zn | Cu | Co | Fe | Mn | Ni |
|------|----|----|----|----|----|----|----|
| Site-I | 0.9019 | 0.8824 | 0.9423 | 0.8721 | 0.9392 | 0.9157 | 0.8964 |
| Site-II | 0.9255 | 0.9616 | 0.6756 | 0.9068 | 0.7082 | 0.8914 | 0.9222 |
| Site-III | 0.8790 | 0.9781 | 0.5891 | 0.8909 | 0.8615 | 0.8528 | 0.8752 |
| Site-IV | 0.5572 | 0.8514 | 0.8640 | 0.8173 | 0.8491 | 0.7281 | 0.8753 |
| Site-V | 0.6312 | 0.7864 | 0.5625 | 0.8361 | 0.5740 | 0.7486 | 0.5931 |
At Site-I, BAF of Cd, Mn, Zn and Fe was higher than that of Cu, Co and Ni. At Site-II, BAF of Cu, Fe and Zn was lower than that of Co, Mn, Cd and Ni. At Site-III, BAF of Fe, Ni, Mn and Zn was higher than that of Co, Cu and Cd. At Site-IV, BAF of Ni, Cd and Mn was lower than that of Cu, Zn, Fe and Co. At Site-V, BAF of Mn, Fe, Cu and Zn was higher than that of Co, Ni and Cd. Across the five various sites, Co and Mn displayed the highest BAF while Cd and Cu displayed the lowest BAF (Table 3).

Levels of diffusion of metals from soil to rice grains diverged among sites, as the EF of the tested elements at the five various sites was as follows: Cd (1.7705–7.355), Zn (0.2072–0.3045), Cu (0.1418–0.2161), Co (1.2605–5.0155), Fe (0.0439–0.0914), Mn (0.0396–0.0677) and Ni (0.2358–0.0.5873) mg/kg individually (Table 4). At all sites, Cd and Zn had the highest translocation factor value, while Cu had the lowest TF value (Table 3).

Table 4. Daily intake of metal and health risk index of rice.

| Site       | Metal | Daily intake of metal | Health risk index | R<sub>pD</sub>* mg/kg/day) |
|------------|-------|-----------------------|-------------------|-----------------------------|
| Site-I     | Cd    | 0.0564                | 0.0378            | 1 × 10<sup>-3</sup>         |
|            | Zn    | 0.0566                | 0.0013            | 3 × 10<sup>-1</sup>         |
|            | Cu    | 0.0084                | 0.0010            | 4 × 10<sup>-2</sup>         |
|            | Co    | 0.0225                | 0.5235            | 43 × 10<sup>-2</sup>        |
|            | Fe    | 0.0697                | 0.0012            | 1 × 10<sup>-1</sup>         |
|            | Mn    | 0.0639                | 0.0003            | 14 × 10<sup>-1</sup>        |
|            | Ni    | 0.0536                | 0.0001            | 2 × 10<sup>-2</sup>         |

Source: * USEPA (2010).

At Site-I, DIM of Zn, Fe, Cd and Mn was higher than that of Cu, Co and Ni. At Site-II, DIM of Cu, Fe and Co was lower than that of Cd, Zn, Ni and Mn. At Site-III, DIM of Ni, Fe, Zn and Mn was greater than that of Cd, Cd and Co. At Site-IV, DIM of Zn, Cd and Cu was lower than that of Fe, Co, Ni and Mn. At Site-V, DIM of Fe, Co and Cu was lower than that of Cd, Zn, Mn and Ni. Among all five different sites, DIM of Fe and Ni was highest and of Co was lowest (Table 4).

HRI determines the extent of hazard arising from ingestion of food polluted with toxic elements [38,44]. Health risk index lower than one is suggested to be safe whereas if higher than one is considered dangerous for humans [44]. The HRI values for intake of rice from the various sites varied from 0.0001–0.785. This suggests that health risk index was minor, as no value exceeded one at any of the five various sites. (Table 4).

Cadmium exhibited a positive but non-significant correlation between soil and root levels and root and shoot levels; however, a significant positive correlation was determined between shoot and grain levels. Zn and Fe indicated a significant positive correlation between soil and root levels, root and shoot levels and shoot and grain levels. In another recent study, a definite significant association was found between root and shoot levels of metals and shoot and grain levels; however, the positive association was not significant between shoot and grain levels. The positive correlations found here reveal that elements from the specific conjoint origin as carbon-based substances were fundamental substances with adaptable availability of elements in soil (Table 5).
Table 5. Metal levels correlation between soil and root, root and shoot and shoot and grain of Basmati rice.

| Metal | Soil-Root | Root-Shoot | Shoot-Grain |
|-------|-----------|------------|-------------|
| Cd    | 0.169     | 0.664      | 0.893 *     |
| Zn    | 0.983 **  | 0.953 **   | 0.899 *     |
| Cu    | 0.548     | 0.480      | 0.820       |
| Co    | 0.815     | 0.986 **   | 0.919 *     |
| Fe    | 0.988 **  | 0.991 **   | 1.00 **     |
| Mn    | 0.981     | 0.949      | 0.978       |
| Ni    | 0.879     | 0.982      | 0.988       |

*, **: Significant at the 0.05 and 0.01 levels.

4. Discussion

In this study of metal elements in soil flooded via water from a canal, levels of Co and Ni were higher while levels of Mn, Fe, Cu and Zn were lower as compared to the findings of Jaishree et al. [47]. Levels of the investigated elements in soil samples obtained from all the examined cultivation sites were below the PML guidelines determined by European Union [48] except for Cd. The current study also found lower levels of Fe than the USEPA [49] suggested values.

In the present study, the mean concentration of metals in samples from five different sites, except for Cu, was higher than the results reported by Othman [50]. Greater absorption of metals indicated that rice plants hyper-accumulate these metals from soil to plant [38,40,51]. Cu level investigated in the current shoot samples was lower than while Zn, Mn, Fe and Cd levels were higher than the outcomes of Othman et al. [50]. Juen et al. [52] found values of Co (0.11 mg/kg) higher to those found in the present inquiry. Mean grain values of all studied elements were less than the maximum values given by FAO/WHO [53], excluding Cd. Yap et al. [13] recorded higher levels of Cd (0.14) and Cu (0.048) and lower levels of Zn (0.05), Co (0.07), Fe (0.34) and Ni (0.34) as compared to the current investigation. Eticha and Hymete [54] recorded higher levels of Mn (15.4 mg/kg) as compared to the present findings.

In these studies Cu, Cd, Ni and Zn pollution in soil was smaller than the standards advanced by Singh et al. [55] which were designated as Zn (44.19), Cd (1.49), Cu (8.39) and Ni (9.06 mg/kg). Cobalt (9.1 mg/kg) contamination in soil in the Dutch Standards [56] also exceeds levels found in the current study. Dosumu et al. [57]’s standard proposed an amount of Fe (56.9 mg/kg) PLI in soil significantly greater than that found in this investigation. Mn contamination in soil was less than the standard determined by Singh et al. [58], which was 46.75 mg/kg. The contamination load index at the five studied sites was highest for Co and lowest for Fe. In the current analysis, PLI for Ni was highest and for Cd was lowest, however, for all metals, PLI values were lower than one. The reasons for the lower pollution load index in the studied region may be due to the low industrial density and reduced application of canal water. This study indicated a lower pollution load index for Ni, Zn, Cu, Mn and Fe than found by Wajid et al. [59].

Bioaccumulation factor for Co, Zn, Fe, Ni, Mn, and Cu in the current analysis was higher than the levels determined by Badawy et al. [60]. BAF for all elements was lower than one, apart from Co. This may be because BAF depends on specific food crop types [38]. Greater BAF for Mn and Ni indicated greater accumulation ability of these metals from soil to rice grains [39].

Singh et al. [61]’s conclusions found a lower TF for Cd (0.82) and Zn (0.85) and a higher TF for Mn (1.38), Fe (1.27) and Ni (0.940 mg/kg) as compared to the current analysis. The mobility factor for Co (0.09 mg/kg) was less than as determined by Juen et al. [52]. The high mobility factors found for Cd and Zn suggests that Oryza sativa has the capacity to hyperaccumulate Zn and Cd from roots to shoots [61].
Brunetti et al. [62]'s outcomes indicated a higher EF for Zn (3.6 mg/kg), Ni (1.5 mg/kg), and Cu (1.4) and lower EF for Cd (1.8 mg/kg) as compared to the current analysis. The enrichment factor of Fe (3.40 mg/kg) and Mn (3.40 mg/kg) were higher in the findings of Singh et al. [61] as compared to this study. Absorption and accumulation of metals from soil to root and root to grains diverged from site to site [63].

In this study, the total amounts of Mn, Ni, Co and Zn were higher than the results found by Mahmood and Malik [64]. Daily intake of metals in the present study for all metals was lower than one. Ogunkunle et al. [65]'s results found a daily ingestion of Zn (0.083 mg/kg/d) that was lower than in this study. Balkhair and Ashraf [66] recorded higher DIM values for Mn (1.6) and Ni (5.2) mg/kg/person/day as compared to the present study. Daily consumption of Fe was less than the result found by Khan et al. [67], which was (0.195 mg/kg).

Satpathy et al. [68] recorded higher levels of Cd and Zn and lower levels of Cu compared to current findings. The HRI for Ni and Fe was lower than that found by Khan et al. [67]. The value of HRI for Co was higher than that found by Bibi et al. [69]. The HRI for Mn was lower than that found of Fan et al. [70]. Possible HRI via ingestion of rice for all metal was <1, indicating no health risk due to consumption of rice.

The study results indicated that the translocation of Zn and Fe from soil to root, from root to shoot and from shoot to grain showed significant association. The study of Khan et al. [67] also showed the same results for Zn and Fe. These findings indicate that these elements may pose an accumulation threat for basmati rice.

5. Conclusions

The results of the study showed that metal deposition occurred mostly in rice grains. Cd concentration in soil samples taken from the study area was above the standards set by FAO/WHO. In addition, a high pollution load index value was determined in the canal water used for irrigation of rice. These may be among the reasons for the high heavy metal accumulation values in the basmati rice samples used in the research. In addition to these, various other factors such as production waste, fertilizer application, herbicide sprays and various agricultural chemicals polluting the canal water are likely among the reasons for the high metal values in basmati rice. As such, the metal values in all commonly consumed grains such as basmati rice and the soil they grow in should be regularly tested, and the risks to human health should be monitored.

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