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# Heavy Metals Contamination in Soil and Rice Grains and Associated Health Risk

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**Abstract:** Rice is a staple food for billions worldwide and increasingly threatened by heavy metal contamination. This review aimed heavy metal pollution in soil and the transformation of them into rice grains. The heavy metal concentration in the soil and rice of different countries was higher than the acceptable limit set by different international organizations like WHO. Without a doubt, the environment and people are at risk from heavy metals and the main cause of many physical illnesses in humans is contaminated food, which highlights the need of protecting one's health. Heavy metal contamination in rice is caused by industrialization, water irrigation, and other human interventions. Heavy metals enter the environment and the increase of heavy metals in soil and rice can be influenced by a number of factors, including geographic location, environmental conditions, farming methods, industrial waste effluents, and a lack of data and monitoring systems. Reports showed that heavy metal pollution in food crops specially rice grains which going to be very crucial concern for human health of the huge population taking rice every day. The heavy metal uptake from rice causes different diseases like heart disease, liver changes, renal problems, etc. Regular monitoring and strict laws enforced by the authorities after increasing awareness on industrial discharge should be recommended for the safety of soil and other grown crops as well as public health.

## 1. Introduction

Rice is cultivated as a main crop worldwide. Around the world, about 40% of people eat rice as the main staple diet (Shahriar *et al.*, 2023). Amino acids, vitamins, and minerals come from rice (Monira *et al.*, 2023). Transmission of toxic substances within the human food chain has become a global issue. Even in China, 15% of the agricultural land has been polluted with heavy metals (Genchi *et al.*, 2020). Our body needs some heavy metals at low levels (Rehman *et al.*, 2018). For instance, Mn, Fe, Cu, and Zn. But other metals, like Cr, Cd, Pb, and As are toxic and harmful (Wasim *et al.*, 2019). Arsenic (As), cadmium (Cd), chromium (Cr), and nickel (Ni) have been classified as group 1 carcinogens by The International Agency for Research on Cancer (IARC) (Zuliana, *et al.*, 2021). Rice is more vulnerable to pollution than other crops (Wei *et al.*, 2023). According to Williams, et al. (2007), the ability of rice to accumulate heavy metals is approximately three times that of wheat and seven times that of barley.

It poses a health risk. So, different international organizations have set the maximum acceptable limit to minimize health risks. Nonetheless, heavy metal(loid)s at concentrations beneath the Maximum Acceptable Concentration (MAC) may still pose health hazards (Wei *et al.*, 2023). According to certain research, prolonged exposure to low levels of As might result in non-cancerous conditions like high blood pressure, neurological issues, and possibly cancer (Lindsay & Maathuis, 2017). On the other hand, continuous exposure to elevated Cd levels can lead to adverse effects on the central nervous system, kidney malfunction, bone fractures, and lung malignancies (Hajeb *et al.*, 2014). As a strong neurotoxin, Pb can harm the neurological system, induce behavioral abnormalities, and delay development, particularly in children. It is crucial for public health and safety to evaluate and comprehend these health concerns (Mlangeni *et al.*, 2023). Therefore, in addition to MAC, several other parameters, including body weight, age, dietary habits, and long-term intake, must be considered in health risk assessments (Wei *et al.*, 2023). Comprehending and evaluating these elements in rice production is essential for assessing and mitigating the hazards linked to rice contamination (Mlangeni *et al.*, 2023).

Heavy metal(loid) is a threat to both humans and the environment. In the modern world, food contamination and contaminated food sources are the primary causes of many physical disorders, which emphasizes the need for health protection. Several processes were proposed to remove heavy metals to limit damages (Seo *et al.*, 2023, Errich, *et al.*, 2021; Deghles, *et al.*, 2019; Barakat *et al.*, 2011). Irrigation of water, industrialization, and other human activities could be the pathway of heavy metal contamination in rice (Shahriar *et al.*, 2023). Besides, heavy metals may come into the environment either from natural or anthropogenic sources (Shahriar *et al.*, 2023, Mohanty, *et al.*, 2023, Proshad *et al.*, 2019). Mlangeni *et al.*, (2023) narrated citing from different articles that, geographical location, environmental conditions, agricultural practices, industrial waste effluents, and a lack of data and monitoring systems can all affect the levels of As, Cd, and Pb in rice and rice paddies. They also mentioned that due to industrial pollution high levels of Cd and Pb are found in Ghana and Nigeria. Even in Senegal and Tanzania, pesticide residues were also found (Irunde *et al.*, 2022). With partial treatment or without treatment, most of the industries discharge the wastage on land or into surface water (Monira *et al.*, 2023). Thus, in both agricultural soil and irrigation water, levels of heavy metals should be determined (Laita *et al.*, 2024). This review aimed to assess the heavy metal contamination of soil, their transformation into rice grains, and their effects on humans.

The review was conducted based on existing literature and data related to the risk assessment of heavy metal contamination in rice grains. Over 30 articles on rice production in contaminated soils, and risk assessment on heavy metals in rice grains, published in different journals were identified. Several Peer-reviewed journal articles, books, reports, and online databases such as PubMed, Science Direct, Google Scholar, ResearchGate, Taylor & Francis, and Multidisciplinary Digital Publishing Institute (MDPI) were used. Keywords used in research are heavy metals, rice contamination, risk assessment, toxic metals in rice, health risks, etc. Different rice-producing countries like Bangladesh, Pakistan, Iran, Nigeria, Ghana India, and China were selected. The papers were selected considering the location of heavy metal contaminated sites. In the studies, an atomic absorption spectrometer (AAS), mercury analyzer, and inductively coupled plasma mass spectrometer (ICP-MS) were used to detect heavy metal levels in rice. And extraction of heavy metals in rice through an acidic digestion method was carried out in all studies (Abtahi *et al.*, 2017). For risk assessment, different models and frameworks like Estimation of daily intake (EDI) of metals through rice consumption, Hazard Quotient (HQ), and Hazard Index (HI) to assess non-carcinogenic risks, Cancer Risk (CR) analysis for carcinogenic metals were reviewed. The objectives of the study include:

- To evaluate the levels of heavy metal contamination in rice across different regions
- To assess the potential human health risk associated with heavy metal exposure through rice consumption
- To promote awareness and policy development for safer rice production and consumption

## 2. Risk Assessment

**Table 1.** Methods for Risk Assessment of Heavy Metal Exposure

| Risk Assessment Parameter | Formula | Description | References |
|---|---|---|---|
| **(i) Estimated daily intakes (EDIs)** | EDI= $\frac{C \times FIR}{BW}$ | C= metal concentration<br>FIR = food ingestion rate<br>BW = body weight | (Proshad *et al.*, 2019) |
| **(ii) Target Hazard Quotients (THQs)** | THQ= $\frac{EDI}{Df}$ | RfD= reference dose | (Mohanty *et al.*, 2023) |
| **(iii) Hazard Index (HI)** | HI = ∑THQs for all metals | Aggregate non-carcinogenic risk | (Mohanty *et al.*, 2023) |
| **(iv) Carcinogenic Risk (CR)** | CR=EDI × $CFS_O$<br>TCR = ∑CR | CR= carcinogenic risk, EDI= estimated daily intake, CSo= carcinogenic slope factor for metals TCR=Cumulative Cancer Risk | (Mohanty *et al.*, 2023) |

To assess health risks, the United States Environmental Protection Agency (USEPA) guidelines were followed by the researchers.

### *2.1 Estimated daily intake (EDI)*

Both the quantity of metal in the diet and the amount of food consumed daily have an impact on the daily intake of metals. The ability of a person to tolerate pollutants can also be influenced by their body weight. The EDI concept was developed to consider these concerns. Adults in Bangladesh typically consume 425 g of rice per day, making it the main diet consumed there (Yunus *et al.*,2019). Shahriar *et al.*, (2023) assigned a weight of 60 kg for each participant. Additionally, the typical amount of rice that a youngster eats was determined to be 200 g each day, and the weight was fixed at 25 kg by Shahriar et al. (2023). But Mohanty *et al.* (2023) used 70 kg for adults and 15 kg for children according to WHO and USEPA guidelines (USEPA, Risk based concentration table, 2010).

### *2.2 Target Hazard Quotients (HQs)*

The reference dose, or THQ, is the ratio of exposure to the hazardous element and is the highest level at which no adverse health consequences are expected (Shahriar *et al.*, 2023). The US EPA's Region III risk-based concentration table contains the THQ approach for each metal or loid (Smith, 1995). Df is the reference dosage for metals, while EDI is the estimated daily intake. Df is 0.001, 0.0035, 0.02, 0.003, 0.0003, and 0.0003 mg/kg/day for Cd, Pb, Ni, Cr, Hg, and As, respectively (USEPA, Risk based concentration table, 2010). THQ values greater than one indicate a negative noncarcinogenic impact on human health. THQ values below one, however, are regarded as safe for ingestion (Antoine *et al.,* 2017, Mohanty *et al.,* 2023).

### *2.3 Hazard Index (HI)*

The USEPA's risk assessment criteria served as the foundation for the development of the hazard index (HI), which was created to measure the possible noncarcinogenic effects of many heavy metals (USEPA, Screening level ecological risks assessment protocol for hazardous waste combustion facilities," in Appendix E: toxicity reference values (Cincinnati, Ohio: United States Environmental Protection Agency), 1999). According to the USEPA (2010), it is the total of the hazard quotients. Human health is negatively impacted by exposure to many elements if HI is larger than one. Mohanty *et al.,* (2023) mentioned that according to Proshad *et al.,* (2020), the magnitude of the adverse effect is thought to be proportionate to the sum of the metal exposures.

### *2.4 Carcinogenic Risk (CR)*

Mohanty *et al.,* (2023) described that the target carcinogenic hazards are associated with metals such as Cd and Pb, which have been demonstrated to cause cancer in humans. It can be estimated using the formula outlined in USEPA risk-based concentration (USEPA, Risk based concentration table, 2010). They also mentioned citing from (DemiRezen and Aksoy, 2006); (USEPA, Regional screening level (RSL) for chemical contaminants at Superfund sites, 2015) that oral cancer slope factors (CPSo) for Pb and Cd are 0.0085 mg $kg^{-1}$ $day^{-1}$ and 0.38 mg $kg^{-1}$ day-1, respectively. Low cancer-causing risks are indicated by TCR values less than 10−6, moderate cancer-causing risks by values between 10−5 and 10−4, and severe cancer-causing risks by values between 10−3 and 10−1.

## 3. Results and Discussions

A useful resource for comprehending soil contamination thresholds is **Table 2**, which lists acceptable limits for heavy metal concentrations in soil as determined by international and regional organizations. These restrictions act as standards for agricultural safety and environmental health.

The WHO has set a comparatively low limit of 0.8 mg/kg for cadmium (Cd). At 1.4 mg/kg, the United Kingdom allows a greater concentration. The Tianjin Standard (China), on the other hand, is much more stringent at 0.159 mg/kg, indicating worries about the dangers of heavy metals in Chinese soils. A much greater dose of 3.0 mg/kg is permitted under the European Union Standard (EU2002), indicating regional tolerance variations.

The WHO sets a cautious threshold of 50 mg/kg for zinc (Zn). In contrast, China's Tianjin Standard allows up to 115 mg/kg, which is more than twice the WHO limit. The most permissive is the European Union, which permits up to 300 mg/kg, reflecting the variety of industrial or agricultural soil.

WHO recommends a limit of 36 mg/kg for copper (Cu); however, the UK permits up to 63 mg/kg, which is almost twice as much. At 43.71 mg/kg, China's Tianjin Standard is more stringent. Once more, the EU Standard establishes a far higher allowable limit of 140 mg/kg, probably to account for industrial soil activity. The WHO sets a baseline of 100 mg/kg for chromium (Cr). A remarkably low 6.4 mg/kg is allowed in the UK, indicating more stringent local environmental regulations. Concerning soil type-specific hazards, China's Tianjin Standard distinguishes between limitations for paddy soil (124 mg/kg) and upland soil (107 mg/kg). At 150 mg/kg, the EU Standard establishes a far higher threshold.

**Table 2.** Permissible limits of heavy metals in soil for rice fields

| Heavy metals (mg/kg) / Country/ Organization | Cd | Zn | Cu | Cr | Pb | Ni | As | Hg | References |
|---|---|---|---|---|---|---|---|---|---|
| **European union standard** | 3.0 | 300 | 140 | 300 | - | - | - | - | (Wang *et al.*, 2015) |
| **WHO** | 0.8 | 50 | 36 | 100 | 85 | 35 | - | - | (Denneman & Robberse, 1990) |
| **United Kingdom** | 1.4 | - | 63.0 | 6.4 | 70 | - | - | - | (Ediene & Umoetok, 2017) |
| **Tianjin Standard, China** | 0.159 | 115 | 43.71 | 107D 124P | 32.83 | - | 16.64P 14.64D | 0.258 | (Wang *et al.*, 2015) |

D= upland soil, P= paddy soil

The United Kingdom restricts lead (Pb) concentrations at 70 mg/kg, but the WHO caps them at 85 mg/kg. The Tianjin Standard is more stringent, allowing 32.83 mg/kg. On the other hand, the EU standard permits the greatest amount of up to 300 mg/kg among the regions under comparison. The WHO has not established any limits for arsenic (As) or mercury (Hg). Mercury levels of 0.258 mg/kg and arsenic limitations of 16.64 mg/kg for paddy soil and 14.64 mg/kg for upland soil are included in the Tianjin Standard (China). These metals are not specifically covered by the EU standard in table 3.

In order to prioritize consumer health inside the European Union, the European Commission Legislation places strict limitations on polished rice, allowing a maximum of 200 µg/kg for iAs, 200 µg/kg for Cd, and 100 µg/kg for Pb. With a tAs limit of 300 µg/kg and relatively higher thresholds for Cd (400 µg/kg) and Pb (200 µg/kg), the WHO/FAO guidelines also adopt globally relevant norms. China has imposed strict standards, with China focusing on polished rice with 150 µg/kg for tAs and 200 µg/kg for Cd, while Turkey has a uniform limit of 100 µg/kg for all metals in rice.

The **Table 3** gives a thorough summary of the Maximum Allowable Limits (MCL) for lead (Pb), cadmium (Cd), total arsenic (tAs), and inorganic arsenic (iAs) in rice grains as set by different governments and international organizations. Because of variations in eating practices, regulatory priorities, and environmental factors, these limitations fluctuate greatly between areas.

Bangladesh, on the other hand, has established far higher limits, especially for Cd (2000 µg/kg), probably because the local soil and water naturally contain greater quantities of heavy metals. For iAs, Cd, and Pb in rice, the Vietnamese government sets universal thresholds of 200 µg/kg, guaranteeing a balance between agricultural practices and health protection. Other areas, like Ghana and Egypt, highlight the effect of processing on contamination levels by establishing limitations for both raw and polished rice. For instance, Egypt's higher Pb limit (300 µg/kg) matches regional conditions, but Ghana permits 100 µg/kg for iAs and 400 µg/kg for Cd in uncooked rice.

Safe trading practices are ensured by the Chile Bureau of Standards and the Southern America Trading Block, which line their boundaries with global standards. Furthermore, Nigeria has no stated limit for Pb but sets a higher limit for tAs at 300 μg/kg and Cd at 500 μg/kg.

**Table 3.** Maximum Allowable limit (MCL) for total arsenic, Cd and Pb (μg kg− 1) in rice grains as reported by various studies

| Organization | Description | iAs | tAs | Cd | Pb | References |
|---|---|---|---|---|---|---|
| **European Commission Legislation** | Polished rice | 200 | – | 200 | 100 | (Commission, 2011) |
| **WHO/FAO** | Polished rice | – | 300 | 400 | 200 | (Satpathy *et al.*, 2014) |
| **Turkish Bureau of Standards (TBS)** | Rice | – | 100 | 100 | 100 | (Gunduz & Akman, 2013) |
| **Southern America Trading Block** | Rice | – | 150 | 400 | 100 | (Meharg *et al.*, 2009) |
| **Chile Bureau of Standards (CBS)** | Polished rice | – | 200 | 400 | 100 | (Meharg *et al.*, 2008) |
| **China** | Polished rice | – | 150 | 200 | 100 | (Meharg *et al.*, 2009) |
| **Ghana Government** | Raw rice | 100 | – | 400 | 200 | (Rahman *et al.*, 2012) |
| **Vietnamese Government** | Rice | 200 | – | 200 | 200 | (Nguyen *et al.*, 2020) |
| **Bangladesh Government** | Rice | 500 | – | 2000 | 200 | (Islam *et al.*, 2014) |
| **Nigeria** | Rice | – | 300 | 500 | – | (Munera-Picazo *et al.*, 2014) |
| **Egypt** | Rice | 200 | – | 200 | 300 | (Mzengeza 2010) |

The variation in these limitations demonstrates how different regions handle heavy metal contamination in rice, depending on dietary intake, regulatory frameworks, and local contamination levels. These standards, which are based on scientific research and global recommendations, seek to safeguard public health while considering trade regulations and agricultural practices.

The concentrations of heavy metals in rice grains from Pakistan, China (Nanhu, Tongxiang, and overall), Australia, India, and Bangladesh are compared in the **Table 4**. Significant geographical variety is revealed by key findings, which reflect variations in agricultural methods and environmental contaminants.

India has the highest concentration of Cd (380 μg/kg), which is significantly higher than that of other regions. Pakistan (12 μg/kg) and Australia (8 μg/kg) record lower levels than China, which comes in second with 34 μg/kg. Bangladesh's somewhat elevated Cd levels (73 μg/kg) suggest that there may be localized contamination issues.

Bangladesh (5 μg/kg) and Pakistan (12 μg/kg) report much lower levels of Co than China (169 μg/kg), which has the highest concentration overall. Moderate Co levels (21 μg/kg) are also observed in Australia. The highest concentration of chromium (Cr) is found in Tongxiang, China (300 μg/kg), followed by Nanhu, China (250 μg/kg) and Pakistan (106 μg/kg). Bangladesh has the lowest Cr value

(119 µg/kg), while Australia and India have similar amounts (183 µg/kg and 144 µg/kg). The highest Ni concentration (476 µg/kg) is reported by China (overall), suggesting serious contamination. India (430 µg/kg) and Pakistan (137 µg/kg) also exhibit high amounts. The amounts reported by Australia (166 µg/kg) and Bangladesh (105 µg/kg) are lower but nonetheless significant.

**Table 4.** Heavy Metal Concentration in Rice Grains (Data from Reviewed Studies)

| Country \ Metals | Cd | Co | Cr | Ni | Pb | Cu | Mn | Zn | Reference |
|---|---|---|---|---|---|---|---|---|---|
| **Australia** | 7.5 | 21 | 144 | 166 | 375 | 2.9 | 24.4 | 17.1 | (Rahman *et al.*, 2014) |
| **Bangladesh** | 73 | 5 | 119 | 105 | 19 | 1.6 | 14.7 | 13.4 | (Rahman *et al.*, 2014) |
| **China (Overall)** | 34 | 169 | 199 | 476 | 355 | 3.3 | 9.4 | - | (Zhao *et al.*, 2014) |
| **India** | 380 | - | 183 | 430 | 830 | 2.2 | 1.7 | 16.8 | (Rahman *et al.*, 2014) |
| **Nanhu, China** | - | - | 250 | - | 250 | 5.5 | 36.3 | 23.2 | (Zeng *et al.*, 2011) |
| **Pakistan** | 12 | 12 | 106 | 137 | 140 | 7.7 | 9.7 | 14.6 | (Wasim *et al.*, 2019) |
| **Tongxiang, China** | - | - | 300 | - | 350 | 4.1 | 36.2 | 22.6 | (Zeng *et al.*, 2011) |

China (355 µg/kg) and Tongxiang, China (350 µg/kg) are the next two countries with the highest lead (Pb) concentrations, after India (830 µg/kg). Pb levels are significantly lower in Bangladesh (19 µg/kg) and Pakistan (140 µg/kg), while Australia has moderate levels (375 µg/kg). China (total) exhibits lower levels (3.3 mg/kg), but Pakistan (7.7 mg/kg) and Australia (2.9 mg/kg) indicate comparable Cu concentrations. Bangladesh has the lowest Cu levels (1.6 mg/kg), while Tongxiang, China has slightly higher levels (4.1 mg/kg). The greatest Mn concentrations are reported in Australia (24.4 mg/kg), Tongxiang, China (36.2 mg/kg), and Nanhu, China (36.3 mg/kg). Relatively lower amounts are reported by Bangladesh (14.7 mg/kg) and Pakistan (9.7 mg/kg).

The highest quantities of zinc (Zn) are found in Nanhu, China (23.2 mg/kg), and Tongxiang, China (22.6 mg/kg). Australia has slightly higher levels (17.1 mg/kg), whereas Bangladesh (13.4 mg/kg) and Pakistan (14.6 mg/kg) have moderate amounts.

## 4. Non-carcinogenic health risk assessment

With an emphasis on populations such as adults, children, and local residents, the **Table 5** offers a comparative overview of non-carcinogenic health risk assessment resulting from rice intake in different nations. In order to determine possible health effects, it computes hazard indices (THQ, HQ, and HRI) and assesses risks from particular heavy metals, including lead, cadmium, copper, Cr, zinc, and arsenic. Significant differences in risks between areas and demographic groupings are shown by the statistics.

High levels of lead and cadmium pose serious health dangers in Bangladesh, especially for young people. Pb has a THQ of 7.075 in adults and 8.0 in children, whereas Cd has a THQ of 15.7 in adults and 7.7 in children. These figures demonstrate how susceptible kids are to exposure to heavy metals, which calls for immediate attention to food safety. With a THQ of 0.8 for both adults and children, China has the highest reported value for arsenic (As) among the countries under study, indicating that it poses significant risks. Children have a slightly higher cumulative hazard index (HI) (2.0) than adults (1.9), which indicates that younger groups are more sensitive. Likewise, residents of China's Hunan Province are at high risk for cadmium (Cd) at 3.047 and zinc (Zn) at 0.771.

**Table 5:** Evaluation of non-carcinogenic risks associated with rice consumption in different countries

| Country | Risk Assessment | Individuals | As | Pb | Cd | Cu | Cr | Zn | HI | References |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bangladesh** | THQ | Adults | - | 7.075 | 15.7 | - | 0.0033 | - | - | (Shahriar *et al.*, 2023) |
| **Bangladesh** | THQ | Children | - | 8 | 7.7 | - | 0.0037 | - | - | (Shahriar *et al.*, 2023) |
| **China** | THQ | Adults | 0.8 | 0.1 | 0.6 | 0.3 | 0.0004 | - | 1.9 | (Fu *et al.*, 2014) |
| **China** | THQ | Children | 0.8 | 0.1 | 0.6 | 0.3 | 0.0009 | - | 2 | (Fu *et al.*, 2014) |
| **Hunan Province, China** | THQ | Local Inhabitants | - | 0.081 | 3.047 | 0.877 | 0.005 | 0.771 | 8.138 | (Wang *et al.*, 2018) |
| **India** | HQ | Adults | - | 0.209 | 0.024 | 0.006 | 0.001 | 0.128 | 1.36 | (Satpathy *et al.*, 2014) |
| **India** | HQ | Children | - | 0.399 | 0.046 | 0.011 | 0.002 | 0.235 | 2.61 | (Satpathy *et al.*, 2014) |
| **Iran** | HQ | Local Inhabitants | 5.23 | 0.14 | 0.15 | 0.32 | - | - | - | (Djahed *et al.*, 2018) |
| **Malaysia** | HQ | Adults | 0.51 | 0.051 | 0.47 | 0.4 | 0.0008 | 0.26 | 27.0 | (Praveena & Omar, 2017) |
| **Malaysia** | HQ | Children | 0.33 | 0.11 | 0.3 | 0.25 | 0.005 | 0.17 | 18.0 | (Praveena & Omar, 2017) |
| **Zhejiang, China** | HQ | Adults | 0.34 | 0.84 | 0.77 | - | - | - | - | (Huang *et al.*, 2013) |
| **Zhejiang, China** | HRI | Children | 0.44 | 1.09 | 1.00 | - | - | - | - | (Huang *et al.*, 2013) |

One of the highest recorded total hazard indices (HIs), 8.138, suggests significant cumulative exposure. Lead (Pb) and cadmium (Cd) are the main causes of the moderate health hazards in India. With a hazard index (HI) of 2.61 against 1.36 for adults, children's exposure levels are continuously higher than those of adults. This discrepancy highlights how youngsters in India are particularly susceptible to heavy metal pollution in rice. With the highest HRI of 5.23 for this element in the dataset, arsenic (As) stands out as a major issue in Iran. Despite the minimal dangers of lead (Pb) and cadmium (Cd), the levels of arsenic suggest possible health risks for the local population.

In a similar vein, Malaysia has dangerously high hazard indices (HI), especially for adults (27.0) and children (18.0). The main causes of these hazards are cadmium (Cd) and lead (Pb); however, zinc also plays a part. In Zhejiang, China, lead (Pb), cadmium (Cd), and arsenic (As) pose moderate dangers to both adults and children. With higher Pb (1.09) and Cd (1.00) readings than adults, children are more vulnerable. This pattern is in line with observations made worldwide that children are particularly vulnerable to exposure to heavy metals.

Lead (Pb) and cadmium (Cd) are the two heavy metals that are most problematic overall in all locations, and they make a substantial contribution to the cumulative hazard index (HI). Children are more susceptible to food exposure than adults, as evidenced by their constant higher risk levels. The biggest cumulative hazards are reported by nations like Bangladesh, Malaysia, and China's Hunan Province, highlighting the urgent need for measures to lower heavy metal pollution in rice and guarantee food safety.

**5. Carcinogenic Risk Assessment**

Research programs on the assessment of carcinogenic risk were carried out by many researchers. Here, a thorough analysis of the cancer risks (CR) and total cancer risks (CRt) linked to heavy metal exposure across different geographical areas has been presented. These studies quantify the possible health risks associated with heavy metals like arsenic (As), lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr) and concentrate on certain populations, such as adults, children, or local residents. Because environmental and exposure factors vary by geography and demographic category, the results show differences in cancer risks.

Two studies in China's Hunan Province shed light on the exposure of the local population to heavy metals. A total cancer risk (CRt) of 0.0423 was reported by Zeng *et al.*, (2015) for a number of metals, including arsenic, cadmium, nickel, and chromium. A higher CRt of 0.1773 was found by Fan *et al.*, (2017), who concentrated on arsenic and lead. These discrepancies point to disparities in the research' analytical techniques or exposure levels.

In Fuzhou, China, Fu *et al.*, (2014) looked into the cancer risks associated with arsenic in both adults and children. However, this study did not have access to total cancer risk (CRt) numbers. This draws attention to a data gap that may be crucial to comprehending the entire scope of health hazards in the area. Praveena and Omar (2017) did a study in Malaysia that assessed both adults and children. While the overall cancer risks for adults were somewhat greater (0.0049) than those for children (0.0032), the results showed low cancer risks for arsenic and lead. This emphasizes how crucial it is to take age-specific vulnerabilities into account when evaluating the health hazards associated with exposure to heavy metals.

Two studies conducted in Iran investigated the cancer risks that local resident faced as a result of exposure to lead and arsenic. Djahed *et al.*, (2018) reported a CR for arsenic in Iranshahr, however they did not include information on the overall risk of cancer. With a CRt of 0.0749, higher CR values for lead and arsenic were found in another study by Fakhri *et al.*, (2017), which may indicate higher exposure levels in this area than others.

All things considered; the table highlights the serious public health issues related to exposure to heavy metals in various geographical areas. It draws attention to the necessity of gathering and analyzing data more thoroughly in order to evaluate cumulative risks (CRt) and get a deeper comprehension of the environmental elements influencing these exposures. The results highlight the significance of focused actions and regulations to lower heavy metal pollution and lessen related health hazards.

## 6. Effects of Heavy Metal on Human Health

Human health is seriously endangered when heavy metal-contaminated rice is consumed. During cultivation, contaminated soil and water can cause heavy metals including arsenic, cadmium, lead, and mercury to build up in rice. These metals can cause a number of acute and long-term health problems after consumption. The most important grain for human nutrition and caloric intake is thought to be rice. They develop bio-toxic chemicals that damage their structures and pose health risks after eating contaminated rice grains (Monira *et al.*, 2023).

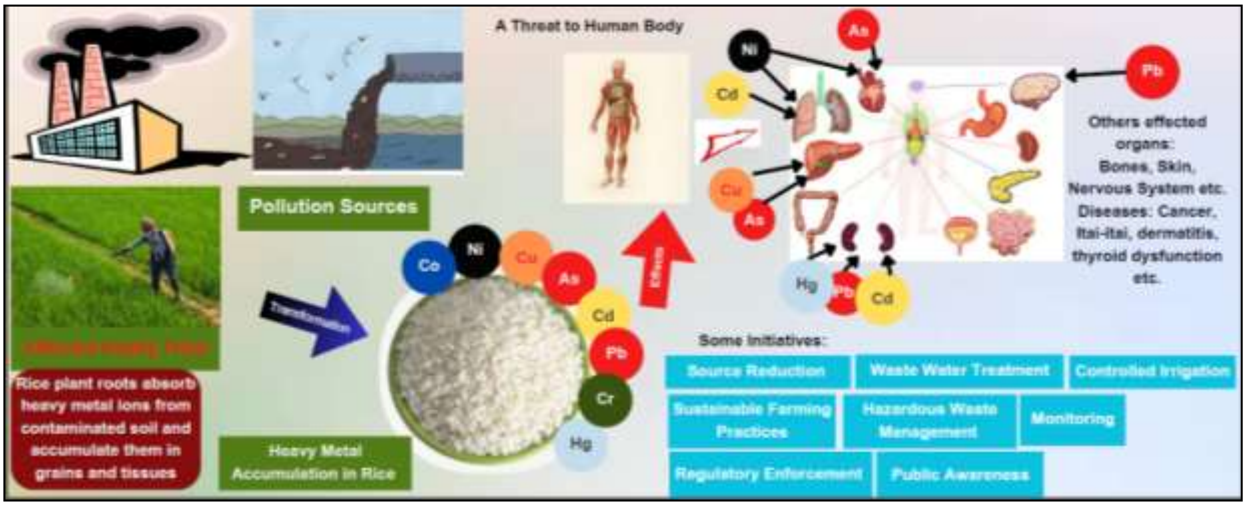


**Figure 1:** Impact of Heavy Metal Contamination in Rice on Human Health and Mitigation Strategies

Arsenic is a metal that is usually odorless and tasteless (ATSDR, 2005). It is commonly known that arsenic causes cancer. Research has connected eating rice contaminated with arsenic to a higher chance of developing bladder, lung, skin, and liver cancers, among other cancers (Rahman *et al.*, 2012). Exposure to arsenic can cause cardiovascular diseases and raise blood pressure (Abhyankar *et al.*, 2012).

Exposure to arsenic can cause cancer of the respiratory tract, peripheral neuropathy, and perforation of the nasal septum (FCHD, 2009). Exposure to arsenic can cause cardiovascular diseases and raise blood pressure (Abhyankar *et al.*, 2012). As a nephrotoxicant, cadmium mainly harms the kidneys, and prolonged exposure can cause chronic kidney disease and renal failure (Satarug, Garrett, Sens, & Sens, 2011). Because cadmium disrupts the metabolism of calcium, it raises the risk of osteoporosis and bone loss (Ma *et al.*, 2021).

Children are especially vulnerable to the negative effects of lead on brain development and cognitive performance. It may result in decreased IQ, behavioral issues, and learning impairments (Papanikolaou *et al.*, 2005). Exposure to lead can raise the risk of cardiovascular disease and high blood pressure (WHO, 2024). Manganism is a neurological condition affecting the central nervous system (CNS) that can be brought on by prolonged exposure to manganese (Mn). Manganism is an extrapyramidal illness characterized by motor problems accompanied by neuropsychiatric and cognitive deficits comparable to Parkinsonism (Bouabid *et al.*, 2016).

A transition element, nickel is widely found in soil, water, air, and the environment.Numerous adverse health effects, including allergies, kidney and cardiovascular disorders, lung fibrosis, and lung and nose cancer, can result from nickel interaction. It is believed that oxidative stress and mitochondrial dysfunctions play a major and important part in nickel's toxicity, even if the molecular mechanisms underlying this metal's toxicity are still unclear (Genchi *et al.*, 2020).

## Conclusion

This review observed that mainly the places near the industrial areas, agricultural lands where irrigation water is used from the waste water sources connected to industrial effluents, are polluted very much. The review showed that anthropogenic activities are the main source of heavy metal concentrations in agricultural fields. The accumulation of heavy metals in rice grains transported from the soil makes the rice toxic for human consumption. Human health is in danger when heavy metal-contaminated rice is ingested.

In the reviewed articles, the highest concentrations of Cd (380 µg/kg) and Pb (830 µg/kg) were found in India. Pakistan (7.7 mg/kg) took the highest position for Cu. And other heavy metals like Co (169 µg/kg), Cr (300 µg/kg), Ni (476 µg/kg), Mn (36.3 mg/kg), and Zn (23.2 mg/kg) were reported in China. Hazard Index was recorded highest for both adults and children in Malaysia. Bangladesh also took a noticeable place for Target Hazard Quotients (THQ) of Pb (8.0) and Cd (15.7).

During production, water and soil that are polluted may trigger heavy metals including arsenic, cadmium, lead, and mercury to build up in rice. People should be conscious of not cultivating rice near industrial waste discharge areas. The industry should dispose of its waste while considering environmental safety and sustainability. The government should take initiatives for awareness-building programs to reduce surface water pollution. Now it is important to formulate the necessary rules and regulations for irrigation water.

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