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UPTAKE AND TRANSLOCATION OF SOME HEAVY METALS BY RICE CROP (*ORYZA SATIVA*) IN PADDY SOILS

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Accumulation of heavy metals in edible crops is amongst major international concerns today. While consuming Lenjan variety of rice is very popular in Iran, limited evidence exists on its safety. Amid increasing public concern about the safety of locally grown and imported rice in the market, a field study was carried out to investigate uptake and translocation of Cd, Pb, Ni, and Zn by a local variety of rice crop (*Oryza sativa*) exposed to contaminated water. At harvest time and in paddy fields, 41 soil and plant samples were collected from four locations of Lenjan, central Iran; irrigated from Zayandeh Rood River. In the laboratory, different parts of the plant were milled, digested via acid digestion method, and then analysed for Cd, Pb, Ni and Zn using atomic absorption spectrophotometry. The results showed that average concentrations of Cd, Pb, Ni and Zn were 1.07, 17.22, 1.73 and 13.75 mg/kg in the plant's stem; and 1.27, 12.32, 1.099 and 19.39 mg/kg in its grain, respectively. In general, both in the plant's stem and grain, the Cd and Pb concentrations were much higher than the FAO/WHO standard and labelled as harmful for consumers. Moreover, among the studied heavy metals, Ni transported very weakly, while Cd and Zn conveyed most easily into the plant's stem and grain. Of course, Pb was the least mobile metal. However, it had highly accumulated in the plant's stem and grain.

Key words: heavy metal, rice plant, translocation factor, paddy soils, paddy crop, *Oryza sativa*

1. INTRODUCTION

Agricultural soil and water contamination has become a severe environmental problem in many developed and developing countries in recent years (Facchinelli *et al*. 2001; Kalavrouziotis *et al*. 2012; Fan *et al*. 2017). Heavy metals, one of such toxic contaminants, are not bio- and thermo-degradable, hence accumulate in the environment up to hazardous levels (Chung *et al*. 2011). Two primary sources of heavy metals in the soil are: (i) the natural background -i.e. metals derived from parent rocks; and (ii) the anthropogenic contamination -i.e. those originated from human activities (Fu *et al*. 2008; Zhao *et al*. 2010). Most of the soil metals today have originated from anthropogenic sources than natural ones (Moura *et al*. 2010). Meanwhile, irrigation of agricultural soil with polluted municipal and industrial wastewater is another vital source of pollution (Mahmoud & Ghoneim 2016).

The soil-to-plant transfer of heavy metals is a process of significant importance (Kalavrouziotis *et al.* 2012). In plants, heavy metals might cause oxidative stress, displace essential metals, disrupt metabolic processes from functioning, and finally reduce yield (Wang-da *et al*. 2006). Furthermore, chronic low-level intake of heavy metals can pose an irreversible detrimental effect on human health

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(Rattan *et al*. 2005; Rodriguez Martin *et al*. 2006; Hang *et al*. 2009; Yang *et al.* 2009; Wu & Zhang 2010). Among agricultural products, rice is widely consumed as a staple food worldwide and especially in Asian countries. So, in case of contamination, it could become a significant dietary source of toxic elements compared to other crops (Park *et al*. 2011; Tariq & Rashid 2013). Therefore, its quality can profoundly affect human health. That is why heavy metals contamination in agricultural soils and their transfer into plants have been of increasing concern (Zhao *et al*. 2010).

Rice as a herbal plant contains protein and is ranked as the second highly consumed cereal in the world. Half of the world populations consume rice as their staple food (Rabbani *et al*. 2015). Some researchers showed a gradual increase of some heavy metals such as cadmium in Iranian rice and mentioned the situation as posing a significant threat (Zazoli *et al*. 2006).

The metal transfer factor (TF) is an indicator of heavy metal accumulation in plants. It quantifies the differences in the bioavailability of metal to plant. In other words, TF is an indicator of heavy metal mobility in the soil. Meanwhile, it is considered a critical parameter regarding the accumulation of heavy metals in plants. Of course, factors that contribute to the increase of heavy metal concentration in soil could have an impact on it, namely sludge application or wastewater reuse (Kalavrouziotis *et al*. 2012).

In recent years, researchers have focused their attention on the significance of soil types and genotype, and their impact on the uptake and accumulation of heavy metals in potted experiments (Chung *et al*. 2011; Lai *et al*. 2012). However, the pot experiments may not be able to predict uptake of heavy metals by a crop under actual field conditions. Accordingly, it is crucial to study heavy metals accumulation in plants' natural environment. Multiple metals' pollution of agricultural soils is turned into a common phenomenon, regarding human activities. It is believed that interactions of such different elements create a different toxic effect on an ecosystem compared to that of single pollutant (Liu *et al*. 2007). Therefore, in the present research, we performed a comprehensive study of toxic heavy metals in rice plants and their agricultural soils under natural conditions from renowned Lenjan paddy fields of central Iran.

2. MATERIAL AND METHODS

2.1 *Study area*

The area selected for present study is located in Lenjan, southwest Isfahan Province, central Iran; with a semi-arid climate, and an average annual temperature and rainfall of 15.7ºC and 157.7 mm, respectively (Iran Meteorological Organization 2017). Many active industrial units were placed adjacent to the study area. The growing period of rice plant (*Oryza sativa*) was about 155 days (May– October) in the Lenjan Region. Traditionally, rice is broadly cultivated in the area, with a great yield annually. However, most of the produced rice is consumed by residents. According to the local records, large amounts of chemical fertilisers, pesticides, and manures have been being applied to above-mentioned paddy fields over a long period. Surrounding industrial activities and urbanisation could have also affected the soil environment.

2.2 *Sampling*

Out of the greatest sources of pollution in the region, samples were collected from 41 sites in 2014. Researchers divided them into four districts, namely: 1-*Zarrinshahr*: an industrial and municipal sewage and river irrigation region, 2-*Sede*: a river and municipal sewage irrigation region, 3-*Chamgordan*: an industrial and municipal sewage irrigation region, and 4-*Varnamkhast*: a municipal sewage irrigation region. All collected samples were stored in polyethylene bags and brought to the soil science laboratory of Bu Ali Sina University, Iran for further preparation and treatment.

2.2.1 Soil sampling

Soil samples were collected from the fields' 0–20 cm soil layer. At first, they were air-dried at room temperature, then finely powdered, homogenised, and grinded to pass through a 2-mm nylon sieve. Later the samples were analysed for some of their physical and chemical properties. The pH (at the ratio of 1:5 soil-distilled water), EC (at the ratio of 1:5 soil-distilled water), calcium carbonate equivalent, soil texture, and soil organic matter plus cation exchange capacity were identified according to Thomas (1996), Sims (1996), Bauycos (1962), and Rowell (1994) guidelines; respectively. Total and available concentrations of heavy metals were measured by the method of Sposito *et al*. (1982) and Lindsay and Norvell (1978).

2.2.2 Water sampling

Water samples were collected from 2 sites (The Zayandeh Rood river and municipal wastewater). They were preserved in 1-L polypropylene sampling bottles at 4°C in darkness and analysed within 48 h (Hai *et al*. 2009).

2.2.3 Plant sampling

The plants' samples were taken in their maturity from approximately very same locations where the soils were sampled and simultaneously for further studies on the heavy metals mobility and bioavailability. In the laboratory, sampled rice plants were separated into their different parts such as roots, stems and grains; Then, they were washed three times with distilled water, rinsed with deionised water, and finally dried in an oven at 65°C. Later, the samples' dry weights were determined, and afterwards, the plant parts grinded with a tissue grinder (Liu *et al*. 2007). Samples digested with 8 mL of 70% HNO_3, then cooling to room temperature, were filtered through a 0.45-μm membrane filter, and adjusted to a final volume of 25 ml (Park *et al*. 2011). At last, some metal concentrations including (Cd, Pb, Ni and Zn), in three parts of the plant comprising (roots, stems and seeds) were determined using atomic absorption spectrophotometry.

2.3 *Bio-accumulation factor*

The bio-accumulation factor (BAF) is defined as the ratio of an element's concentration in plant's grain to that element's concentration in the corresponding soil. BAF was calculated for each plant sample to quantify the plant's bio-accumulation effect, up-taking heavy metals from the soils (Hang *et al*. 2009). The BAF was computed with the following formulae (eq. 1):

$$BAF = \frac{Cr}{Cs} \qquad \text{eq. 1,}$$

where Cr and Cs represented the heavy metals'

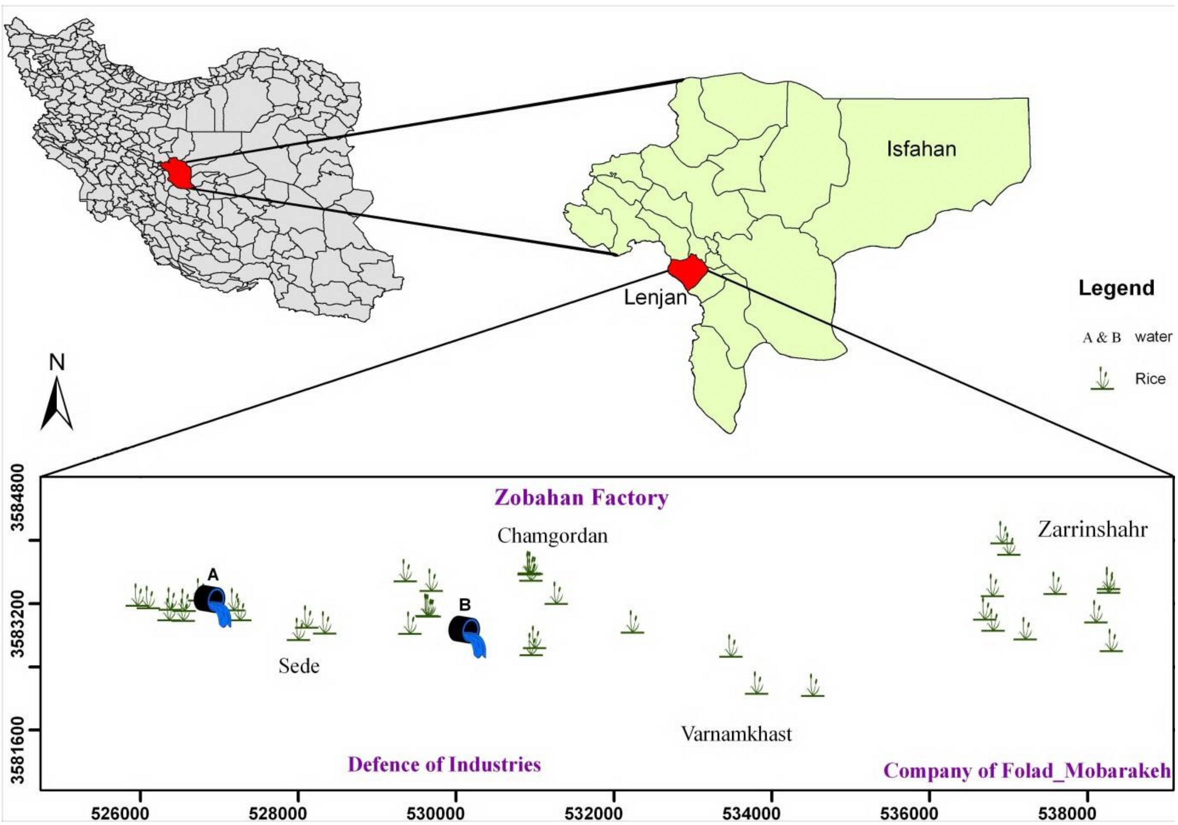

Figure 1. Map of the study area and four sampling locations

concentrations in the grain and soils extracts; respectively, on a dry weight basis (Hang *et al*. 2009; Singh *et al*. 2011).

2.4 *Transfer of heavy metals from the soils to the rice plants*

Concentrations of heavy metals in rice plant vary depending on total metal concentrations in their paddy soils (Jung & Thornton 1997). Therefore, the transfer factor (TF) of the heavy metals were calculated by dividing the concentration of every metal in the plant over its total concentration in the soil. Higher TFs reflect relatively poor retention in soil or greater efficiency of the plant to absorb metal; while lower TFs indicate strong sorption of metal to the soil colloid (Zhen *et al*. 2009).

Moreover, the translocation factor is calculated as the ratio of metal concentration in aerial parts of any plant over that metal's concentration in the plant root. In other words, $TF = (C_{aerial} / C_{root})$, where, C_{aerial} is the metal concentration in plant's aerial part, and C_{root} is that metal concentration in the plant's root (Tiwari *et al*. 2011; Singh *et al*. 2011).

3. RESULTS AND DISCUSSION

3.1 *Physico-chemical parameters of the soil*

As shown in Table 1, the main physicochemical parameters determined for topsoil's from the study area were as the followings: (i) The OM contents were within the range of 0.76–4.14%, (ii) values of pH fell in a narrow range (7.02–8.24), indicating sub-alkaline conditions for all the sampled topsoils; (iii) values of CEC showed high variation (10.1–47.56 cmol/kg) with a mean value of 20.81 cmol/kg. (IV) The $CaCO_3$ content ranged from 17.91 to 36.83; (V) the electrical conductivity ranged from 0.152–3.266 dS/m. Also, the contents of clay, silt and sand varied between 16–31, 16–48 and 27–57 percentages, respectively.

3.2 *Soil contamination*

Total and available heavy metal concentrations in the soils are presented in Table 2. Total and available concentrations of Cd and Pb, measured in the soils exceeded those in arable soils not subject to gross anthropogenic pollution, reported by Bi *et al*. (2010) that ranged between 0.1–2 mg/kg and 20–50 mg/kg; respectively.

The maximum allowable concentration of Ni in agricultural soils was proposed to be 50 mg/kg (Kabata Pendias 2010). However, in the present study, the mean concentration of Ni, obtained from all the sampled regions, was higher than what considered safe for agricultural soils.

The threshold of Zn is defined at 60 mg/kg in the topsoil (Sposito 1989; Manata & Angelone 2002; Kabata Pendias 2010). In comparison with the above standard, in approximately 50% of the samples, the Zn concentrations were higher than the standard, emphasising on anthropogenic sources of the contaminant which might be due to irrigating the rice crops with industrial and municipal wastewater. Tiwari *et al*. (2011) found that agricultural soils which repeatedly irrigated with industrial effluent were contaminated with Pb, Cd, Cu, Fe, Mn, Ni and Zn.

The DTPA extracted-metal contents, which are commonly recognised as available for uptake by plants, also differed among the soils. Among the four heavy metals in the study, Zn showed the most substantial relative difference, presented as the ratio of the maximum/minimum concentration, which was

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Some soil properties in the study area

	$CaCO_3$ [%]	pH	EC [dS/m]	CEC [cmol/kg]	OM [%]	Clay [%]	Silt [%]	Sand [%]
Min	17.91	7.02	0.152	10.10	0.76	16.00	16.00	27.00
Max	36.83	8.24	3.266	47.56	4.14	31.00	48.00	57.00
Mean	24.80	7.68	0.487	20.81	2.49	23.28	33.43	43.27

1.51 Pb ranked the second with a relative difference of 1.28 among the locations. Meanwhile, the other two elements had smaller differences, -i.e. 1.21 and 1.14 for the Cd and Ni, respectively. It could be due to different levels of contamination.

3.3 *Chemical properties and metal concentrations of the water samples*

The mean values for chemical properties and heavy metal concentrations -i.e. Cd, Pb, Ni and Zn, in the sampled water from a local river and municipal wastewater are shown in Table 3. The pH of river water samples ranged from 8.04 to 8.31; while those of sampled municipal wastewater varied between 7.27 to 7.38 in the study area. The electrical conductivities of the wastewater samples were higher perhaps due to concentrated salts previously reported in municipal wastewater (Kiziloglu *et al*. 2008). According to the Table 3, Cd, Pb and Zn concentrations in river water and municipal wastewater, commonly utilised for irrigation, were below the standard. Nevertheless, Ni concentrations in both groups of sampled water exceeded the pollution standards. The higher concentration of Cd, Pb and Zn in the river, compared to municipal wastewater, can be attributed to the later discharge of industrial pollutants into the river. Of course, depending on the type of industrial activity, discharged waste into the water resources may contain different heavy metals. Continued use of such polluted water would lead to accumulation of heavy metals in soil and plant (Singh *et al*. 2010; Mahmoud & Ghoneim 2016).

3.4 *Tracing the elements' concentrations in rice plant's parts*

3.4.1 Cd

The range and mean concentrations of Cd, Pb, Ni and Zn in various parts of the plants cultivated

T a b l e 2

Concentrations [mg/kg] of total and available heavy metal in the soils

Elements	*Zarrinshahr*	*Sede*	*Varnamkhast*	*Chamgordan*	aggregate	MAC*
Cd-Total	1.320	2.360	0.628	1.051	1.700	0.1–2[a]
Cd-DTPA-extractable	0.067	0.078	0.076	0.064	0.073	–
Pb-Total	48.700	44.600	80.230	71.010	53.540	20–50[a]
Pb-DTPA-extractable	3.140	3.126	2.520	2.440	2.956	–
Ni-Total	63.920	54.710	55.410	52.920	52.460	50[b]
Ni-DTPA-extractable	2.270	2.195	2.170	1.980	2.177	–
Zn-Total	95.436	63.032	51.755	50.352	66.648	60[c]
Zn-DTPA-extractable	8.065	7.061	5.410	7.317	7.129	–

*: maximum allowable concentrations (MAC)
a: Bi *et al*. (2010)
b: Kabata Pendias (2010)
c: Sposito (1989); Kabata Pendias (2010); Manata and Angelone (2002)

T a b l e 3

Some chemical properties and heavy metals' concentration in the sampled river and municipal wastewater

	pH	EC	Cd	Pb	Ni	Zn
Zayandeh Rood River	8.3	0.276	0.005	0.14	0.481	0.150
Municipal Wastewater	7.3	0.820	0.002	0.05	0.507	0.033
MAC[a]	–	–	0.020	5.00	0.200	2.000
MAC[b]	–	–	0.010	–	–	5.000

MAC[a]: maximum allowable concentrations for irrigation purposes, Ayers and Westcott (1985)
MAC[b]: maximum allowable concentrations for irrigation purposes, Montgomery (1985)

on paddy soils from four different areas of Lenjan, Iran are presented in Table 4. The mean value of Cd concentration in roots, stems and seeds of rice from different regions were 1.57, 1.07 and 1.27 mg/kg on dry weight basis, respectively. Fakoor Janati *et al*. (2011) studying 100 samples of rice purchased from some supermarkets in Iran, discovered 21 ng/g as the maximum content of Cd in rice. Zazoli *et al*. (2006) found that mean Cd concentration in Tarom rice (another variety of Iranian rice) was 0.41±0.17 mg/kg on dry weight basis. The allowable amount of Cd in plants (as shown in Table 5) has been reported to be 0.01–0.3 mg/kg dry weight (Alloway 1968). Moreover, the healthy food standard of Cd in rice, set by FAO/WHO codex (1984), was 0.3 mg/kg dry weight. Therefore, the average content of Cd in stems and grains of the sampled rice were 3.5 and 4.2 times more than the permissible limit, respectively. Findings revealed that amounts of Cd in all samples were above 0.3 mg/kg level. Also, Table 4 shows that concentrations of Cd in the plant's grains were higher than its stems. It was consistent with evidence that proved Cd possessed high mobility and easy absorption properties in plants, and could be easily absorbed by plants' root and skin, and then enter its tissues (Kabata Pendias 2010). With no proven beneficial effects on plants and animals; Cd proved to be toxic to plants, by reducing their photosynthesis, and water/nutrients uptake (Singh *et al*. 2011). It confirmed findings by Casado *et al*. (2008) that showed high Cd concentration in grasses induced by polluted soils.

The highest amount of Cd, in different parts of the plant, was seen in the *Sede* region. However, ANOVA analysis revealed that there wasn't a significant difference ($P < 0.05$) in Cd contents of the rice plant from the four different regions (Table 4).

Results from previous studies (Khan *et al*. 2008) demonstrated that plants grown on wastewater-irrigated soils contaminated with heavy metals could pose a significant health risk to humans. Opposite to current study, Liu *et al*. (2007) stated that amounts of Cd in rice grains irrigated with municipal wastewater, river, and ground-water were 0.016, 0.038 and 0.0079 mg/kg; respectively.

3.4.2 Pb

Among the four regions, the highest, but not

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Concentrations of heavy metals in various parts of the rice plants [mg/kg dw]

	Zarrinshahr (n= 11)		*Sede* (n= 21)		*Chamgordan* (n= 5)		*Varnamkhast* (n= 4)		Total (n= 41)
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Mean
Cd									
Root	1.20–1.75	1.58	1.05–2.15	1.60	1.20–1.75	1.41	1.35–1.80	1.56	1.57
Stem	0.75–1.15	0.92	0.50–5.45	1.20	0.80–1.10	0.92	0.80–1.50	1.05	1.07
Grain	1.02–1.60	1.27	1.05–2.05	1.28	1.25–1.40	1.32	1.10–1.25	1.18	1.27
Pb									
Root	22.5–42.5	29.34	24.0–34.0	27.82	25.50–28.00	26.30	23.0–30.0	26.37	27.90
Stem	11.0–28.0	18.72	9.5–24.0	16.35	11.33–21.50	18.23	11.5–23.5	16.37	17.22
Grain	11.0–15.3	12.65	10.2–14.2	12.36	11.00–12.75	11.70	24.5–28.5	11.94	12.32
Ni									
Root	5.85–18.7	11.80	2.7–17.05	9.98	5.5–16.2	11.35	7.15–15.20	11.20	10.75
Stem	1.52–2.85	2.13	0.5–2.60	1.50	1.4–2.1	1.78	1.13–3.06	1.75	1.73
Grain	0.10–2.50	1.19	0.2–3.00	1.07	0.1–2.3	1.10	0.45–1.50	0.95	1.099
Zn									
Root	19.60–56.3	29.27	12.6–50.3	23.83	9.24–33.70	23.48	13.60–37.40	28.57	25.71
Stem	6.13–36.2	16.20	0.23–37.9	12.70	4.00–19.31	11.77	6.30–25.39	14.96	13.75
Grain	16.20–33.6	24.26	5.08–35.0	18.75	8.25–17.30	14.17	8.02–24.50	15.84	19.39

significant, concentration of Pb in the roots, stems and seeds of the plant were seen in *Zarrinshahr* as shown in Table 4. While FAO (1984) recommended 5 mg/kg as the safe limit of Pb uptake concentration for plants, Alloway (1968) and Kabata Pendias (2010) reported 3 mg/kg as the tolerable limit of Pb for upper parts of the plants. Meanwhile, Hang *et al*. (2009) introduced the 0.2 mg/kg as the Pb limit. Comparatively studying, Pb concentrations in the studied rice plants were much higher than the standard limit. Jahed Khaniki and Zazoli (2005) also found higher than the FAO/WHO guidelines' Pb content in the rice plants from northern Iran.

While Pb may easily be absorbed by plant roots and stems, only a small proportion of it moves into the aerial parts of the plants (Pais & Jones 1997; Agarval 2002). In general, it is less mobile in the rice plants (Liu *et al*. 2007). Moreover, no significant correlations were observed between Pb concentrations in the sampled soils and aerial parts of the plant in the study (Table 6). Fu *et al*. (2008), in their study regarding heavy metal pollution in the rice crop, obtained a low correlation between soil and high levels of heavy metals in rice grains representing atmospheric deposition as a significant potential source of metals contamination of rice grains. Therefore, it seems to us that in the present study, an external factor such as atmospheric deposition could be blamed for Pb accumulation in aerial parts of the studied rice plants.

Anthropogenic entry and accumulation of Pb in the human food chain initiated from cultivated crops (Sillanppa & Jansson 1992; Pais & Jones 1997). Hang *et al*. (2009) in a risk assessment of contaminants in soil and rice from Changshu City, China discovered that concentrations of some heavy metals such as Pb in the plant could be related to substantial industrial activities in the region.

3.4.3 Ni

Ni concentrations in the rice grains were less than other parts of studied plans in paddy fields from various regions. The maximum concentrations of Ni in the roots, stems and seeds of the plant were found in *Zarrinshahr*, again. Not a substantial difference was revealed among the regions (Table 4). The Ni content in the plant roots was higher than other plant parts, and the Standard of China (2005). In the present study, Ni concentrations in sampled waters from the Zayandeh Rood river and municipal wastewater had reached the critical level (Table 3). It could play

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Maximum levels of contaminants in plant tissues quoted from various sources

Reference	Cd	Ni	Zn	Pb
FAO and WHO (1984)	0.3	20	60	5
SEPA (2005)*	0.2	10	100	9
Doberman and Fairhurst (2000)	–	–	20[a], 40[b]	–
Alloway (1968)	0.3	–	100	3
Hang *et al*. (2009)**	0.2		50	0.2

*: State Environmental Protection Administration, China
**: Maximum levels of contaminants in foods
a and b: Maximum levels of Zn in grain and stem, respectively, Doberman and Fairhurst (2000)

T a b l e 6

Pearson correlation coefficients between Cd, Pb, Ni and Zn concentrations in soils and the plant parts

Parts of the plant	Cd	Pb	Zn	Ni
Root	0.322*	–0.134	0.316*	0.353*
Stem	0.080	0.020	0.199	0.190
Grain	0.030	–0.220	0.080	0.240

*significant difference at $p < 0.05$ by the Duncan test a significant role in the consequent contamination of local soil and plants. Rattan *et al*. (2005) by investigating the impact of municipal effluent on the amount of Ni in cereals, illustrated that Ni uptake was dependent on its concentration in irrigation water.

3.4.4 Zn

The average Zn concentration in the stems was less than that of the roots and grains of the paddy crop across various regions. The maximum allowable concentration of zinc in plants varies in different sources. FAO and WHO (1984) reported the normal concentration of Zn in plants to be 60 mg/kg dry weight; whereas, Hang *et al*. (2009), SEPA (2005) and Alloway (1968) proposed 100 mg/kg as the permissible limit (Table 5). According to the proposed limits, the Zn contents in the stems and grains of the plant stood within the normal range. Of course, the Zn concentration in the rice roots cultivated in *Zarrinshahr* region was higher than expected, and exceeded the FAO (1984) standards.

Zarrinshahr had the highest total and available concentration of Zn in soils, as well (Table 2). Releasing industrial and municipal wastewater into water resources could have led to increasing concentrations of Zn in the soil and plants of the study area. Abbas *et al*. (2007) in a study on the effects of contaminated water of Nullah Dek on rice paddy saw elements accumulation in different parts of rice plant and soil. Moreover, they delineated that concentrations of all trace elements including (Zn, Cu, Fe and Mn) were increased by applying the Nullah Dek water which was already contaminated with industrial effluents carrying different micronutrients.

3.5 *Translocation of metals from soil into the rice plants*

3.5.1 Bio-accumulation factor

Figure 2 shows the bio-accumulation factors (BAF) calculated for heavy metal transfer from soils to the rice grain. The BAFs for heavy metals across studied regions in a descending order were as the following: Cd (*Varnamkhast* > *Zarrinshahr* > *Chamgordan* > *Sede*, with a significant difference in TF values among different regions), Ni (*Chamgordan* > *Zarrinshahr* > *Sede* > *Varnamkhast*, with no significant difference in TF values among different regions), Pb (*Sede* > *Zarrinshahr* > *Varnamkhast* > *Chamgordan*, with a significant difference in TF values among different regions), and Zn (*Varnam-*

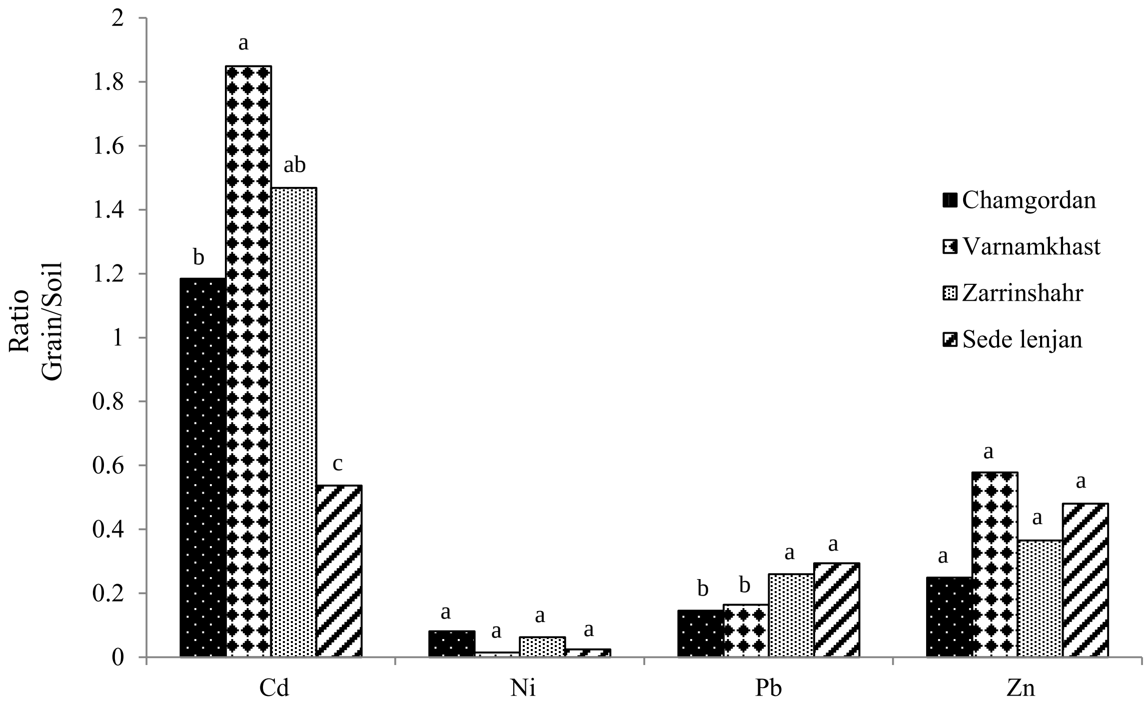

Figure 2. BAFs of the metals in the study area

khast > *Sede* > *Zarrinshahr* > *Chamgordan*, with no significant difference in TF values among different regions).

Principally, the food chain (soil–plant–human) is recognised as the major pathway for human exposure to soil contamination. The soil-to-plant transfer is one of the key components of human exposure to metals through the food chain. When BCF < 1 or BAF = 1, this denotes that the plant only absorbs but do not accumulate heavy metals; when BCF > 1,

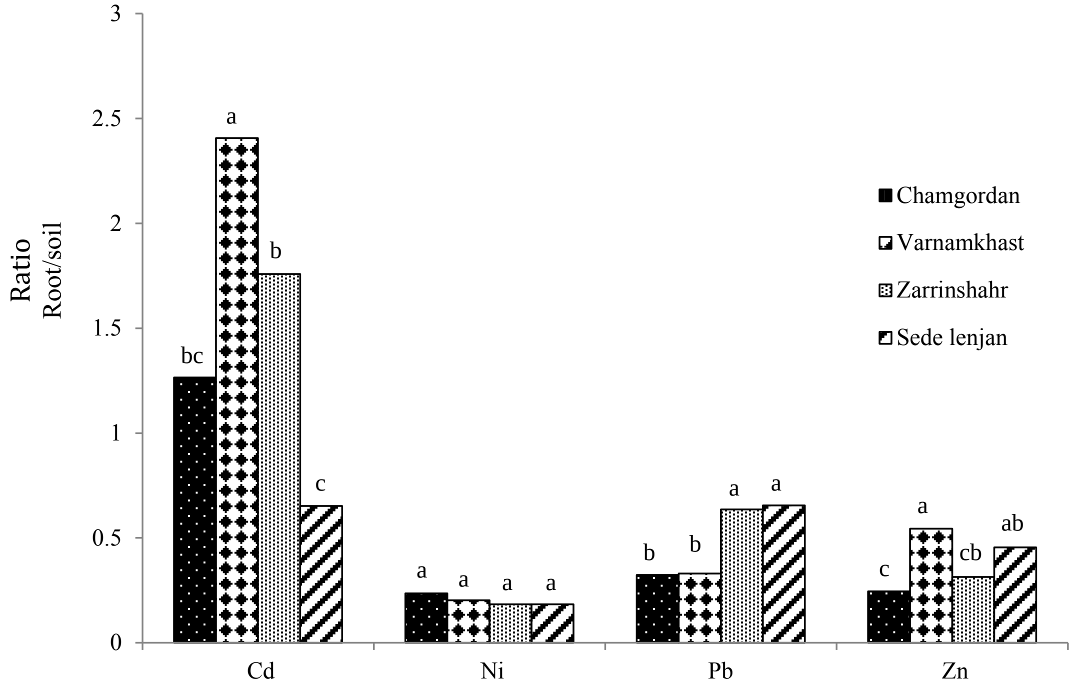

Figure 3. Metal transfer factor from soil to roots of rice (same letters indicate no significant difference)

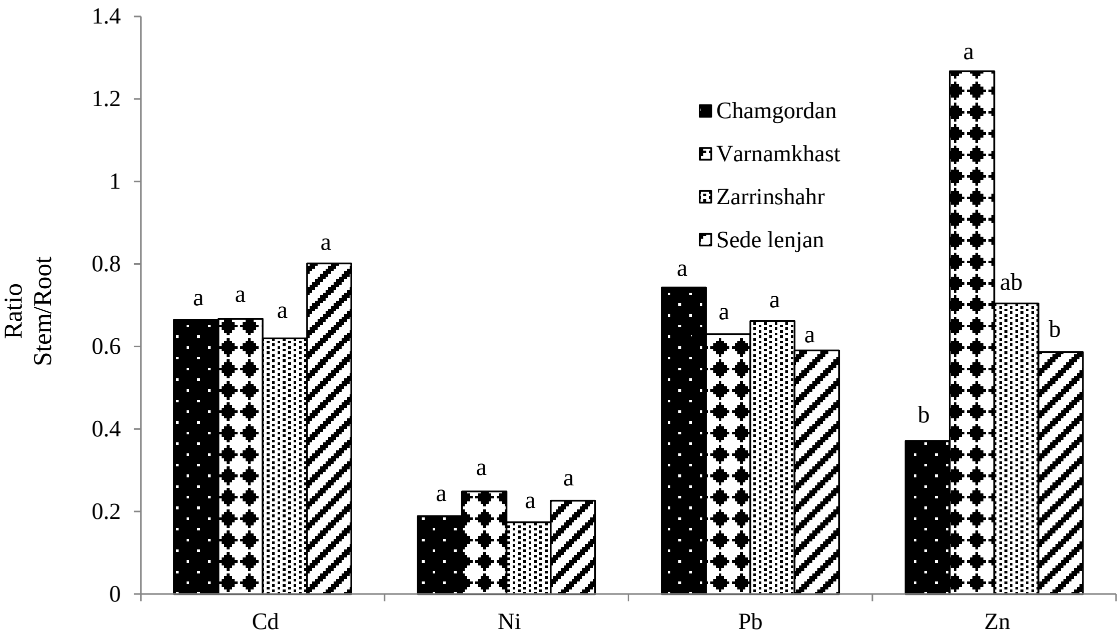

Figure 4. Metals transfer factor from root to stem of rice (same letters indicate no significant difference)

this indicates that plant accumulates metals (Singh *et al*. 2011). BAF values of Pb, Ni and Zn, were less than 1 in the rice grain. The results indicated that metal bioavailability was low in the study area.

3.5.2 Translocation of metals from roots into the upper parts of the rice plant

The translocation factor (TF) is an indication of the degree of metal translocation from soil to plant. It expresses a plant's capacity to store heavy metals in its upper part. The TF is described as the ratio of metal concentration in the upper part to that in the roots (Boularbah *et al*. 2006). Figures 3, 4 and 5 show the translocation factors (TF) of different heavy metals from soil to the rice plant. The TF is regarded as one of the key components of human exposure to heavy metals through the food chain (Singh *et al*. 2011). The TFs of metals from soil to root (TF_{Soil}), root to stem (TF_{Root}) and stem to grain (TF_{stem}) were calculated in the study. The average soil-to-root translocation (TF_{Soil}) were found to be in order of Cd (1.52) > Pb (0.486) > Zn (0.389) > Ni (0.201). It is illustrated that rice root accumulated high quantities of Cd^{+2} when grown in non-polluted areas, hence Cd^{+2} was proved to be more bioavailable to plants than other heavy metals, resulting in a higher biological absorption coefficient for Cd (Singh *et al*. 2011). The TF_{Root} values were found in the following order: Zn (0.732) > Cd (0.688) > Pb (0.656) > Ni (0.209).

The root-to-straw translocation values in the study area were less than 1 (except Zn), with no significant difference in TF values among different regions. The translocation values for the straw to grain (TF_{Straw}) in the study area were found in the following order: Zn (1.228) > Cd (0.854) > Pb (0.456) > Ni (0.24). For most metals (except Zn), the straw-to-grain TF values were less than 1, with no significant difference in TF values among different regions. It is because most of the heavy metals are often confined in the roots after paddy plant uptake. Also, for all the heavy metals, the TF values at stem were less than the grain, while at the grains, the values come close to the TF at the root. It appears due to atmospheric deposition and the plants' exposure to factory chimneys all over the years.

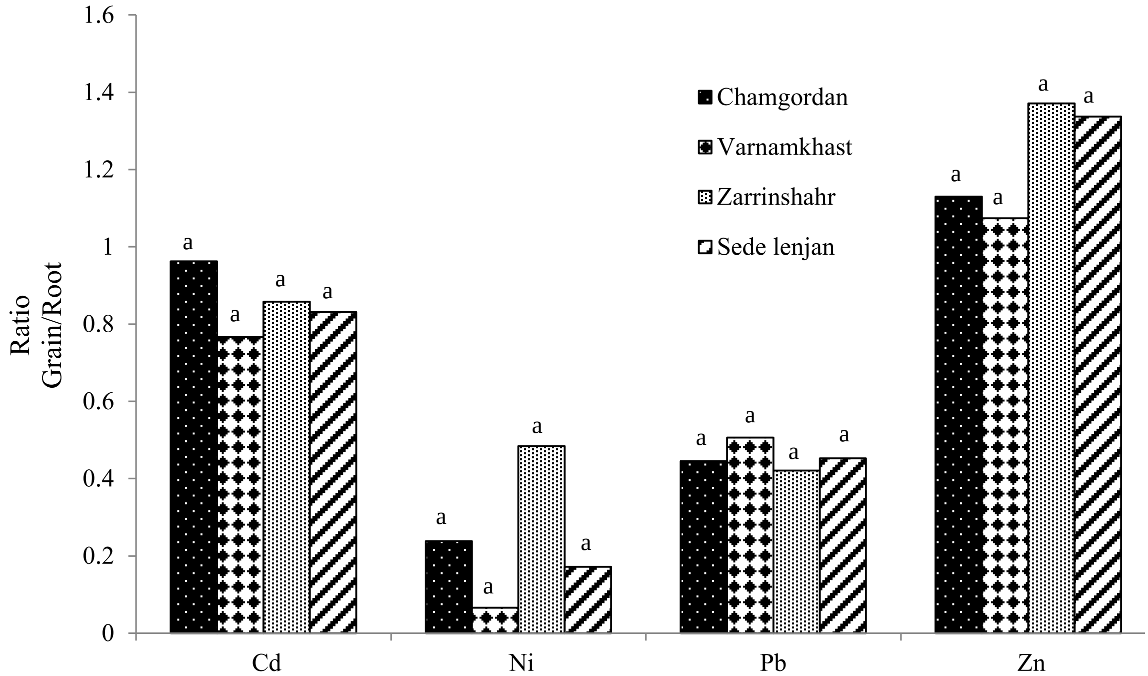

Figure 5. Metal transfer factor from root to grain of rice (same letters indicate no significant difference)

3.5.3 Coefficients of correlation between metals in the soils and the rice plants

Variability in soil properties and plant growth conditions often lead to not a direct relationship between total metal concentrations in soils and plants (Obrador *et al*. 2007). However, one of the reasons for the lack of a significant relationship between metal concentrations in soils and plants can be attributed to sources of contamination in the soil. In the present study, the concentrations of Cd, Zn and Ni in soil with their concentrations in the rice plant's roots showed a significant positive correlation (Table 6). The correlations between the stem and seed were positive but not statistically significant. Singh *et al*. (2010) in a study, obtained a positive correlation between the concentration of Cd in soil and its concentration in rice, but same correlations were negative for Ni. Also, Hang *et al*. (2009) found out a significant positive correlation (r = 0.353, $p < 0.05$) between Cd, Zn and Ni concentrations in soils and rice. In the present study, the concentration of Pb in the soil did not correlate with the amount absorbed by the rice, which was consistent with the findings of Zhao *et al*. (2010).

Pb is taken up by plants to some extent. Plants took up only 0.003–0.005% of the total soil Pb (Kalavrouziotis *et al*. 2012). However, in the present study, relatively high accumulation of Pb was observed in stems and grains of the plant (Figures 4 and 5). Data revealed that Pb concentrations in all examined parts of the rice plant were much higher than the preset normal standard -i.e. (1–5 mg/kg DM. It was consistent with the results of Nayek *et al*. (2010). It seems to us that adjacent factory chimneys could be blamed for such high Pb concentrations.

CONCLUSIONS

This study determined the accumulation of heavy metals in some paddy soils and rice plants which were collected simultaneously at harvest period. Meanwhile, the farms had been irrigated with contaminated water amid rising public and consumer concerns about the safety and health of local and imported rice in the market. It was found out that contrary to residents' expectations, anthropogenic industrial, municipal and agricultural activities have been changing the famous image of Lenjan aromatic rice for long, exceeding many safety standards in some cases. Based on the data obtained in the study, the agricultural soils, collected from four different locations in Lenjan region, central Iran were severely contaminated by Cd, followed by Ni, Pb and Zn. Assessed levels of Cd, Pb, Ni and Zn were above the standard limits in this area. However, concentrations of metals in the studied water samples were found to be within the permissible limit set by international authorities, except for Ni. High concentrations of Ni in the Zayandeh Rood river could be attributed to the aggregating discharge of municipal and industrial wastewater. The BAF for Cd was at maximum compared to other metals among the four locations. Most of the studied heavy metals were found accumulated mostly in the roots of the paddy plant. All of them had concentrations higher than the standard levels. Meanwhile, some plant parts, including the stems and grains contained, relatively high concentrations of Cd and Pb in comparison with the standards in all studied locations. They were much higher than the standards of FAO/WHO, meaning that consumption of such rice could be harmful to consumers (both humans and animals). In some cases, they had far exceeded the critical level. Low correlation discovered between the concentration of Pb in different parts of the plant and the soil on one, hand, and the relatively high metal contents detected in the rice grains on the other, suggested that aerial deposition was a potential source of metal contamination in rice. In regards to the national food safety criteria, Pb content in all rice samples exceeded the national MAC. In general, factors such as municipal and industrial wastewater increased the traced metal concentrations. Stricter monitoring of soil, plant, and water quality, together with tougher implementation of governmental regulations are among prerequisites to decline potential health hazards caused by irrigating with metal-polluted river water.

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