Soil to grain transfer factors of heavy metals in rice and health risk analysis in the vicinity of Narora Atomic Power Station (NAPS), Narora, India

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This study was conducted to investigate the uptake of heavy metals by rice grains and related health risk analysis to the people living around Narora Atomic Power Station, Narora, India. The mean heavy metal concentration for Cu, Pb, Mn, Cr, Co, Cd and Fe in soil was 27.95, 21.84, 21.71, 8.12, 5.18, 2.42 and 2300.9 mg kg⁻¹ respectively. The concentration of heavy metals in rice grain was 1.12, 0.237, 0.236, 0.086, 0.143, 0.034 and 63.24 mg kg⁻¹ for Cu, Pb, Mn, Co, Cd, Cr and Fe respectively. The rice grain accumulated all the heavy metals lesser than their concentration in the field soil. Soil to grain transfer factors for Cu, Mn, Pb, Co, Cd, Cr and Fe were 0.071, 0.015, 0.02, 0.032, 0.07, 0.005 and 0.04 respectively. The results showed that heavy metal uptake was different for different metals. The maximum transfer factor was for copper and minimum was for chromium. Total Hazard Quotient (THQ) was also calculated for all samples in accord with all metals which were lesser than significant value of 1.0.

Keywords: Heavy metals, Atomic Absorption Spectroscopy, Transfer factors, Total hazard quotient.

Introduction

The haphazard industrialization and broad use of agrochemicals have induced the soil pollution and human food quality deterioration. The presence of heavy metals in the atmosphere, soil, water and agricultural products may cause serious health problems, especially cardiovascular, kidney, nervous and bone diseases. Trace elements are required by plants to perform various physiological functions for completing their life-cycle but their accumulation in food crops is a cause of concern in modern times. Heavy metals like cadmium, chromium, lead and manganese are major contaminants in food supplies¹. Heavy metals enter the human body through inhalation and ingestion, but ingestion is the major route ². Bioaccumulation of heavy metals in food chain may be harmful to human health due to their persistent nature and potential toxicity³,⁴.

Soil contains natural elements and heavy metals coming from earth’s crust and distributed in ground formations⁵,⁶. The movement and accumulation of heavy metals in the soil-plant system involves several mechanisms, namely, run-off, capillary, leaching, re-suspension and root uptake etc.⁷. The bioavailability of heavy metals to crops is influenced by several factors such as nature of heavy metal, soil properties (soil type, pH, cation exchange capacity (CEC), nutrient status, organic matter content, redox potential, texture and characteristics of the deposition/composition), plant species, agronomic conditions etc.⁸,⁹,¹⁰. Evaluation of metal uptake by crops from soil is vital for human dose and risk assessment models¹¹,¹². The uptake of heavy metals from soil to crop is usually described by transfer factor (TF), which is the ratio of the concentrations of heavy metals in plant (mg Kg⁻¹ dry mass) to soil (mg Kg⁻¹ dry mass)¹³,¹⁴ and quantifies the bioavailability of heavy metals to agricultural products. Therefore, accurate measurement of the heavy metal content in soil and crops is required to assess the potential risk of heavy metal pollution in the vicinity of any industrial facility.

In the present study, heavy metal uptake in rice grains from the agricultural soil under natural conditions has been evaluated. The objective of this study was to evaluate the transfer factors for heavy metals in transplanted rice grains grown in kharif
season and risk analysis to human beings due to heavy metal ingestion through rice grains.

Material and methods

Study area

Narora Atomic Power station is situated at Narora, a village block in Bulandshahar district of Uttar Pradesh, approximately 150 km. from Delhi. NAPS, Narora is located at 28°09′N and 78°24′E with an average elevation from sea level of 174 meters. The area has a climate of hot summers in April to July and quite cold and foggy in November to February. Geographically, the area is that of Gangatic plain with highly fertile soils rich in alluvial silt and clay with high organic content. The soil from nuclear power plant site of the Ganga is richer in organic matter, clay and silt mainly. People of the area are mainly marginal farmers and labourers. The main water source is Ganga water supplied through canals for irrigation. Very little ground water is pumped out through electrically operated tube-wells.

Sample collection and preparation

A total of 26 sampling stations were identified, in the villages namely, Asadpur (2), Ramghat (3), Gunnau (3), Junavai (1), Gangagarh (1), Rasoolpur (1), Maharajpur (1), Dharakpur (2), Nibari (2), Belaun (4), Rampur (3), Silari (2) and Nandpur (1) based on the wind pattern of the study area. The rice grain samples were collected directly from agricultural fields at the time of harvest in the late October to early November (2010) along with their corresponding soil samples. The soil samples were collected from (0-15 cm. deep) from 12 locations of each field randomly and mixed to get a composite sample. Initially, the samples were air-dried at room temperature and finally dried in hot air oven at 110°C for 24 hours. The soil samples were homogenized by grinding and sieving through BSS-30 sieve.

The grain samples were de-husked and oven dried at 110°C for 24 hours. One hundred grams of the dried grain samples were taken in silica crucibles for ashing in the Muffle furnace at a temperature of 350°C for 90-125 hours till all the carbon present was eliminated. One gram of each grain sample and 1g of dried soil sample were digested under pressure in Teflon vessels using 7 ml of HNO₃:HClO₄ (9:1 v/v) in microwave digester (Model MARS, 2011, USA). After digestion and cooling, the mixtures were filtered through Whatman 42 filter papers and the volume was made up 50 ml with double distilled water.

Heavy metals analysis

Heavy metals were analyzed by Atomic Absorption Spectroscopy (Shimadzu, 6300) using air-acetylene flame. All reagents used were of analytical grade. A control sample was digested and analyzed with each batch of samples to validate the accuracy and precision of analytical methods. All samples were analyzed in triplicate and results were reproducible with ±3% error limit. The AAS characteristics during elemental quantification are given in the Table 1.

Transfer Factor and Total Hazard Quotient calculation

Transfer factors of heavy metals were calculated using the given formula:

\[ TF = \frac{\text{Conc. of heavy metals in rice}}{\text{Conc. of heavy metal in corresponding soil}} \]

Total Hazard Quotient (THQ) was calculated using the formula given by USEPA\textsuperscript{15}

\[ \text{THQ} = \frac{\text{EF}_r \times \text{ED} \times \text{FI} \times \text{MC} \times 10^{-3}}{\text{R}_f \text{D}_o \times \text{BW} \times \text{AT}} \]

Here, THQ= Total hazard quotient, \(\text{EF}_r\) = Exposure frequency (365 days/year), \(\text{ED}\) = exposure duration in years (65 years)\textsuperscript{16}, \(\text{FI}\) = food ingestion per day (kg/person/day) (0.208 kg per day)\textsuperscript{17}, \(\text{MC}\) = metal concentration in food (mg/kg on fresh weight basis), \(R_fD_o\) = oral reference dose (mg/kg/day), \(\text{BW}\) = average body weight (53 kg for Indian standard man), \(\text{AT}\) = averaging time for carcinogens (i.e. number of exposure years × days in a year). Oral reference doses were 4E-02, 1.4E-01, 4E-03, 3E-04, 1E-03, 5E-03, and 9E-03 FOR Cu, Mn, Pb, Co, Cd, Cr and Fe correspondingly\textsuperscript{18, 19}.

<table>
<thead>
<tr>
<th>Element</th>
<th>Wave length (nm)</th>
<th>Slit width (nm)</th>
<th>Flame system</th>
<th>Sensitivity (µg/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>217.0</td>
<td>1.3</td>
<td>Air - Acetylene</td>
<td>0.06</td>
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<tr>
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<td>0.7</td>
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<tr>
<td>Co</td>
<td>345.4</td>
<td>0.2</td>
<td>Air - Acetylene</td>
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<tr>
<td>Cr</td>
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<tr>
<td>Fe</td>
<td>372.0</td>
<td>0.2</td>
<td>Air - Acetylene</td>
<td>0.45</td>
</tr>
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</table>
Results and discussion

Heavy metals in soil samples

Heavy metals have a vital role in soil chemistry and eco-toxicology but high concentrations show tendency to deposit in plants and further in human and animal organs. In current study, soil and rice samples have significant concentrations of the studied heavy metals. In soil samples the order of heavy metals’ concentration was Fe > Cu > Pb > Mn > Cr > Co > Cd. Copper concentration in soil samples ranged from 6.4 - 97 mg kg\(^{-1}\) with an average of 27.95 mg kg\(^{-1}\) and geometric mean of 21.71 mg kg\(^{-1}\). Manganese concentration was in range of 3.6 - 35.5 mg kg\(^{-1}\) with geometric mean of 3.51 mg kg\(^{-1}\). Cadmium concentration ranged from 0.01 - 0.7 mg kg\(^{-1}\) with geometric mean of 0.21 mg kg\(^{-1}\). Cobalt was in the range of 0.33 - 2.21 mg kg\(^{-1}\) with arithmetic mean of 1.02 mg kg\(^{-1}\). Iron content ranged from 720 - 2820 mg kg\(^{-1}\) with a mean value of 2300.8 mg kg\(^{-1}\). The maximum intervention (above which remedial measures are necessary) for copper, 360 mg kg\(^{-1}\) with geometric mean of 3.51 mg kg\(^{-1}\), for cadmium, 3.9 - 21.5 mg kg\(^{-1}\) with an average of 8.12 mg kg\(^{-1}\) and geometric mean of 7.58 mg kg\(^{-1}\) and for lead, 190 mg kg\(^{-1}\) for copper, 360 mg kg\(^{-1}\) for chromium, 12 mg kg\(^{-1}\) for cadmium. Iron content ranged from 720 - 2820 mg kg\(^{-1}\) with a mean of 2300.89 and geometric mean of 2248.8 mg kg\(^{-1}\) (Table 2). Frequent range of heavy metals for agricultural soil is provided as: Cr (1-1000 mg kg\(^{-1}\)), Cd (0.01-0.7 mg kg\(^{-1}\)), Pb (2-200 mg kg\(^{-1}\)) and Cu (2-100 mg kg\(^{-1}\)). Cu and Cd were higher in some samples than Lindsay (1979) range.

The main factors which govern the movement of metals in soil include pH, electrical conductivity, organic matter, oxides & hydroxides and microorganisms. Hence, soil physico-chemical parameters were also measured for the soil. The results indicated that physico-chemical characteristics of the soil were significantly variable. The pH of the soil in the study area varied from 6.6 - 7.9, electrical conductivity 97.7 - 530.8 \(\mu\)S, cation exchange capacity 42.1 - 93.6 meq/100gm of soil, total organic carbon 2.5-3.63 per cent, total calcium 0.75-3.95 mg kg\(^{-1}\) and available sodium and potassium were 317-417 mg kg\(^{-1}\) and 102-622 mg kg\(^{-1}\) respectively. But, no significant correlation was found in metal concentrations and soil quality parameters. Although, slight correlations were found in lead and copper (\(r = 0.516; p \leq 0.01\)), cadmium and copper (\(r = 0.414; p \leq 0.05\)), lead and cadmium (\(r = 0.476; p \leq 0.05\)), iron and copper (\(r = 0.516; p \leq 0.01\)), cadmium and copper (\(r = 0.414; p \leq 0.05\)) and cadmium and copper (\(r = 0.414; p \leq 0.05\)).

Heavy metals in rice samples

The order of metal concentration in rice grain samples was: Fe > Cu > Mn > Pb > Cd > Co > Cr. No relationship was found in the metals with each other, of the rice samples. The copper concentration ranged from 0.33 - 2.21 mg kg\(^{-1}\) with arithmetic mean of 1.12 mg kg\(^{-1}\) and a geometric mean of 1.02 mg kg\(^{-1}\). Cu is essential for body and deficiency of it can

<table>
<thead>
<tr>
<th>Soil (mg Kg(^{-1}))</th>
<th>Cu (mg kg(^{-1}))</th>
<th>Mn (mg kg(^{-1}))</th>
<th>Pb (mg kg(^{-1}))</th>
<th>Co (mg kg(^{-1}))</th>
<th>Cd (mg kg(^{-1}))</th>
<th>Cr (mg kg(^{-1}))</th>
<th>Fe (mg kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>6.4</td>
<td>3.6</td>
<td>2</td>
<td>0.75</td>
<td>0.6</td>
<td>3.9</td>
<td>720</td>
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<tr>
<td>Max.</td>
<td>153.5</td>
<td>35.5</td>
<td>46</td>
<td>9.5</td>
<td>4.6</td>
<td>21.5</td>
<td>2820</td>
</tr>
<tr>
<td>Mean</td>
<td>31.79</td>
<td>21.71</td>
<td>21.84</td>
<td>4.06</td>
<td>2.42</td>
<td>8.12</td>
<td>2300.8</td>
</tr>
<tr>
<td>±SD</td>
<td>26.4</td>
<td>8.9</td>
<td>14.8</td>
<td>6.2</td>
<td>1.2</td>
<td>3.5</td>
<td>391.7</td>
</tr>
<tr>
<td>Rice (mg Kg(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>0.33</td>
<td>0.08</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>30.1</td>
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<tr>
<td>Max.</td>
<td>2.21</td>
<td>0.73</td>
<td>0.46</td>
<td>0.27</td>
<td>0.25</td>
<td>0.07</td>
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<tr>
<td>Mean</td>
<td>1.13</td>
<td>0.25</td>
<td>0.18</td>
<td>0.09</td>
<td>0.13</td>
<td>0.03</td>
<td>63.44</td>
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<tr>
<td>±SD</td>
<td>0.46</td>
<td>0.18</td>
<td>0.11</td>
<td>0.06</td>
<td>0.07</td>
<td>0.02</td>
<td>18.84</td>
</tr>
<tr>
<td>Transfer Factor of Heavy metals from soil to rice grains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>0.01</td>
<td>0.003</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.001</td>
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<tr>
<td>Max.</td>
<td>0.21</td>
<td>0.083</td>
<td>0.095</td>
<td>0.1</td>
<td>0.211</td>
<td>0.014</td>
<td>0.32</td>
</tr>
<tr>
<td>Mean</td>
<td>0.074</td>
<td>0.017</td>
<td>0.018</td>
<td>0.032</td>
<td>0.065</td>
<td>0.005</td>
<td>0.049</td>
</tr>
<tr>
<td>±SD</td>
<td>0.052</td>
<td>0.018</td>
<td>0.022</td>
<td>0.029</td>
<td>0.056</td>
<td>0.003</td>
<td>0.058</td>
</tr>
</tbody>
</table>
cause anaemia but in excess can cause Wilson’s disease\textsuperscript{24}, gastrointestinal, haematological and hepatic disorders. Manganese concentration was in range of 0.08 - 0.73 mg kg\textsuperscript{-1} with an arithmetic mean of 0.236 mg kg\textsuperscript{-1} and a geometric mean of 0.19 mg kg\textsuperscript{-1}. Manganese is ubiquitous in nature, essential for normal growth and physiological functioning but in high concentrations can cause Manganism; a syndrome characterized by weakness, lethargy, tremors, psychological disturbances and impotency\textsuperscript{15}. Comparatively elevated manganese content was reported by Batista \textit{et al} (2010)\textsuperscript{25} in rice from Brazil.

Lead was present in the range of 0.003 - 0.46 mg kg\textsuperscript{-1} with an average of 0.237 mg kg\textsuperscript{-1} and geometric mean 0.18 mg kg\textsuperscript{-1}. Lead absorption depends on physical and chemical state in which lead is present, age and physiological status of the person. 20-30\% of Pb in adults and 50\% of Pb in children is absorbed through gastro-intestinal tract. Organic lead has greater tendency to absorb than inorganic lead\textsuperscript{26}. Lead excess in diet is specifically associated with neurological, musculoskeletal, ocular and developmental diseases. Concentration of cobalt was 0.02 - 0.27 mg kg\textsuperscript{-1} with a mean value of 0.086 mg kg\textsuperscript{-1} and geometric mean 0.06 mg kg\textsuperscript{-1}. Cobalt excess in diet can cause cardiovascular, developmental, hematological and respiratory damages. The range of cadmium was monitoring 0.032 - 0.25 mg kg\textsuperscript{-1} with an arithmetic mean of 0.143 mg kg\textsuperscript{-1} and geometric mean 0.12 mg kg\textsuperscript{-1}. Cadmium causes ailments of respiratory, gastrointestinal, cardiovascular systems and is a known carcinogen\textsuperscript{27}. Chromium concentration was 0.01 - 0.07 mg kg\textsuperscript{-1} with an average value of 0.034 mg kg\textsuperscript{-1} and geometric mean 0.03 mg kg\textsuperscript{-1}. Chromium is a known carcinogen and responsible for immunological, renal and respiratory ailments when consumed in higher quantities\textsuperscript{25}. The iron content was in the range of 30.1-102 mg kg\textsuperscript{-1} with arithmetic mean of 63.24 mg kg\textsuperscript{-1} and geometric mean 60.33 mg kg\textsuperscript{-1}. (Table 2) Iron is useful for the body and seldom exceeds in concentration in the food unless there is contamination in soil and shortage of iron in food can cause anemia, gastrointestinal diseases, nose bleeding and myochordial infarction\textsuperscript{28}.

Solidum \textit{et al} (2012)\textsuperscript{29} reported cadmium and chromium levels of 0.0127 - 0.043 mg kg\textsuperscript{-1} and 6.3× 10\textsuperscript{-6} - 6.5×10\textsuperscript{-6} mg kg\textsuperscript{-1} respectively, in rice from Philippine market which are quite low in comparison with this study. Higher lead concentration (61.17 mg kg\textsuperscript{-1}) was reported in rice from Oweri, South–Eastern Nigeria\textsuperscript{30}, while nickel and cadmium were non-detectable. Metal levels in rice were also compared with permissible limits in the food stuff given by various regulating bodies for different metals. Except Co which had slightly higher values (i.e. 0.1 mg kg\textsuperscript{-1}; EC, 2011)\textsuperscript{31} in 11 out of 26 samples, all other studied heavy metals were well within permissible limits. Copper content was significantly lower in all the rice samples than prescribed limits of 150 mg kg\textsuperscript{-1} by Prevention of Food Adulteration Act (1954). Manganese, lead, cadmium, chromium and iron also have their quantified concentration well below 5.0 mg kg\textsuperscript{-1} (USEPA, 2007)\textsuperscript{15}, 10 mg kg\textsuperscript{-1} (PFA, 1954), 0.3 mg kg\textsuperscript{-1} (WHO/FDA, 1993)\textsuperscript{16}, 0.1 mg kg\textsuperscript{-1} (USDA, 2006)\textsuperscript{32}, 10-60 mg day\textsuperscript{-1} (Kaplan \textit{et al}, 1993)\textsuperscript{33} respectively. A comprehensive graphical representation of heavy metals in soil and rice samples is given in Fig 1 and Fig 2.

Transfer factors of heavy metals

The mean transfer factors (TF) for Fe, Cu, Mn, Pb, Co, Cd and Cr were 0.04, 0.0712, 0.0149, 0.0156, 0.0305, 0.0643 and 0.0045 respectively. The TF for different heavy metals were in the range of 0.01 - 0.21 for Cu, 0.003 - 0.083 for Mn, 0.0 - 0.095 for Pb, 0.0 - 0.1 for Co, 0.0 - 0.211 for

![Fig 1](image-url)
Cd, 0.001 - 0.014 for Cr and 0.012 - 0.32 for Fe which shows quite variation (Table 2). This wide range of element concentration can be attributed to the soil chemistry and soil physico-chemical properties\(^1\). Uptake of Pb with Cd has been found to be positively correlated with a value of 0.621 of Pearson’s coefficient. Cu-Pb, Mn-Co, Cu-Co, Cu-Cd, Cu-Fe, Pb-Co, Fe-Co, Co-Cd, Fe-Cd showed marginal correlations.

### Target Hazard Quotient

Health risk from consumption of rice by populace of the studied area for the heavy metals monitored was evaluated using Target Hazard Quotient (THQ), a method of risk assessment provided by USEPA (2007)\(^1\). Using this method of assessment of risk due to heavy metals consumption, a population is likely to have hazardous impact if the value of THQ is \(\geq 1.0\).

But, in the present study all the values calculated are far below 1.0 (Table 3). THQ followed the following order: Fe > Co > Cd > Pb > Cu > Cr > Mn i.e. 2.8E-01 >1.21E-02 > 5.93E-03 > 2.17E-03 > 1.03E-03 > 2.5E-04 > 701E-05 respectively. Liu et al (2011)\(^3\) have also reported health risk assessment through rice consumption in the similar manner to be <1.0. In another study, it was found to be 9.15 for cadmium and 1.32 for nickel in rice grain while for other metals being well below 1.0, on a wastewater irrigated site. It indicates that there is no evident risk regarding heavy metals by the consumption of rice in the studied area\(^3\).

### Conclusion

Food being the main probable pathway for the exposure to toxic heavy metals along with drinking water makes it necessary to monitor its quality. Rice being the main food crop is very much accountable to be examining for heavy metals. In present study, all heavy metals in rice grain have their concentrations well within permissible limits, except cobalt having slightly higher amount in 11 samples. Cu, Cd and Fe showed the higher transfer in comparison of Mn, Pb, Co and Cr. Further studies under controlled conditions are required in aspect of transfer factors. Total hazard quotient for the studied heavy metals was found to be <1.0 making the rice grain to be safe for human diet structure.

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