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ORIGINAL ARTICLE

Chromium and Cadmium Assessment in Selected Rice Varieties Under Various Irrigation Sources

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ABSTRACT

Background: Toxic metal accumulation in food crops poses significant public health risks. In particular, chromium (Cr) and cadmium (Cd) contamination in rice crops can lead to human exposure through dietary intake, emphasizing the need for ongoing monitoring and assessment.

Objective: This study aimed to evaluate the levels of chromium and cadmium in four rice varieties-Super Kernel, Kainat, Basmati, and Irri 6-cultivated in Sargodha, Pakistan, and to assess potential health risks among different age groups in the local population.

Main Outcome: The main outcome of the study measures the Cr and Cd concentrations in soil, rice, and serum samples were measured, revealing a predominance of Cd contamination relative to Cr. Super Kernel and Kainat rice varieties exhibited the highest uptake of Cd and Cr, respectively. Contamination factors indicated moderate enrichment of Cd in the study area, with higher Cd contamination compared to Cr.

Result: There were five distinct age groups among the humans that lived there. Group I: ages 5 to 15; Group II: ages 16 to 25; Group III: ages 26 to 35; Group IV: ages 36 to 45; and Group V: ages 46 to 55. Chromium concentration was observed as 9.07±0.002 mg/kg in soil samples, 3.89±0.001 mg/kg in rice samples and 0.03± 0.001mg/L in serum samples. Cadmium concentration was observed as 1.02±0.00 mg/kg in soil samples, 0.4±0.00 mg/kg in rice samples and 0.0028±0.00 mg/l in serum samples. Super kernel and Kainat rice showed the highest Cd and Cr uptake in their tissues respectively.

Conclusion: Contamination factor results (CF>1) showed higher Cd contamination in the study area as compared to Cr metal. Cd metal also showed moderate level of enrichment in study area. As all THQ values were less than 1 in every age group, so there was no expected carcinogenic hazard to local consumers. Although current risk assessments suggest minimal carcinogenic hazard, elevated Cd levels warrant government intervention to implement strategies aimed at reducing cadmium contamination in rice grains, thereby safeguarding future public health.

Keywords	*Address of Correspondence	Article info.
Cadmium, Chromium, Contamination, Food Chain, Human Health, Oryza Sativa, Soil System.	*faiza.zubair@uos.edu.pk*	*Received: January 25, 2025* *Accepted: June 17, 2025*

Cite this article: *Aslam M, Khan ZI, Ahmad K, Zubair F, Riaz N, Ashfaq A, Noorka IR, Ullah S, Ashraf MI. Chromium and Cadmium Assessment in Selected Rice Varieties Under Various Irrigation Sources. RADS J Biol Res Appl Sci. 2025; 16(1):12-21.*

INTRODUCTION

Rice (*Oryza sativa* L.) is an important member of family Gramineae and one of the essential cereals in the world. Because it includes crops like rice, maize, oats, wheat, and others, the Gramineae family of grasses is extremely diverse and economically significant[1]. Rice is of prime importance because it is consumed as major source of calories for about 50% of world population. It is cultivated in both hot and humid climates worldwide. About 11% of agricultural land is used annually for rice production consuming about 163 million hectares of land and is ranked second cash crop after wheat crop[1].

Water scarcity is a major global problem. In arid regions of the world freshwater is not sufficiently available and as a result salt present in soil have caused soil salinity making the soil unsuitable for agriculture[2]. To compensate the shortage of freshwater, domestic wastewater after treatment is used for agricultural irrigation. About 20Mha land use untreated and treated wastewater worldwide for irrigation purpose. Heavy metals being part of the wastewater decrease the fertility of soil, crop quality and natural ecosystem[3].

Cadmium is a heavy metal and plant's exposure to this metal is continuously increased by manmade activities. The metal causes browning of root tip, chlorosis and visible injuries which leads to the death of the plant. Lipid peroxidation caused by accumulation of Reactive oxygen species was also induced by Cadmium toxicity[4]. In plants, Cd is largely associated with cell walls and is less widely dispersed in mitochondria and chloroplasts[5]. Cd is absorbed mostly through the air ways and to a lesser extent through the gut while surface sorption is rarely observed. When cadmium get into the body, it effects the renal, hepatic and digestive organs before entering into the main bloodstream[6]. Cereals, vegetables, roots, and tubers are the primary food origin for human vulnerability to Cd. It is also present in the plant products such as root and other harvested parts. The majority of the Cd in soil comes from contamination brought on by human activity. Phosphate fertilizers, urban emissions from industrial land, organic and mineral additions all contribute to contamination[7]. Chromium is a heavy metal which is more commonly used in industrial process and is potentially toxic for human. Chromium is found in its two natural forms which are; Cr (III) and Cr (VI). Cr (III) form is considered as vital for living creatures including humans while its other form Cr (VI) is very harmful and dangerous for humans and all other living organisms. Trivalent form of chromium Cr (III) is necessary for metabolism of fats and proteins in humans. While hexavalent form cause health problems related to the respiratory tract on chronic and acute inhalation exposures[8]. The purpose of existing study was to analyze the Cr and Cd mobility in various rice varieties and its impact on human health. Objectives of this study are: 1) to calculate the heavy metal content in different parts of rice, (2) to estimate the metal uptake in varieties by using different indices, (3) to analyze the potential health risk for local consumers via rice consumption.

MATERIALS AND METHODS

Study Area

Agricultural fields in the Tehsil Sahiwal (Sargodha district) were chosen as study area. Sargodha is located in Punjab Province of Pakistan. Sargodha is located between 32° 10' in north latitude and 72° 40' longitude east (Figure **1**). Four Varieties of rice (named as Super Kernel, Kainat, Basmati and Irri 6) irrigated with two irrigation sources; T1 is Tube well water irrigation and T2 is Mixed Water irrigation (Tube well + Domestic wastewater).

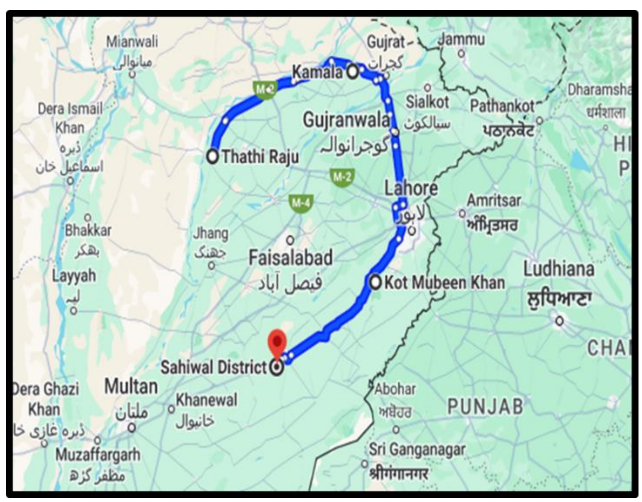

Figure 1. Map of study area.

Sample Collection and Preparation

The soil samples were collected from depth of 0-15 cm and their corresponding rice (shoot and grain) samples were also taken from selected sites. All debris and stones were removed from soil samples and was stored in sampling bags. Three replications were used for each soil and rice sample Soil samples were dried in air for almost 3-5 days and after that in oven for 72 hours. All contaminants on rice grains were also removed by washing them twice and dried at 65 ºC for 48 h in a furnace to maintain constant weight for further analysis. Humans that were residents of that site were divided into five different age groups. Group1: 5-15 years (Y), Group 2: 16-25 Y, Group 3: 26-35 Y, Group 4: 36-45 Y and Group 5: 46-55 Y. Five blood replicates of each group were used. Microwave digestion method was used for all sample digestion. Approximately 0.25 g of sample was weighed and acid-digested by 10 mL of HCl-HNO_3 (3:1) and 2 mL of $HClO_4$ solutions at 140–160 °C. The digested material was filtered through filtered paper and the final volume (10 ml) was made by addition of distilled water. Metals level was determined using CE™ 3400 AAS Atomic Absorption Spectrometer (Thermo Scientific™).

Contamination Factor

It was evaluated by formula[9].

$$\mathrm{CF} = \frac{\text{metal concentration in sample}}{\text{Background concentration of metal}}$$

Transfer Factor

It was evaluated by formula[9].

$$\mathrm{TF} = \frac{\text{Metal concentration in plant mg/kg}}{\text{Metal concentration in soil mg/kg}}$$

Enrichment Coefficient

Its calculating formula is

$$EF = \frac{Conc.of\ metal\ in\ edible\ part\ /\ Conc.of\ metal\ in\ soil}{Standard\ conc.of\ metal\ in\ edible\ part\ /\ Standard\ conc.of\ metals\ in\ soil}$$

Cd and Cr Standard concentration was 2.8mg/kg and 9.07 mg/kg in soil[10] while 0.2mg/kg and 2.3mg/kg in rice grains[11].

Target Hazard Quotient

It is an estimated risk level of pollutant exposure. The formula for THQ is given as:

$$THQ = \frac{EF \times ED \times FIR \times CM}{BW \times AT \times RfD} \times 10^{-3}$$

In above formula, EF stands for exposure frequency (365 days per year), and ED for exposure duration (70 years in the study for non-cancer risk). FIR stands for food ingestion rate (g/person/day), and CM for rice's heavy metal content. RfD is for oral reference dose (mg/kg-d) which was 0.0003mg/kg for Cd[12] and 1.5mg/kg for Cr[12]; BW stands for mean body weight of consumers; and AT stands for the average time for non-carcinogenic effects (70 years).

Experimental Design

The impact of two irrigation sources (Tube well vs. Mixed Water) on the growth and performance of four rice varieties (Super Kernel, Kainat, Basmati, and Irri 6) under field conditions in Sahiwal was assessed using the Randomized Complete Block Design (RCBD).

Statistical Analysis

All the obtained data is presented statistically with the help of Two-way ANOVA and SPSS-25 version. Significant differences are examined in all samples data according to[13].

RESULTS AND DISCUSSION

Chromium Concentration in Soil, Rice and Human Serum Samples

The statistical data showed significant variation ($p<0.001$) among soil, shoot grain and serum samples (Table **1**). Chromium concentration in the soil samples was found between 9.633-17.581 mg/kg. Minimum Cr value was observed in S1 (Basmati rice soil) at T1 while maximum value in S1 (Super kernel variety soil) at T2 (Figure **2**)[14] reported the mean concentration of Cr in soil as 43 mg/kg which was much greater than current study. The results presented by[15] indicated the level of Cr as 0.135 mg/kg, which was much lower than present results. Cr concentration (12-14 mg/kg) in the soil reported by[16] was also lower than the present study but the result was consistent with[17]. Present results showed that the observed Cr range (9.333-17.6mg/kg) in this study was lowered than EU standards. The low mobility of Cr ion in soil is due to their binding ability with organic matter or iron oxides present in soil[18].

Cr concentration in shoot samples was found between 4.768-11.567 mg/kg. Minimum value was observed for Super Kernel at T1 while maximum value was also observed for the same variety at T2 site (Figure **2**). Cr concentration in grain samples was ranged from 0.122-0.924mg/kg. The minimum value was observed for Irri 6 (0.122 mg/kg) and its maximum value was found in Kainat (Figure **2**). Concentration of Chromium in the shoot was reported as 18.1 mg kg-1 by[19] which is greater than current suggestion[20] also reported the higher concentration of Cr in rice shoot (4.280-15.54mg/kg) and grain samples (4.653-12.21mg/kg) than current study. Cr range observed by[21] was 0.6–3.4 mg/kg, which is lowered than present study investigations. The concentration of Chromium in grains was lower than standard level (2.3mg/kg) recommended by[22] Cr toxicity inhibits the root shoot biomass, nitrogen uptake by plant, balanced mineral concentration while its trigger the accumulation of ROS and lead towards the cellular death of plant[23,24].

Cr in serum samples was found between 0.023-0.093mg/L in different ages. Minimum Cr level was found in individuals between 16-25 years in age while maximum level was observed for 36-45 years age (Figure **2**). Chromium level in serum of different age groups was evaluated to assess potential health risks in different human ages over rice consumption[25] reported the lowered Cr level than present study while a higher concentration was given by[26]. All the analyzed serum samples showed Cr concentration greater than standard limit. A minute quantity of Cr is needed by human in their diet. Cr improves blood circulation, metabolism of fat and increase the body weight but its toxicity causes dysfunctioning of liver and kidney[27].

Cadmium Concentration in Soil, Rice and Human Serum Samples

Cd showed significant variation among all soil samples while varieties are non-significantly varied in shoot and grain samples. Serum and Treatments*Serum samples were also non-significant (Table **1**). The observed Cd range in soil was found between 1.178-1.903mg/kg. Minimum concentration was evaluated for S3 (Basmati variety soil) (1.178 mg/kg) while a maximum value was also observed for the same variety (1.903 mg/kg) at T2 (Figure **3**). The results of current study were supported by[28] work. As compared to present results,[21] reported the higher Cd content in soil while a lowered Cd level in soil was reported by[29]. Present results showed that the observed Cd range in soil was lowered than WHO/FAO[22] limits. Cd mobility is associated with pH of the soil. Cd form water soluble complexes in acidic conditions while its carbonate formation in alkaline pH reduces its uptake mobility[30].

Table 1. Analysis of Variance in Soil, Rice and Serum Samples.

Source of Variance	Degree of Freedom	Chromium			Cadmium		
		Soil	Shoot	Grain	Soil	Shoot	Grain
Treatments	1	41.6317***	60.7157***	1.00287***	0.903264***	2.44371***	0.002432^{ns}
Varieties	3	29.1532***	5.3169***	0.09790***	0.065125***	0.00281^{ns}	0.003075^{ns}
Treatments*Varieties	3	13.1721***	14.5215***	0.06310***	0.216883***	0.04345*	0.005164*
Error	16	0.1843	0.001	0.001	0.0342	0.01254	0.0011

Serum			
Source of Variance	**Degree of Freedom**	**Cr-Mean Square**	**Cd-Mean Square**
Treatments	1	0.007316***	0.000241*
Serum	4	0.001152***	0.00398^{ns}
Treatments*Serum	4	0.001373***	1.98^{ns}
Error	19	0.000002	0.000034
* Means p<0.05 and *** means p<0.001			

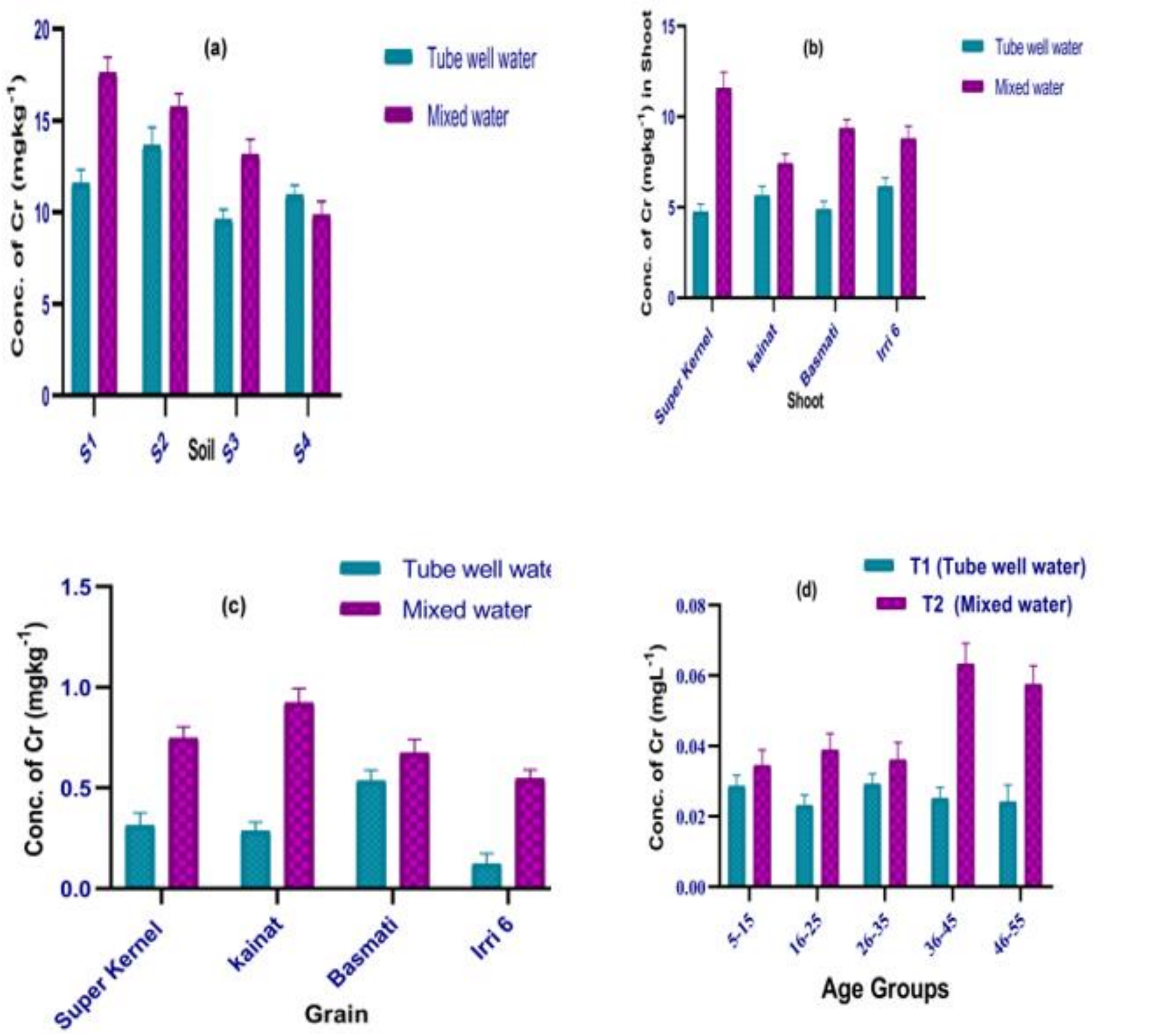

Figure 2. Cr concentration in (**a**) Soil (**b**) Rice shoot (**c**) Rice grain (**d**) Human serum samples.

Cadmium in shoot samples was ranged as 0.231-0.944mg/kg. Lowest value was found in Basmati (0.231 mg/kg) while highest values were observed for Super Kernal (0.944mg/kg) (Figure **3**). Grain samples analyzed the Cd ranged between 0.0151-1.1914mg/kg. Minimum concentration observed at Super Kernal while maximum level is found in same variety at T2 site (Figure **3**). Previous work by[31] presented their results as 6.56 mg/kg, being higher than present study[32] evaluated the mean Cd level in rice grain higher than recent results[33] reported the average content of Cd in grains as 0.014 mg kg^{-1} for experimental and 0.011 mg kg^{-1} for control site which were significantly lowered than current results. Mean Cadmium level in grains samples was greater than Standard limits of WHO[34].

Cd toxicity in human can lead to kidney failure and bone deformation. There will be a higher risk of diabetes by high cadmium intake[35].

In serum samples, Cd range was 0.0013-0.0035mg/l in this study. Maximum value was observed in individuals having 36-45 years age while its minimum absorption was observed in individuals between 26-35 years (Figure **3**). In contrast to this study, a higher Cd level was observed by[25] while lowered content was reported by[36]. All the analyzed serum samples showed Cd concentration lowered than standard limit. Cd binding with metallothionein protein forms a complex that is easily enter into kidney and causes nephrotoxicity. Cd level in blood antagonistically regulates the level of essential metals such as Ca, Fe and Zn[37].

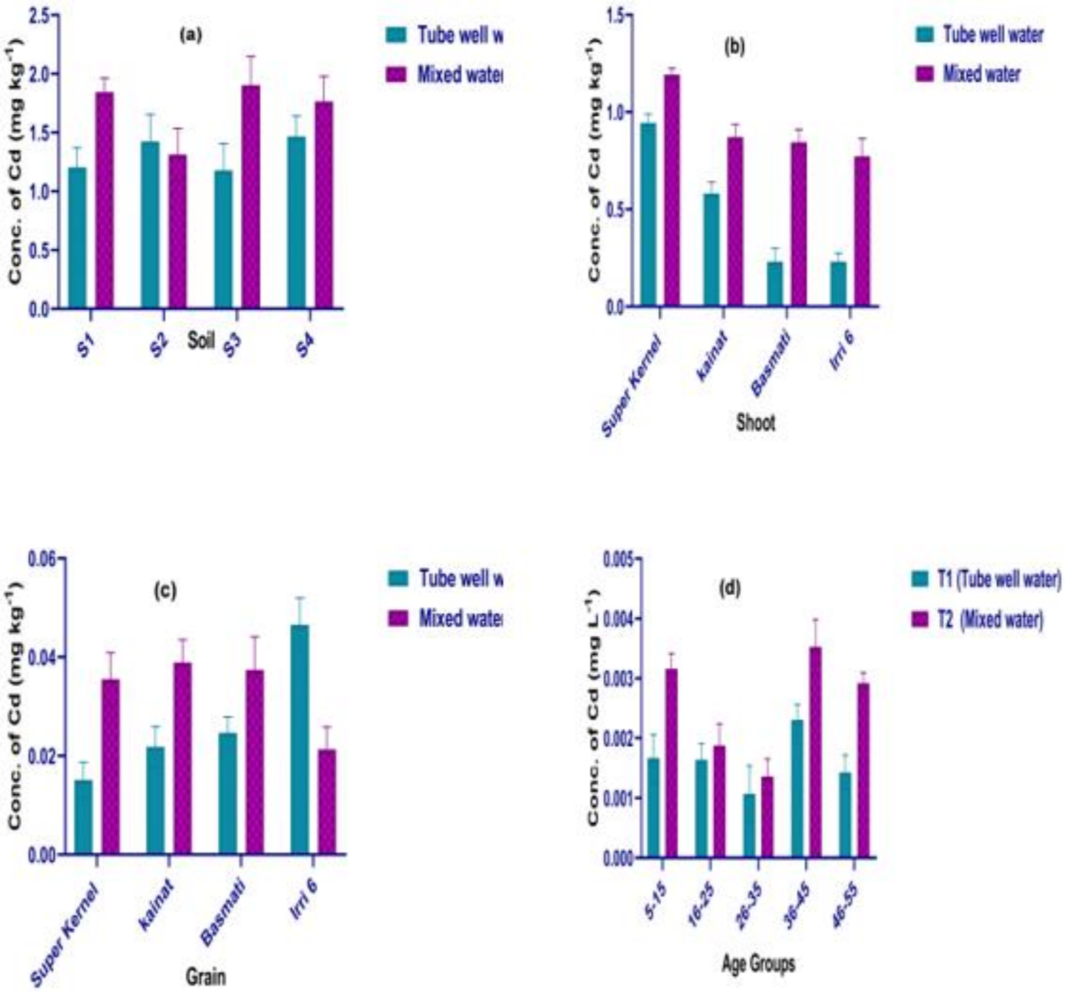

Figure 3. Cd concentration in (**a**) Soil (**b**) Rice shoot (**c**) Rice grain (**d**) Human serum samples.

Contamination Factor

Contamination factor values for Cr, were ranged from 0.096-0.175. Its highest value was observed for Super kernel while lowest level was found in Basmati variety (Figure **4**). Cadmium contamination was ranged from 1.095-1.730. Highest contamination was in Basmati variety while least contamination was observed in Super Kernal rice (Figure **5**). According to reports by[38], the Cr values was 0.68 that is much higher than current investigations. [39]Described that CF was 0.01 for Chromium which is lower than current observation. The heavy metal evaluation showed that contamination for chromium was observed to be less than 1, indicating negligible Cr contamination in soil. According to[40], the values of contamination factor was 0.008 that were much lowered than current results while[21] reported the CF as 3.42 that were higher than present values. Overall, all the samples showed CF greater than 1 for Cd, representing that study area soil is contaminated with cadmium metal.

Enrichment Factor

EF range for Cr was 0.154-0.387. Highest EF was noticed in Irri 6 variety while lowest amount was observed in Basmati rice (Figure. **4**). EF range observed for Cd was 0.2717-3.64. Highest level was noticed in Kainat variety while minimum level was found in Basmati rice (Figure **5**)[41] reported the higher Cd enrichment than current results. According to[42], the EF range for Cr was 0.76–16.38 greater than the current observations while the ranged from 0.05-0.15 observed by[43] was lower than current study values.

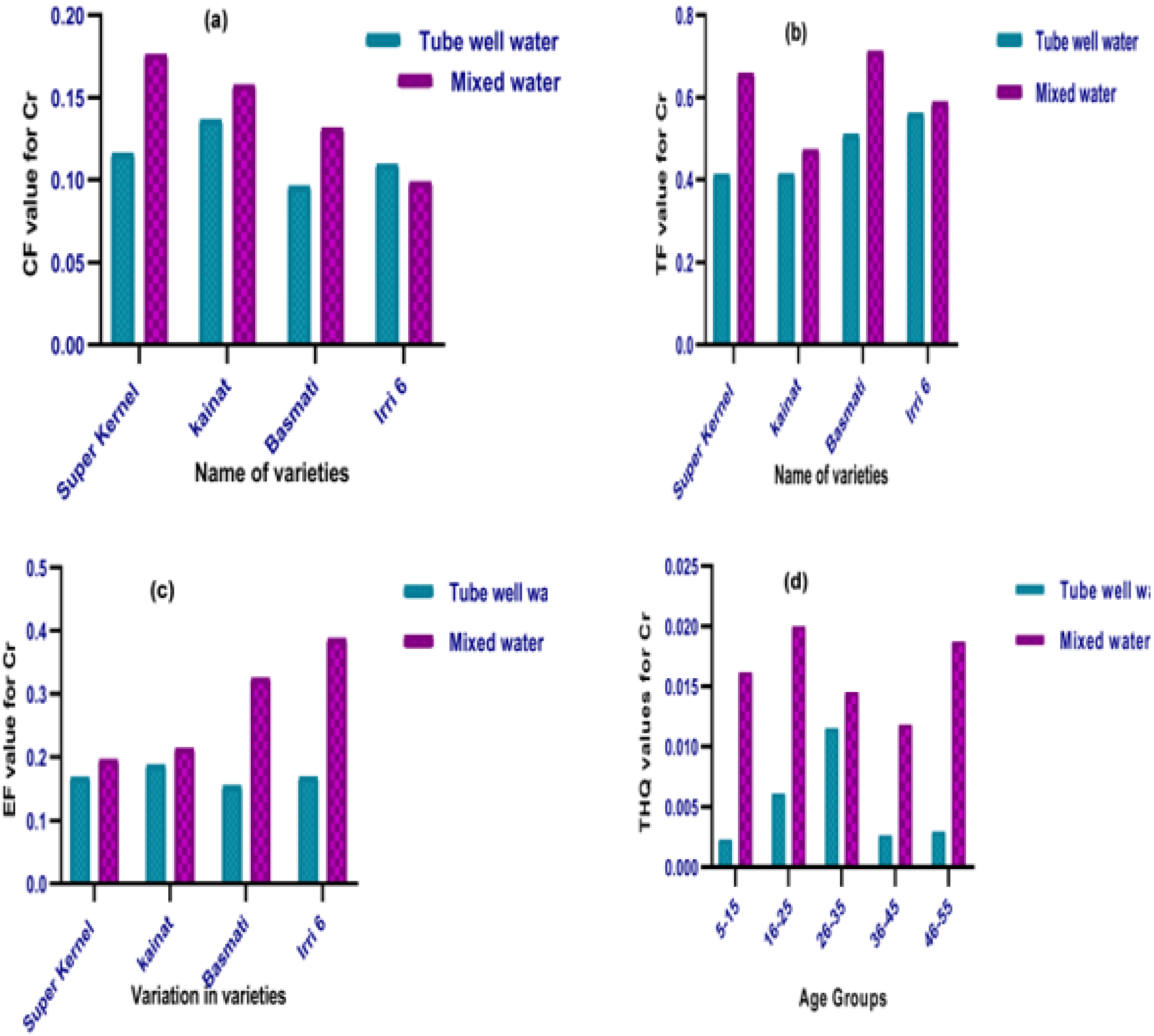

Figure 4. Cr concentration in (**a**) Contamination factor (**b**) Transfer factor (**c**) Enrichment factor (**d**) Target hazard quotient.

Transfer Factor

Transfer factor for Cr was ranged between 0.411-0.712. Highest Cr transfer was shown by Basmati while its concentration was found in Super kernel (Figure **4**). Cadmium range was found between 0.049-0.663. Lowest TF was observed for Basmati rice while highest TF was found in Kainat variety (Figure **5**). Transfer factor analysis can be used to compare the levels of heavy metals in soil to the presence of heavy metals in plant tissues. TF values for the Cr were lower than those observed by[44] while[45] reported the values as 0.73 from soil to grain which is higher than present results. Similarly, higher concentration for Cd was reported by[46]. Results pointed out that rice varieties actively uptake the Cr content from their root to shoot biomass.

Target Hazard Quotient

The THQ levels observed for Cr in different age groups was 0.0022 - 0.0195. Highest value was observed for 16-25 age while lowest concentration found in 5-15 age (Figure **4**). Cd range for THQ was 0.00009-0.0007 lowest Cd value observed in 5-15 age group while maximum value is in 46-55 age group (Figure **5**). Total hazard quotient computed for chromium metal was below than observed by[46]. [47]Reported the THQ values (0.05) for different age groups which were greater than present study. [18]stated that the THQ level was ranged from 0.16-1.79 that is greater than current investigations. The THQ level recorded by[48] and this was lower than current investigations. As THQ was lower than 1 in all age groups so there was no potential risk of carcinogenic effect on human health.

CONCLUSION

Present results concluded that Cr and Cd concentrations were significantly increased in waste water treatment as compared to tubewell water. Kainat variety showed maximum Cr uptake in their grains while maximum Cd uptake was observed in Super kernel variety grains. Over all, Cr and Cd concentrations in soil and rice grains samples were lower than permissible limits. Contamination factor results (CF>1) showed higher Cd contamination in the study area as compared to Cr metal. Cd metal also showed moderate level of enrichment in study area. As all THQ values were lower than 1 in all age groups, so there was no potential carcinogenic risk to local consumers. Further investigations are needed to evaluate how rice varieties respond towards other metals uptake and their transport in plant tissues. Government should organize strategies to reduce Cd contamination in rice grains that may pose carcinogenic risk to human health.

CONFLICT OF INTEREST

All authors declared that they have no conflict of interest.

ACKNOWLEDGEMENT

None.

ETHICAL STATEMENT

The institutional Human Ethics Committee of University of Sargodha (Approval No.25-A18 IEC UOS) has allowed all the protocols used in this experiment. All the experimental methods of this study have followed all the appropriate guidance and regulations including NRC standards.

FUNDING

No funding was received for this work.

REFERENCES

1. Fazal U, Ud Din I, Khan AM, Khan FU, Khan MN, Iqbal N, *et al*. Evaluation of agro-morphological traits, seed characterization and genetic diversity of local rice (Oryza sativa L.) varieties of Pakistan. Genet Resour Crop Evol. 2023; 70(3): 935-949.
2. Khan ZI, Muhammad FG, Ahmad K, Akhtar S, Sohail M, Nadeem M, *et al*. Effects of diverse irrigation with wastewater in soil and plants: assessing the risk of metal to the animal food chain. Environ Sci Pollut Res. 2022; 1-10.
3. Soleimani H, Mansouri B, Kiani A, Omer AK, Tazik M, Ebrahimzadeh G, *et al*. Ecological risk assessment and heavy metals accumulation in agriculture soils irrigated with treated wastewater effluent, river water, and well water combined with chemical fertilizers. Heliyon. 2023; 9(3).
4. Janeeshma E, Puthur JT. Physiological and metabolic dynamism in mycorrhizal and non-mycorrhizal Oryza sativa (var. Varsha) subjected to Zn and Cd toxicity: A comparative study. Environ Sci Pollut Res. 2023; 30(2): 3668-3687.
5. Han Z, Wei X, Wan D, He W, Wang X, Xiong Y. Effect of molybdenum on plant physiology and cadmium uptake and translocation in rape (Brassica napus L.) under different levels of cadmium stress. Int J Environ Res Public Health. 2020; 17(7): 2355.
6. Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A. The effects of cadmium toxicity. Int J Environ Res Public Health. 2020; 17(11): 3782.
7. Sterckeman T, Thomine S. Mechanisms of cadmium accumulation in plants. Crit Rev Plant Sci. 2020; 39(4): 322-359.
8. Prasad S, Yadav KK, Kumar S, Gupta N, Cabral-Pinto MM, Rezania S, *et al*. Chromium contamination and effect on environmental health and its remediation: A sustainable approach. J Environ Manag. 2021; 285: 112174.
9. Naz R, Khan MS, Hafeez A, Fazil M, Khan MN, Ali B, *et al*. Assessment of phytoremediation potential of native plant species naturally growing in a heavy metal-polluted industrial soils. Braz J Biol. 2022; 84: e264473. doi: 10.1590/1519-6984.264473. eCollection 2022.
10. Singh A, Sharma RK, Agrawal M, Marshall FM. Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food Chem Toxicol. 2010; 48(2): 611-619 https://doi.org/10.1016/j.fct.2009.11.041
11. Tegegne WA. Assessment of some heavy metals concentration in selected cereals collected from local markets of Ambo City, Ethiopia. J Cereal Oil Seeds. 2015; 6(2): 8-13.
12. Saha N, Mollah MZI, Alam MF, Rahman MS. Seasonal investigation of heavy metals in marine fishes captured from the Bay of Bengal and the implications for human health risk assessment. Food Control. 2016; 70: 110-118.
13. Liu Y, Cao X, Hu Y, Cheng H. Pollution, risk and transfer of heavy metals in soil and rice: a case study

in a typical industrialized Region in South China. Sustainability. 2022; 14(16): 10225.

14. Ullah N, Ur Rehman M, Ahmad B, Ali I, Younas M, Aslam MS, *et al*. Assessment of heavy metals accumulation in agricultural soil, vegetables and associated health risks. Plos One. 2022; 17(6): e0267719.
15. Pratishtha SJ, Sura S. Analysis of Heavy metals (Nickel, Chromium, Cobalt, Cadmium, Lead) in Wheat and Rice grown in agriculture soil. Pak Heart J. 2023; 56(2): 1148-1153
16. Zhou J, Chen H, Tao Y, Thring RW, Mao J. Biochar amendment of chromium-polluted paddy soil suppresses greenhouse gas emissions and decreases chromium uptake by rice grain. J Soil Sediments. 2019; 19: 1756-1766.
17. Singh PK, Yadav JS, Kumar I, Kumar U, Sharma RK. Carpet industry irrigational sources risk assessment: Heavy metal contaminated vegetables and cereal crops in northern India. Toxicol Rep. 2020; 9: 1906-1919.
18. Chen L, Zhang H, Ding M, Devlin AT, Wang P, Nie M, *et al*. Exploration of the variations and relationships between trace metal enrichment in dust and ecological risks associated with rapid urban expansion. Ecotoxicol Environ Saf. 2021; 212: 111944.
19. Du F, Yang Z, Liu P, Wang L. Accumulation, translocation, and assessment of heavy metals in the soil-rice systems near a mine-impacted region. Environ Sci Pollut Res. 2018; 25: 32221-32230.
20. Tariq F, Wang X, Saleem MH, Khan ZI, Ahmad K, Malik IS, *et al*. Risk assessment of heavy metals in basmati rice: Implications for public health. Sustainability. 2021; 13(15): 8513.
21. Wang J, Wang PM, Gu Y, Kopittke PM, Zhao FJ, Wang P. Iron–manganese (oxyhydro) oxides, rather than oxidation of sulfides, determine mobilization of Cd during soil drainage in paddy soil systems. Environ Sci Technol. 2019; 53(5): 2500-2508.
22. WHO/FAO (World Health Organization/Food and Agriculture Organization). 2007. Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty-Eight Session of the Codex Committee on Food Hygiene. Houston, TX, ALINORM 07/30/13
23. Ali S, Mir RA, Tyagi A, Manzar N, Kashyap AS, Mushtaq M, Bae H.Chromium toxicity in plants: signaling, mitigation, and future perspectives. Plants, 2023; 12(7): 1502.
24. Khan ZI, Liu W, Mubeen I, Alrefaei AF, Alharbi SN, Muhammad FG, *et al*. Cobalt availability in the soil plant and animal food chain: a study under a peri-urban environment. Braz J Biol. 2023; 83: e270256.
25. Sani A, Abdullahi IL. Evaluation of some heavy metals concentration in body fluids of metal workers in Kano metropolis, Nigeria. Toxicol Rep. 2017; 4: 72-76.
26. Anderson RA, Bryden NA, Polansky MM. Serum chromium of human subjects: effects of chromium supplementation and glucose. Am J Clin Nutr. 2019; 41(3): 571-577.
27. Chen F, Ma J, Akhtar S, Khan ZI, Ahmad K, Ashfaq A, *et al*. Assessment of chromium toxicity and potential health implications of agriculturally diversely irrigated food crops in the semi-arid regions of South Asia. Agric Water Manag,2022; 272: 107833.
28. Kinuthia GK, Ngure V, Beti D, Lugalia R, Wangila A, Kamau L. Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. Sci Rep. 2020; 10(1): 8434.
29. Ren Y, Lin M, Liu Q, Zhang Z, Fei X, Xiao R, *et al*. Contamination assessment, health risk evaluation, and source identification of heavy metals in the soil-rice system of typical agricultural regions on the southeast coast of China. Environ Sci Pollut Res. 2021; 28: 12870-12880.
30. Suhani I, Sahab S, Srivastava V, Singh RP. Impact of cadmium pollution on food safety and human health. Curr Opin Toxicol. 2021; 27: 1-7.
31. Kwon JC, Nejad ZD, Jung MC. Arsenic and heavy metals in paddy soil and polished rice contaminated by mining activities in Korea. Catena. 2017; 148: 92-100.
32. Ezeofor CC, Ihedioha JN, Ujam O, Ekere NR, Nwuche CO. Human health risk assessment of potential toxic elements in paddy soil and rice (Oryza sativa) from Ugbawka fields, Enugu, Nigeria. Open Chem.2019; 17(1): 1050-1060.
33. Singh J, Upadhyay SK, Pathak RK, Gupta V. Accumulation of heavy metals in soil and paddy crop (Oryza sativa), irrigated with water of Ramgarh Lake, Gorakhpur, UP, India. Toxicol Environ Chem. 2011; 93(3): 462-473.
34. FAO/WHO. 2001. Report on the 32nd session of the codex committee on food additives and contaminants. ALINORM 01/12, Beijing. China. 20–24 March 2000. Joint FAO/WHO food standard programme. Codex Alimentarius Commission, 24th session, 2–7 July, Geneva.
35. Batool F, Hussain MI, Nazar S, Bashir H, Khan ZI, Ahmad K, *et al*. Potential of sewage irrigation for heavy metal contamination in soil–wheat grain system: Ecological risk and environmental fate. Agric Water Manag. 2023; 278: 108144.
36. Alrobaian M, Arida H. Assessment of heavy and toxic metals in the blood and hair of Saudi Arabia smokers using modern analytical techniques. Int J Anal Chem. 2019; 2019.

37. Balali-Mood M, Naseri K, Tahergorabi Z, Khazdair MR, Sadeghi M. Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. Front Pharmacol. 2021 227.
38. Jannat N, Mottalib MA, Alam MN. Assessment of physico-chemical properties of surface water of Mokeshbeel, Gazipur. Bangladesh J. Environ Sci Curr Res. 2019; 2(3): 1-6.
39. Mukhtar S, Mohammed MA, Aznie RCR. Temporal Variation and Pollution Levels of Some Heavy Metals on Irrigated Land Along Airport Road Kano State, Nigeria. Malays J Appl Sci. 2017; 2(2): 1-9.
40. Song D, Zhuang D, Jiang D, Fu J, Wang Q. Integrated health risk assessment of heavy metals in Suxian County, South China. Int J Environ Res Public Health. 2015; 12(7): 7100-7117.
41. Tariq SR, Rashid N. Multivariate analysis of metal levels in paddy soil, rice plants, and rice grains: a case study from Shakargarh, Pakistan. J Chem. 2013; https://doi.org/10.1155/2013/539251
42. Chen F, Muhammad FG, Khan ZI, Ahmad K, Nadeem M, Mehmood S, *et al*. Ecological risk assessment of heavy metal chromium in a contaminated pastureland area in the Central Punjab, Pakistan: soils vs plants vs ruminants. Environ Sci Pollut Res. 2022; 29(3): 4170-4179.
43. Siddiqui E, Pandey J. Assessment of heavy metal pollution in water and surface sediment and evaluation of ecological risks associated with sediment contamination in the Ganga River: a basin-scale study. Environ Sci Pollut Res. 2019; 26: 10926-10940.
44. Hasan GMM, Das AK, Satter MA. Accumulation of heavy metals in rice (Oryza sativa. L) grains cultivated in three major industrial areas of Bangladesh. J Environ Public Health. 2022; 2022.
45. Liu J, Zhang XH, Tran H, Wang DQ, Zhu YN. Heavy metal contamination and risk assessment in water, paddy soil, and rice around an electroplating plant. Environ Sci Pollut Res. 2011; 18: 1623-1632.
46. Navaretnam R, Soong AC, Goo AQ, Isa NM, Aris AZ, Haris H, *et al*. Human health risks associated with metals in paddy plant (Oryza sativa) based on target hazard quotient and target cancer risk. Environ Geochem Health. 2023; 45(5): 2309-2327.
47. Abtahi M, Fakhri Y, Oliveri Conti G, Keramati H, Zandsalimi Y, Bahmani Z, *et al*. Heavy metals (As, Cr, Pb, Cd and Ni) concentrations in rice (Oryza sativa) from Iran and associated risk assessment: a systematic review. Toxin Rev. 20217; 36(4): 331-341.
48. Abdi L, Molaee AE, Nazmara S, Alipour MR, Fakhri Y, Mousavi KA. Potentially toxic elements (PTEs) in corn (Zea mays) and soybean (Glycine max) samples collected from Tehran, Iran: a health risk assessment study. Int J Environ Anal Chem. 2022;102(16): 4640-4651.