




# Ecological and human health risk evaluation of potential toxic metals in paddy soil, rice plants, and rice grains (*Oryza sativa*) of Omor Rice Field, Nigeria

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**Abstract** Potential toxic metals from natural and anthropogenic sources accumulate in soil and plants, and represent important environmental contamination challenges. The ecological and human health risks of the potential toxic metals in rice grain, paddy soil, and rice plants of Omor rice field were assessed. The total metal concentration from the four sampling sections (mg/kg) were soil—Zn ( $29.51 \pm 2.23$ ), Mn ( $55.27 \pm 8.10$ ), Cd ( $5.49 \pm 2.24$ ), Cu ( $2.94 \pm 1.47$ ), Pb ( $14.35 \pm 6.54$ ), and Cr ( $27.06 \pm 8.31$ ); rice grain—Zn ( $21.70 \pm 5.44$ ), Mn ( $3.30 \pm 0.21$ ), Cd ( $0.14 \pm 0.11$ ), Cu ( $2.80 \pm 0.34$ ), Pb ( $11.98 \pm 0.58$ ), and Cr ( $15.86 \pm 2.79$ ); and for rice plant—Zn ( $5.24 \pm 1.93$ ), Mn ( $4.68 \pm 1.91$ ), Cd ( $0.21 \pm 0.11$ ), Cu ( $4.88 \pm 0.61$ ), Pb ( $15.24 \pm 6.16$ ), and Cr ( $46.5 \pm 6.05$ ). The estimated daily intakes for adult showed that Cd and Pb exceeded the safe limit by 1% and 93%, respectively. The metal hazard quotients (Zn-0.0007, Mn-0.00019, Cd-0.16, Cu-0.19, and Cr-0.000077) were less than 1 indicating no probable health risk originating from their exposure. The total hazard index (0.35) also suggests no probable health risk connected with the rice

consumption. The metals' ecological risk indices of the soil showed low-risk ( $<40$ ), except Cd in some sections of the rice field which indicated moderate potential ecological risk (40—80).

**Keywords** Potential toxic metals · Paddy soil · Rice · Contamination · Risk assessment · Omor

## Introduction

Various problems have emerged in modern times of which potentially toxic metal pollution is a major issue, especially on roadside and urban soil (Shi et al., 2007). A few potentially toxic metals (PTM) are naturally essential for healthy living in minute concentrations (Tasharofi et al., 2018) and are called trace elements (iron, copper, manganese, and zinc). These elements commonly discharged from mining and industrial wastes, vehicular emission, lead-acid batteries, fertilizers, paints, and treated woods (Wuana & Okieimen, 2011) are widespread in the soil, foodstuffs, fruits, and vegetables (Tasharofi et al., 2018). Some toxic metals such as Pb, Cr, and Cd accumulates in the environment owing to their non-biodegradability and long residence time, thus are usually termed chemical time bomb (Stiglian et al., 1991). These metals directly influence public health as they easily enter the human body by oral dust ingestion, dermal contact, and/or inhalation (Abrahams, 2002).

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Although these potentially toxic metals occur naturally in the earth crust, they tend to enrich the agricultural soil from uncontrolled application of agrochemicals, refining, smelting, and burning of fossil fuel and sewage sludge (Gimeno-Garcia et al., 1996a, b). Pollution of agricultural soil by PTMs has become a source of worry to scientist and policymakers alike as a result of food safety concerns and potential health risks associated with their consumption (McLaughlin et al., 2000).

Soil is an important reservoir of PTMs in the terrestrial ecosystem, and thus, serves as an indicator of environmental pollution (Li, 2013). Studies have shown that PTM concentration in rice plants and grain is significantly related to their concentrations in the soil (Liu et al., 2005a, 2005b). The assessment of metal uptake by crops from soils is essential for human health risk assessment (Seel et al., 1995). Through ingestion, inhalation, and dermal contact, the potential toxic metals' estimated daily intake rate from different routes (food, soil, water, and air) can be established (Nadal et al., 2005). The hazard quotient (HQ) established by the US Environmental Protection Agency (USEPA, 2000a, b) has long been applied in assessing the potential health risk associated with long-term exposure to potential toxic metals in different media.

In Nigeria, rice consumption per capita is about 32 kg, making rice the most staple food in the country (PwC, 2018). Consumption has increased in the past decades to about 4.7%, almost four times the world's rice consumption growth which surpassed 6.4 million tons in 2017, amounting to 20% of Africa's consumption (PwC, 2018). But in all these, domestic production has failed to meet demand, and the increase is largely made-up by costly imports (Murphy, 2019). Between 2012 and 2015, Nigeria imported \$4 billion worth of rice to meet expanding consumption (Murphy, 2019). Comparatively, Nigeria's rice statistics proffer an enormous potential to increase productivity and boost production (Murphy, 2019). Yields have stagnated at 2 ton per hectare, within half or less of the average produced in Asia (PwC, 2018). Besides the increasing population, and rural to urban migration, guaranteeing food security in cardinal staples like rice becomes imperative. With the recent ban on importation of rice by Nigerian government, local rice production has grown significantly, requiring large investments in agriculture. This increase in local rice production has necessitated

the need to study soil quality and rice composition of essential elements and toxic metals such as cadmium and lead.

The many rice cultivars grown across the world vary greatly in sensory, cooking, and processing quality. Rice desirable to one group of people or suitable for an individual, may not be so for another (Bergman, 2019). To some, it refers to the quantity of whole kernels remaining after polishing or milling; to others, it is the visual appeal of the rice after milling, and then some use it to mean the palatability or eating quality of rice compared to local preferences. Across the world, rice exists in many combinations of length–width ratio, grain weight, brand, color, and endosperm chemical characteristics (Bergman, 2019). Most rice does not enter the export market but is consumed close to where it is produced. Consequently, consumers are often exposed only to local cultivars and are unaware of the great variation in the physical and chemical characteristics of the world's rice germplasm. Therefore, the only quality types the food industry experiences are those with a defined set of quality attributes, and the total amount of variation in end-use quality that exists in the world's rice germplasm.

Nigerians have less confidence in locally grown rice due to poor agricultural practices among the farmers and poor quality assessment of the produced rice. Consumers' concerns are mainly on the rice's nutritional content, ignoring the importance of health problems that may arise from possible contamination of the rice. Looking at the constituents of agrochemicals and poor environmental management and demarcation for different purposes (agriculture, residential, business, and industrial areas), extrapolation can be made that there is possible contamination of rice farms and rice products in Nigeria.

Omor is a rural community with little or no industrial activities, but there are many road-side mechanics, welders, and other artisans operating in the community. A major federal road connecting Anambra state to Adani town (a major rice producing community) in Enugu State traverses through the town. Indiscriminate disposal of metal-containing wastes, vehicular emissions, sewage water irrigation, and use of agrochemicals around Omor rice field is on the increase. Therefore, it is of great importance to continuously assess the soil and the rice grown in all parts of Omor in particular and Nigeria as a

whole. Ihedioha et al. (2016), Ezeofor et al. (2019), and Ihedioha et al. (2019) have reported heavy metal contamination of paddy soil, and rice in Ada and Ugbawka fields in Enugu State and Abakaliki rice fields in Ebonyi State respectively. In line with continuous monitoring of paddy soil and rice grains in Nigeria, this study determined concentration of selected potential toxic metal (PTM) in the rice grain, paddy soil, and rice plant of Omor rice field, Anyamelum area of Anambra State, Nigeria, with the view of assessing the ecological and human health implication to the consumers.

## Methods and materials

### Study area

Omor is a community in Anyamelum Local Government Area of Anambra State, Nigeria, bordering Enugu State and Anambra State. The community lies between 7°14' East and 6°31' North and at an altitude of 213 m above sea level (Herose & Wakaruki, 2002). Omor is on the shores of Omambala River, and it has good vegetation, fertile lands for the production of food crops such as rice, maize, yam, and cassava (Iheke & Nwaru, 2009). The climate is tropical with wet and dry seasons, and an annual average temperature of 20 to 28 °C (Iheke & Nwaru, 2009). Omor rice field vegetation is Guinea savanna that is easily plowed since it is loamy soil, and has the affinity to retain substantial amount of moisture and other essential minerals (Ihedioha et al., 2016). The topography is riverine, which supports the production of a variety of rice (Onumadu & Osahon, 2014). The Anambra Imo River Basin Development Authority, and the Lower Anambra Irrigation Project (LAIP) at Omor, built by Nigerian Government, has resuscitated rice growing in that part of the State. This is why over 104,047 of its population's main economic activity is agriculture, with rice as their major crop. Omor rice field is one of the major rice fields in Anambra State with an annual output of over ten thousand metric tons of rice. Omor rice fields were specifically chosen because of the increased agricultural activities within the area.

### Sampling and sample preparation

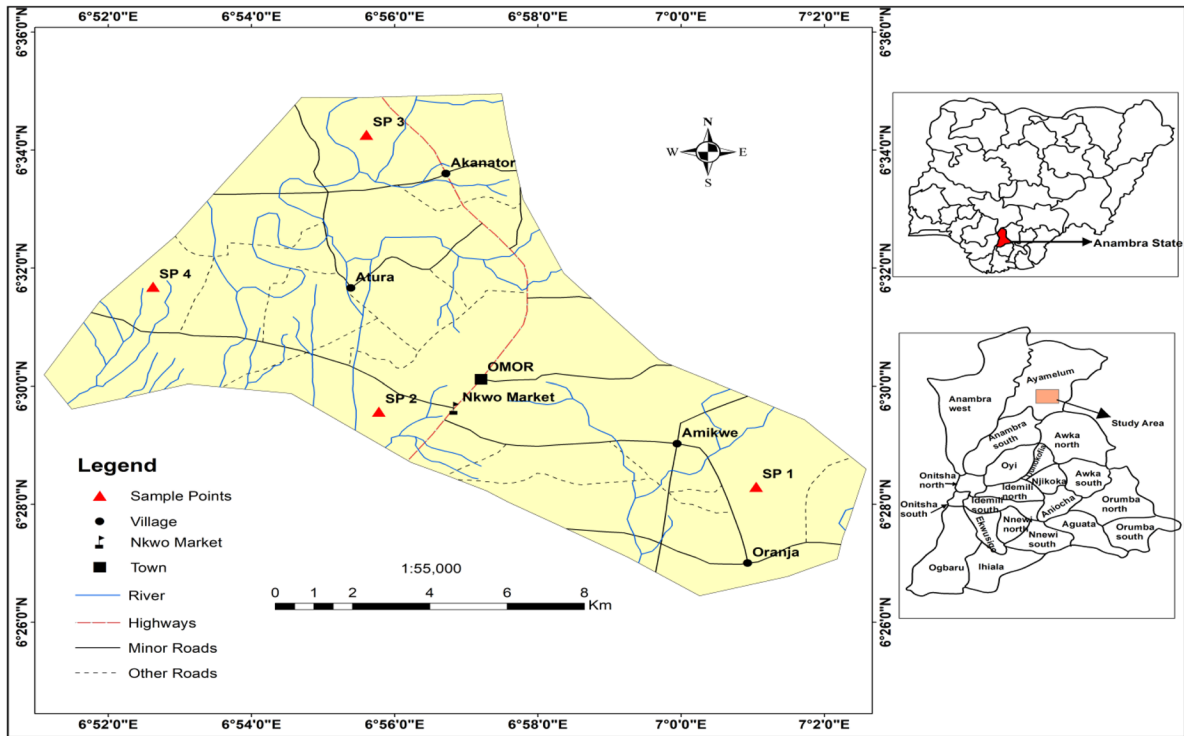
The composite technique was adopted in the sample collection. The rice field was divided into four sections: North, South, East, and West, and ten (10) samples each of paddy soil, rice grain, and rice plant were collected in each location between October and November 2019 (Fig. 1). Each composite soil sample comprises of 10 sub-samples randomly collected from (0–10-cm depth) topsoil from each location. In all, 120 samples constituting 40 each of rice grains, rice plant, and soil were collected. All samples were kept in clean polythene bags and taken to the laboratory for analysis. Rice grains and plant (shoots) samples were also collected from their corresponding soil locations. The rice plants' samples were collected at maturity, washed three times with distilled water, rinsed with deionized water, and dried in an oven at 65 °C to constant weight. The dried rice plants were pulverized, homogenized, and sieved through a 2-mm stainless steel mesh. The soil samples were air-dried in the laboratory at ambient temperature, pulverized to fine particles, homogenized, and later sieved with the mesh. The rice grains were de-husked manually, oven-dried at 70 °C for 72 h and ground into a fine powder with porcelain mortar (Ihedioha et al., 2016; Markert, 1996). Quartering method was applied in homogenizing the samples.

### Sample digestion and metal determination

About 2 g each of the paddy soil, ground rice plant, and rice grain samples were wet-digested with 20 mL of HNO<sub>3</sub>:HClO<sub>4</sub> (5:1) mixture to obtain a clear solution (Ihedioha et al., 2016; Markert, 1996). The digested samples were cooled, filtered, and transferred to 25-mL standard flasks. The flasks were made to mark with deionized water, and the metal concentrations were determined with an Atomic Absorption spectrophotometer (Varian AA240, United States) equipped with air-acetylene flame.

### Quality control procedure

All the reagents used were of analytical grade, and the glass wares were washed and rinsed with deionized water. Standard addition method was used to validate the analytical procedure. This was achieved through



**Fig. 1** Map of Omor rice field

triplicate determination of the metals in spiked and un-spiked rice grain, rice plant, and soil samples (Table 1). In spiking, 1 mL of each metal standard solution was added to 2 g of the sample and digested as described earlier. The percentage recoveries were calculated using Eq. 1:

$$\text{Percentage Recovery} = \frac{\text{conc. of spiked sample} - \text{conc. of un-spiked sample}}{\text{Spiking Concentration}} \tag{1}$$

Blank samples were prepared by digesting 20 mL of the digestion mixture and the metal content determined.

**Ecological risk assessment**

Six ecological indices (potential ecological risk index PERI, degree of contamination, modified degree of contamination, pollution load index, transfer factor, and bioaccumulation factor) were assessed. PERI was conducted to evaluate the ecological risk index (ERI) using the version by Hakanson (1980). The PERI is represented in Eq. 2:

$$E_r^i = \sum(C_f^i \times T_r^i) \tag{2}$$

where  $T_r^i$  is the toxic response factor (Cd=30, Cr=2, Pb=5, Cu=5, Zn=1, and Mn=1),

$C_f^i$  is the contamination factor (mean metal concentration divided by the pre-industrial concentration,

$$C_o, \text{ that is, } C_f^i = C^i / C_o \tag{3}$$

$C_o$  (mg/kg) for Cd, Cr, Pb, Cu, Zn, and Mn is 3, 100, 164, 100, 421, and 5 respectively (Hakanson, 1980). The risk grade indices and grades of potential ecological risk of potential toxic metal pollution as provided by Hakanson (1980) are presented in Table 2.

The degree of contamination estimates the degree of overall contamination in the sampling site's soil surface (Eq. 4). A modified model for calculating the prevailing degree of contamination as proposed by Abraham and Parker (2008) is Eq. 5.

**Table 1** Percentage recoveries of spiked samples

Heavy metal	% mean recovery in soil	% mean recovery in rice	% mean recovery in rice plant
Zn	96.8 ± 1.93	97.8 ± 2.01	97.8 ± 1.38
Mn	99.2 ± 1.43	98.9 ± 2.76	99.7 ± 1.79
Cd	91.5 ± 2.01	97.9 ± 1.78	94.7 ± 2.45
Cu	98.4 ± 1.23	96.8 ± 2.45	97.9 ± 1.65
Pb	99.0 ± 1.34	99.9 ± 1.65	96.9 ± 2.76
Cr	92.1 ± 1.948	99.0 ± 1.47	99.7 ± 2.98
% precision range	0.01–0.03	0.01–0.02	0.002–0.3

$$DC = \sum_{i=1}^n C_f^i \tag{4}$$

where *n* is the number of metals assessed and mDC is the modified degree of contamination. The modification has an edge by giving room for as many metals as possible in contamination determination.

$$mDC = ((\sum_{i=1}^{i=n})/n)C_f^i \tag{5}$$

The pollution load index (PLI) permits the comparison of pollution loads of different points at different periods (Tomlinson et al., 1980). The PLI was determined using Eq. 6 (Tomlinson et al., 1980):

$$PLI = n\sqrt{C_f^i1xC_f^i2xC_f^i3 \dots \dots xC_f^in} \tag{6}$$

**Transfer factor and bioaccumulation factor**

Metals from the soil are absorbed or adsorbed by roots and then distributed in various tissues. Such transmission of metals from soil to plant tissue is studied using an index called transfer factor (TF) or mobilization ratio. TF was calculated as the ratio of the concentrations of specific metal in plant tissue to

the same metal concentrations in the soil (Machiwa, 2010).

$$TF = \frac{\text{metal concentration in plant tissue } (\frac{mg}{kg})}{\text{metal concentration in the soil } (\frac{mg}{kg})} \tag{7}$$

A high TF value (≥ 1) indicates high absorption of metals from the soil by plant and high suitability of the plant for phytoextraction and phytoremediation of such metal.

BAF is the ratio of the metal concentration in the grain to that in the corresponding soil. It helps to determine the bioaccumulation effect of the metal on rice grains.

$$BAF = \frac{\text{metal concentration on rice grain } (\frac{mg}{kg})}{\text{metal concentration on the soil } (\frac{mg}{kg})} \tag{8}$$

**Health risk assessment of PTMs in rice grains**

Carcinogenic and non-carcinogenic health risk assessment methods are usually used to determine potential health risks of pollutants (USEPA, 2016). The probability of cancer risk (PCR) is used to determine the health risk of carcinogenic pollutants, while target hazard quotient (THQ) is used to estimate the non-carcinogenic risks (USEPA, 2016). PTMs find their way into the human body through so many processes, but in this study, we considered ingestion as one of the means through which metals enter the human system. The non-carcinogenic health risk resulting from rice consumption was evaluated using THQ and total hazard index (THI) (Ihedioha et al., 2016; USEPA, 2000a, b). THQ is the ratio of estimated intake of a pollutant to the oral reference dose

**Table 2** PERI grades

PERI	Potential ecological risk grade
< 40	Low
40 to 79	Moderate
80 to 159	Considerable
160–319	High potential
≥ 320	Significantly high

Hakanson (1980); Ogundele et al. (2020)

(RFD), while THI evaluates the perceived risk from a mixture of chemical contaminants (Ihedioha et al., 2016). When the THQ is < 1, it is assumed that there will be no probable health risk. However, values > 1 show concern on the health exposure to pollutants (USEPA, 2016). THQ method of assessment provides an indication of the health risk status owing to these pollutants but still, it does not estimate the quantitative odds of an exposed population to experience health effects (USEPA, 2016). This health risk assessment method has been used and had proven to be factual and worthwhile (Chien et al., 2002). Hence, this study adopted it to assess the health implication resulting from potential toxic metal pollutants in rice grain from Omor Rice field.

$$EDI = \frac{C \times RI \times ED \times EF}{BW \times AT} \quad (9)$$

$$THQ = \frac{EDI}{Rfd} \quad (10)$$

$$THI = HQ1 + HQ2 + HQ3 \dots \dots .HQn \quad (11)$$

where EDI is the estimated daily intake; EF is the exposure frequency (350 day/year); ED is the exposure duration, (70 years); RI is the rice ingestion (0.07 kg/person/day); C is the metal concentration in rice (mg/kg); RFD is the oral reference dose, mg/kg body weight/day (Cd = 0.001, Pb = not available, Zn = 0.3, Mn = 0.14, Cr (III) = 1.5, and Cu = 0.04 (USEPA, 2020; Ihedioha et al., 2019; USEPA, 2000a, b)), BW is the average body weight (60 kg); and AT is the average time for non-carcinogens (Ihedioha et al., 2016)(365 days/year × ED). The RFD for Cr (III) was applied to represent Cr in the study since all Cr (VI) will be reduced to Cr (III) in an acidic condition (DeFlora et al., 1997; Ihedioha et al., 2016).

#### Data analysis

Principal component analysis (PCA) and Pearson correlation analysis (CA) were used in the multivariate approach of the data obtained. These were used to analyze the interrelationships between parameters and their factor loadings (Egbueri, 2019; Egwuonwu et al., 2021) and to understand the relationship among the PTMs and their possible sources into the soil, rice grain, and rice plant, respectively. Significant levels

of correlations were obtained at 0.01 and 0.05. Factor loadings were classed as high, medium, and weak for 0.75, between 0.50 and 0.75, and below 0.50, respectively ((Egwuonwu et al., 2021; Tziritis et al., 2017). This was based on the fact that the higher a factor loading of a parameter, the greater its participation to the examined factor group. Discriminant analysis was also performed to investigate whether there are differences in the heavy metal concentrations by a cross-validation test, using the 'leave-one-out' procedure. The results of this analysis were assessed by examining the canonical correlation statistics, the Wilk's lambda, the significance level, and the percentage of original group cases correctly classified. All the analyses were performed with statistical package SPSS 16.0 for Windows (IBM, USA).

#### Results and discussion

Concentrations of potential toxic metals in the paddy soil, rice plant and rice grain

The mean concentration of the PTMs in soil, rice grains, and rice plant of Omor rice field are presented in Table 3. It showed that soil had a higher concentration of the PTMs followed by rice plant, and rice grain (soil > rice plant > rice grain). The trend of the PTM concentrations in soil, rice plant, and rice grain were Mn > Zn > Cr > Pb > Cd > Cu, Cr > Pb > Mn > Zn > Cu > Cd, and Zn > Cr > Pb > Mn > Cu > Cd, respectively. The concentration of cadmium in this study is comparable to  $0.49 \pm 0.09 - 0.59 \pm 0.10$  mg/kg reported for cadmium by Ihedioha et al. (2013) on rice locally grown in Nigeria. Satpathy et al. (2014) has reported mean concentration range ( $\mu\text{g/g}$ ) of Pb ( $5.3 \pm 0.4 - 19.8 \pm 1.3$ ), Cd ( $0.02 \pm 0.005 - 0.6 \pm 0.04$ ), Cu ( $0.03 \pm 0.004 - 5.4 \pm 1.5$ ), Cr ( $1.3 \pm 0.01 - 7.8 \pm 0.3$ ), Mn ( $12.5 \pm 0.2 - 53.9 \pm 1.5$ ), and Zn ( $3.8 \pm 1.7 - 33.8 \pm 1.3$ ) in soil from East Coast of India, which were lower than values reported in this study. However, higher metal concentrations has been reported by.

Jafari et al. (2019) for Cr (115.77 mg/kg), Ni (139.07 mg/kg), Cu (80.47 mg/kg), Pb (56.27 mg/kg), and Zn (135.73 mg/kg) in soil around Douroud cement factory, Iran, compared to the values reported in this study. Also, Tariq and Rashid (2013) reported

**Table 3** Potential toxic metal concentration (mg/kg) in soil, rice grain, and rice plant

Metal	SA	SB	SC	SD	Total mean±SD	RA	RB	RC	RD	RPA	RPB	RPC	RPD	Total mean±SD
Zn	32.10±5.43	26.69±1.59	30.01±8.27	29.23±7.83	29.51±2.23	27.50±25.20	24.54±16.46	19.57±2.29	15.17±7.64	6.76±4.33	3.31±1.30	7.03±5.86	3.84±3.13	5.24±1.93
Mn	45.29±8.79	54.34±13.77	65.03±21.64	56.43±15.43	55.27±8.10	2.99±0.94	3.35±0.93	3.50±0.75	3.34±1.83	3.79±1.73	3.32±2.06	4.10±1.99	7.51±5.40	4.68±1.91
Cd	5.84±3.81	7.06±1.66	6.85±1.68	2.22±1.23	5.49±2.24	0.29±0.11	0.14±0.09	0.08±0.11	0.05±0.03	0.14±0.11	0.29±0.09	0.31±0.31	0.17±0.27	0.21±0.11
Cu	2.04±0.74	1.95±0.34	2.66±0.20	5.09±2.92	2.94±1.47	2.37±0.38	2.70±0.27	2.95±0.32	3.16±0.55	4.28±0.58	4.42±0.49	5.50±4.10	5.30±2.91	4.88±0.61
Pb	10.47±8.01	21.39±1.07	18.18±5.52	7.34±3.54	14.33±6.54	12.54±0.91	11.38±2.67	12.40±2.51	11.59±1.91	17.45±0.49	20.19±0.79	17.09±1.06	6.23±3.96	15.24±6.16
Cr	22.87±1.66	22.84±4.32	23.00±2.16	39.53±10.51	27.06±8.31	12.72±3.68	14.30±2.87	18.34±4.09	18.07±6.05	49.12±16.95	42.07±8.96	41.02±8.75	53.79±4.82	46.5±6.05

SA soil section A samples, SB soil section B samples, SC soil section C samples, SD soil section D samples, RA rice section A samples, RB rice section B samples, RC rice section C samples, RD rice section D samples, RPA rice plant section A samples, RPB rice plant section B samples, RPC rice plant section C samples, RPD rice plant section D samples

**Table 4** International and National standards (mg/kg) for potential toxic metals

Metal	WHO <sup>m</sup> (rice grain)	DPR (Agric soil)	EU (2000) (Agric Soil)
Zn	50	140	300
Mn	-	476	-
Cd	0.1 (0.2) <sup>a</sup>	0.8	3
Cu	40*	-	140
Pb	0.2	85	300
Cr	1	100	-

WHO<sup>m</sup> (Cheng et al., 2004) = WHO standard metal concentration in rice grains. DPR = Department of Petroleum Resources, Nigeria

\*WHO Recommended permissible limit in food, <sup>a</sup>EU limit (Commission Regulation, 2006)

higher mean (mg/kg) of Cd (35.02), Pb (1065), and Cr (37.80) in paddy soil of Shakargarh, Pakistan.

The Nigerian Department of Petroleum Resources (DPR, 2002) metal standard for agricultural soil (Table 4) indicates that Omor soil has concentration of these metals within acceptable limit except Cd. The high values obtained in Cd could be from atmospheric descends resulting from urban and industrial activities, sewage sludge application as manure, and frequent application of organic and complex fertilizers (Ihedioha, 2016; Bai et al., 2015). Studies have shown that potassium fertilizer application significantly influences Cd concentration in paddy soils (Nouri et al., 2008). Gimeno-Garcia et al. (1996) reported that phosphate fertilizers have about 0.1–170 mg/kg of Cd.

In rice plant, Cr had the highest mean concentration (46.5 ± 6.05 mg/kg), while Cd recorded the lowest mean concentration (0.21 ± 0.11 mg/kg). According to Adriano (1986), a wide range of heavy metals exists in most agricultural soils and this depends on many factors including, anthropogenic inputs and parent material. Cadmium concentration in rice plants is dependent on the genotypic differences of the plants (Arao & Ishikawa, 2006; Uruguchi et al., 2009). Its accumulation in rice grains from shoots is mediated by the transport processes such as root uptake, translocation via phloem, and xylem-load-mediated translocation to shoot (Clemens et al., 2002). Satpathy et al. (2014) reported mean concentration range (µg/g) of Pb (0.3 ± 0.01–1.2 ± 0.01), Cd

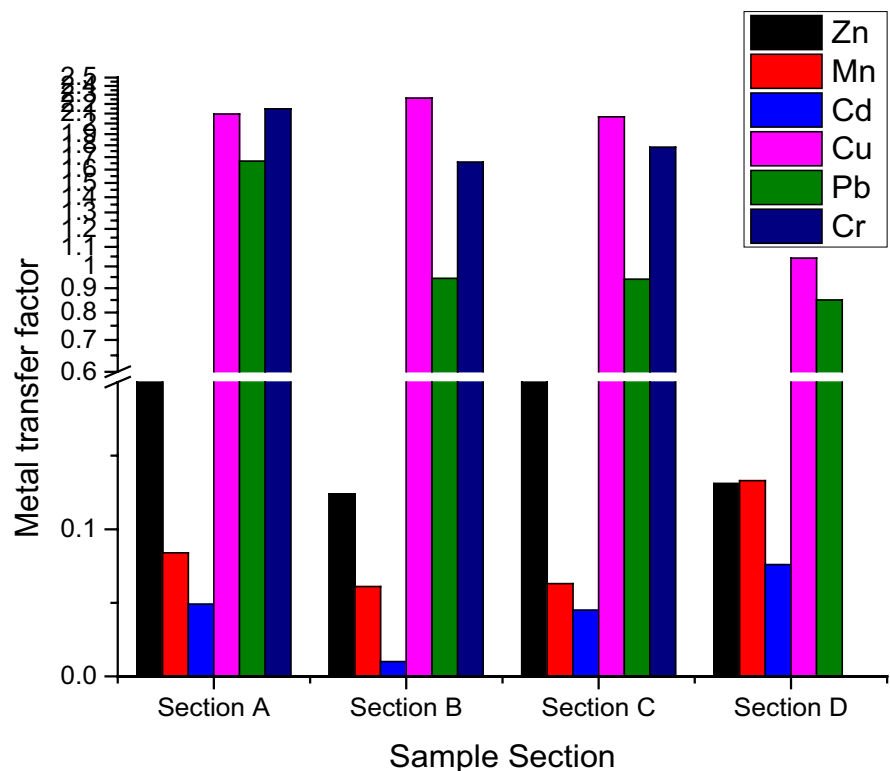
( $0.2 \pm 0.01$ – $0.3 \pm 0.01$ ), Cu ( $0.04 \pm 0.008$ – $0.3 \pm 0.03$ ), Cr ( $0.4 \pm 0.01$ – $0.9 \pm 0.04$ ), Mn ( $25 \pm 2.8$ – $32.9 \pm 1.9$ ), and Zn ( $2.3 \pm 0.01$ – $6 \pm 0.2$ ) in rice plant shoot in East Coast of India. These values were below the values observed in our study. Tariq and Rashid (2013) observed higher mean concentrations (mg/kg) of Cd (0.849), Pb (48.81), and Cr (9.173) in rice plant from Shakargarh, Pakistan. Chu et al. (2021), also reported appreciable amount of these heavy metals in Vietnamese rice.

The mean concentration of Zn in rice grain was below WHO standard of 50 mg/kg (Table 4). However, Cr, Cd, and Pb exceeded the WHO standard of 1.0, 0.1, and 0.2 mg/kg in rice, respectively. Omor town is a rural community with little or no industrial activities but there are many roadside mechanics, welders, and other artisanal activities are carried out in the town. A major federal road connecting Anambra state to Adani town (a major rice producing community) in Enugu State traverses through the town. Indiscriminate disposal of metal-containing waste, vehicular emissions, sewage water irrigation, and use of agrochemicals could have led to these metals accumulation in rice grains.

Mean concentrations (mg/kg) higher than values in this study have been reported by Tariq and Rashid (2013) on Cd (0.859), Pb (45.75), and Cr (6.988) in rice grain of Shakargarh, Pakistan. Satpathy et al. (2014) also reported ranges ( $\mu\text{g/g}$ ) of Pb, Cd, Cu, Cr, Mn, and Zn to be  $0.01 \pm 0.001$ – $1 \pm 0.02$ ,  $0.02 \pm 0.001$ – $0.05 \pm 0.002$ ,  $0.1 \pm 0.008$ – $0.3 \pm 0.01$ ,  $0.1 \pm 0.02$ – $0.6 \pm 0.01$ ,  $5.6 \pm 0.04$ – $7.5 \pm 0.03$ , and  $3.2 \pm 0.05$ – $7.2 \pm 0.008$ , respectively, in rice grains which were lower than the values obtained in rice grains in this study.

Cadmium accumulation in rice grains could be enhanced by physiological processes as noted by Kanu et al. (2017). This observation supports the assertion that rice grain serves as a sink for Cd as noted by Ishikawa (2020). This observation is also in line with the report of Ihedioha et al. (2013), who reported values of Cd in rice grown in seven states of Nigeria to be higher than the permissible level by JECFA (0.4 mg/kg) and WHO (0.1 mg/kg). Also, Ihedioha et al. (2016) and Ezeofor et al. (2019) reported Pb and Cd concentrations above permissible limits in rice grains from Ada and Ugbawka rice fields respectively.

**Fig. 2** Metal transfer factor





The uptake of metals by plants from the soil is affected by many factors such as the redox potential, soil pH, root system, metal foliar deposits, soil aeration, leaf types, and soil moisture content (Yamamoto & Kozłowski, 1987). A rise in soil pH and a decrease in redox potential reduce PTMs availability to plants (Ihedioha et al., 2016; Misra & Mani, 1991). The keeping of paddy fields flooded before and after heading leads to a reduction in Cd uptake by rice (Ihedioha et al., 2019) because under that condition, the soil gets reductive and forms CdS with low solubility (Ihedioha et al., 2016). However, draining the field, makes the soil oxidative leading to the formation of Cd<sup>2+</sup>, which is Cd best form for plant uptake (Ito & Iimura, 1976).

Transfer and bioaccumulation factors

The transfer of metals from soil to plant is a function of the soil’s physical and chemical properties, and the plant species, and is altered by many environmental and human factors (Zurera et al., 1987). Soil to plant transfer is one of the main means of human exposure to metals through the food chain. The highest and

least TFs were recorded in section B, (2.263) for Cu and t(0.010),for Cd, respectively (Fig. 2). The transfer factor of Cu, Pb, and Cr were above unity in almost all the sampled sections, but Zn, Cd, and Mn were below one. The uptake of Cu in roots is via a system involved in the transport of another essential divalent micronutrient possibly Zn<sup>2+</sup>. Copper is a chemical analog of Zn, and plants may not be able to differentiate between the two ions (Chaney et al., 1994).

The BF<sub>s</sub> of Zn, Cr, Cd, and Mn in rice grain were less than 1 (Fig. 3) showing that the rice plant’s physiological need for these elements is rather limited (Chakroun et al., 2010). However, BF<sub>s</sub> of Cu and Pb were greater than 1 in A, B, and D sections of the farm. Bioaccumulation factor above one is an indication that the plant root is able to solubilize and take up metals from very low soil levels. The BF is an important indicator for evaluating the mobility of heavy metals in plants (Zhao et al., 2001). This study showed that *Oryza sativa* plant can serve as Cu and Pb hyper-accumulator, and bio-accumulator of Zn, Cd, Cr, and Mn (Prasad, 2003). This finding is in line with the observations of Zakka et al. (2014), Mukut and Arundhuti (2012), and Stefan and Todor (2005).

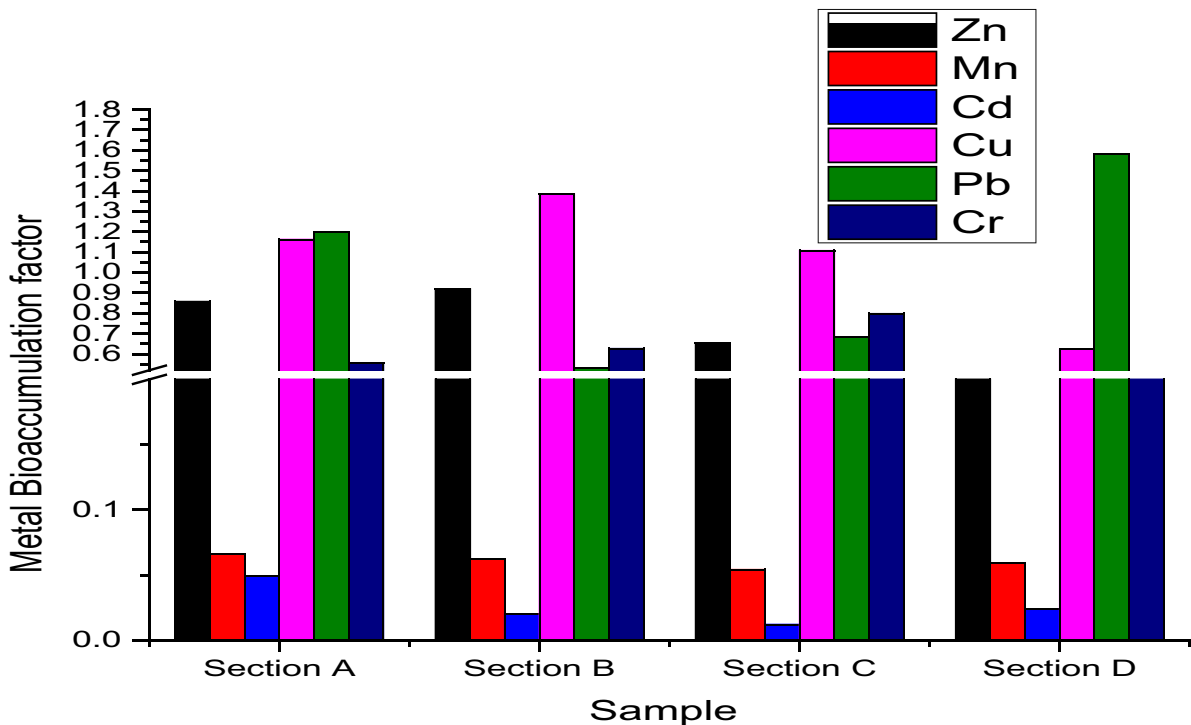


Fig. 3 Metal bioaccumulation factor

## Metal bioaccumulation factor

### Correlation and principal component analysis

The correlation result (Table 5) showed a positive correlation between Pb–Cd and Cr–Cu in soil at 0.01 significant levels with  $r$ -value of 0.513 and 0.635, respectively. This positive correlation suggests a similar origin or source of the soil's potential toxic metals, probably from agrochemicals used by the farmers. Ihedioha et al. (2016), and Ezeofor et al. (2019), have reported strong correlations among Cr, Mn, and Ni in Ada and Ugbawka rice fields and inferred that the metals may be from similar pollution source. Negative correlations were observed between Cu–Cd, Cd–Cr, and Cr–Pb, indicating the inverse relationship between the metals, suggesting different sources of the soil's PTMs. In rice grain, there were no positive correlations between the metals. However, negative relationships occurred between Cr–Cd and Pb–Cd at 0.01 significant level, and Cr–Pb at 0.05 significant levels (Table 5). In rice plant, positive correlation was observed between Cd–Zn at 0.01 significant level

( $r=0.612$ ) and negative correlation between Cr–Pb at 0.05 significant level ( $r= -0.384$ ) (Table 5).

### Principal components analysis

Varimax rotated component matrix was used to understand the metals' sources in paddy soil, rice grain, and rice plant (Table 6). In soil, three rotated factors were acquired for the total metal contents with a cumulative eigen value of 96.192%, for the different metals in the soil samples. Cr and Cu gave the major contribution to the first factor, Zn, Mn, and Cd to the second factor, while the third factor received the major contribution from Pb. One rotated factor and two rotated factors were observed in rice grain and rice plant with cumulative eigen values of 86.829% and 50.436%, respectively. The only rotated factor in the rice grain received its major contribution from Cr, Cu, and Mn. In contrast, the rice plant's two rotated factors received their major contributions from Cr, Mn, Pb and Cu, Zn, Cd, respectively. These observations collaborates the correlation results suggesting their similar sources.. Based on this, we infer

**Table 5** Pearson's correlation between different metals

Soil	Zn	Mn	Cd	Cd	Pb	Cr
Zn	1					
Mn	-0.142	1				
Cd	-0.114	-0.019	1			
Cu	0.035	-0.140	-0.316*	1		
Pb	-0.084	0.010	0.513**	-0.275	1	
Cr	-0.036	-0.091	-0.436**	0.635**	-0.434**	1
Rice grain						
Zn	1					
Mn	-0.082	1				
Cd	0.156	-0.282	1			
Cu	0.024	0.156	-0.446**	1		
Pb	0.085	0.051	0.247	-0.067	1	
Cr	-0.284	0.142	-0.421**	0.239	-0.132	1
Rice plant						
Zn	1					
Mn	-0.170	1				
Cd	0.612**	-0.151	1			
Cu	-0.229	-0.030	-0.085	1		
Pb	0.139	-0.297	-0.070	-0.164	1	
Cr	0.024	0.199	0.187	0.096	-0.384*	1

\*\*Correlation is significant at the 0.01 level (2-tailed)

\*Correlation is significant at the 0.05 level (2-tailed)

**Table 6** Varimax rotated component matrix for metal loading in paddy soil, rice grain, and rice plant

	Metal factor	Cr	Cu	Zn	Mn	Cd	Pb	Eigen value	% Total variance	Cumulative eigen value	Cumulative %
Soil components	1	<b>0.98</b>	<b>0.914</b>	-0.694	-0.065	-0.241	-0.033	3.313	39.007	3.313	39.007
	2	-0.026	-0.25	<b>0.634</b>	<b>0.99</b>	<b>0.917</b>	0.091	1.376	38.225	3.432	77.232
	3	0.027	-0.185	-0.262	-0.005	0.253	<b>0.985</b>	1.082	18.96	5.772	96.192
Rice grain components	1	<b>0.942</b>	<b>0.987</b>	-0.94	<b>0.871</b>	-0.996	<b>-0.458</b>	71.492	86.829	71.492	86.829
Rice plant components	1	<b>0.818</b>	0.482	-0.424	<b>0.994</b>	-0.176	<b>-0.987</b>	3.071	50.436	51.224	50.436
	2	b	<b>0.538</b>	<b>0.885</b>	0.105	<b>0.965</b>	<b>-0.161</b>	2.041	50.436	85.247	50.436

Strong correlation is shown in bold font

**Table 7** Classification Results<sup>b, c</sup>

	Component	Predicted Group Membership			Total
		1	2	3	
Original	Count	1	2	3	3
	%	100.0	.0	100.0	100.0
	Count	3	0	3	3
Cross-validated <sup>a</sup>	Count	3	0	3	3
	%	100.0	.0	100.0	100.0
	Count	3	0	3	3

<sup>a</sup>Crossvalidation is done only for those cases in the analysis. In cross validation, eachcase is classified by the functions derived from all cases other than thatcase

<sup>b</sup>100.0% of original grouped cases correctly classified

<sup>c</sup>50.0%of cross-validated grouped cases correctly classified

**Table 8** Standardized canonical discriminant function coefficients

	Function 1
Crcomp	1.883
cucomp	-0.678
zncom	0.774
mncomp	0.817

that these metals could be from the prolonged use of agrochemicals and pesticides by the Omor rice field farmers. According to USEPA (1999), phosphate fertilizers produced from phosphate ores, may be contaminated with heavy metals such as Mn, Cr, and Pb. Kukulamude et al. (2020) in the assessment of metals in rice consumed in Thailand reported that potential toxic metals are mainly from various anthropogenic activities and application of chemical fertilizer and pesticides. Gimeno-Garcia et al. (1996), reported concentration (mg/kg) of 0.1–170 Cd, 7–38 Ni, and 7–225 Pb, on nitrate fertilizers and 0.05–8.5 Cd on phosphate fertilizer. Another potential source of metals in agricultural soil is sewage sludge. It has been used as fertilizer and soil conditioner owing to the ease of accessibility (Sigua et al. 2005). Wong et al. (2007) and Selivanovskaya and Latypova (2003) have reported a substantial concentration of metals in sewage sludge. Metals in sewage sludge are known to be very mobile resulting from the organic matter present in it (Liu et al., 2007a, b).

A classification was obtained with an overall correct classification rate of 100% and a cross-validation rate of 100% (Table 7). Simultaneously, the discriminant analysis was also carried out on the basis of six components associated with the PTMs matrices (soil, rice grains and rice plant). The average correct

classification rates of 100% of the samples for original and cross-validation were obtained. One canonical discriminant function was derived on the basis of these six components associated with the matrices (Table 8). The canonical correlation function accounted for 99.6% (0.998 squared) of the total variance. Wilks' Lambda (which runs from 0.0 to 1) was significant (Sig=0.028) with a value of 0.004 (close to zero) indicating high discrimination (Table 7). The high discrimination received the greatest impact from Cr (1.883), followed by Mn (0.817) and Zn (0.774) as shown in Table 8.

### Ecological risk assessment

The risk indices of the PTMs in soil (Table 9) showed that all the metals fell within low-risk category (<40), except Cd in sections A, B, and C which fell on moderate potential ecological risk category (40–80). This suggests that these pollutants pose a low ecological risk in Omor agricultural rice field.

Contamination factor ( $C_f^i$ ) is grouped into low contamination factor ( $C_f^i < 1$ ), moderate contamination factor ( $1 < C_f^i < 3$ ), considerable contamination factor ( $3 < C_f^i < 6$ ), and very high contamination factor ( $C_f^i > 6$ ) (Liu et al., 2005b). The soil of Omor rice field had low contamination by Zn, Cu, Pb, and Cr but moderate contamination by Cd ( $C_f^i = 1.83$ ). The soil was highly contaminated by Mn ( $C_f^i = 11.054$ ).

The gradation of modified degree of contamination are  $mDC < 1.5$  Nil (a very low degree of contamination),  $1.5 \leq mDC < 2$  (low degree of contamination),  $2 \leq mDC < 4$  (moderate degree of contamination),  $4 \leq mDC < 8$  (high degrees of contamination),  $8 \leq mDC < 16$  (very high

**Table 9** Potential ecological risk index, contamination factor, degree of contamination, and pollution load indices

Element	PERI				$C_f^i$	DC	mDC	PLI
	Section A	Section B	Section C	Section D				
Zn	0.076	0.063	0.071	0.069	0.070102	13.3416	2.2236	1.89E-01
Mn	9.058	10.868	13.006	11.286	11.054			
Cd	58.4	70.6	68.5	22.2	1.83			
Cu	0.102	0.098	0.133	0.255	0.0294			
Pb	0.319	0.652	0.554	0.224	0.0875			
Cr	0.457	0.457	0.46	0.791	0.2706			

**Table 10** Estimated daily intake and hazard quotient of the metal from rice consumption

Metal	Daily intake (mg/pers/day)	Daily intake (mg/kg bw/day)	Safe value (mg/kg bw/day)	Exceeding % of safe value	THQ
Zn	4.85	0.081	1000 <sup>C</sup>	0.01	$2.7 \times 10^{-4}$
Mn	1.58	0.03	40–70 <sup>d</sup>	0.04	$1.9 \times 10^{-4}$
Cd	9.40	0.16	0.83 <sup>b</sup>	18.86	$1.6 \times 10^{-1}$
Cu	46.90	0.78	6.6 <sup>t</sup>	n/a	$1.9 \times 10^{-1}$
Pb	200.993	3.34975	3.6 <sup>a</sup>	93.049	–
Cr	0.71	0.01	50–200 <sup>x</sup>	0.01	$7.7 \times 10^{-6}$
THI					0.35

Assumed 60 kg bodyweight

n/a not available

<sup>t</sup>WHO (1988, 1989)

<sup>b</sup>JECFA (2010)

<sup>c</sup>JECFA (1982)

<sup>d</sup>NRC (1991)

<sup>x</sup>NRC (1989)

degree of contamination),  $16 \leq mDC < 32$  (extremely high degrees of contamination), and  $mDC \geq 32$  (ultra-high degrees of contamination) (Abraham & Parker, 2008). The overall degree of contamination (13.3416) and the modified degree of contamination (2.2236) showed very high and moderate degrees of contamination, respectively. The observed modified degree of contamination was different from that reported by Ekere et al. (2020) and Shakeri et al. (2014) which indicated ultra-high and very low degree of contamination respectively.

The composite value was determined using the pollution load index (PLI) to ascertain the overall status of the soil and the PLI result showed a low (0.189) pollution load.

### Health risk exposure assessment

The estimated daily intakes of the PTMs were calculated using the average concentration of each PTM in rice grains and the daily consumption rate of rice. The average daily consumption rate of rice in Nigeria is 70 g/person/day (IRRI, 2001). The estimated daily intakes of Zn, Mn, Cd, Cu, Pb, and Cr per person per day were presented in Table 10. The daily intakes for a 60-kg adult were compared with tolerable daily intakes as stipulated by WHO, JECFA and NRC. Cd and Pb exceeded the safe limit by 18.8% and 93%, respectively. Similar appreciable EDI has

been reported by Ihedioha et al. (2016) and Ezeofor et al. (2019) on Pb and Cd in rice grain from Ada and Ugbawka rice fields, Enugu, Nigeria. The daily intakes of Cr (0.006%), Zn (0.008%) and Mn (0.038%) were very low, and comparable to the safe value. Low daily intake has also been reported by Zhuang et al. (2009) and Ihedioha et al. (2016) on rice grains.

The EDI of the PTMs through the consumption of rice followed the trend  $Cu > Cd > Zn > Mn > Cr$ . The trend is in agreement with the reports of Fu et al. (2015), Li et al. (2012), and Mohammadia et al. (2019).

The HQ trend is  $Cr < Mn < Zn < Cd < Cu$  (Table 10). HQ of the PTMs were less than 1; thus, the consumption of rice from this field will likely induce no adverse health effects arising largely from their exposure. This indicates no probable potential non-carcinogenic health risks associated with most of these potential toxic metals in rice from Omor rice field. A similar result was obtained by Jafari et al. (2018) in Iranian grown and imported rice. The total hazard index (THI) was less than 1 (0.35) indicating no probable health risk.

### Conclusion

This study evaluated the ecological risk of Omor rice field and the associated human health risks exposure

to PTMs arising from consumption of rice from this field. The concentrations of some of the metals (Mn, Cu, Zn and Cr) assessed were within the limit of the WHO for rice grain. However, cadmium and lead concentrations in the rice grains exceeded this limit. Also, the metals in the soil were all within limit of DPR except Cd. The Omor rice field's soil had low contamination by Zn, Cu, Pb, and Cr but moderate contamination by Cd, while the soil was highly contaminated with Mn. The overall degree of contamination and the modified degree of contamination showed a very high and moderate degree of contamination. Moderate correlations were observed among some of the metals indicating similar pollution sources of the metals. The HQ of all the potential toxic metals was less than one, indicating no probable potential non-carcinogenic health risks associated with most of these PTMs in rice from Omor rice field. Though the PLI and non-carcinogenic health risk assessment showed no probable potential risk associated with most of these potential toxic metals in rice from Omor rice field, there is need for continuous monitoring of these PTMs especially Cd and Mn of paddy soil of Omor rice field.

**Availability of data and materials** Not applicable.

**Declarations**

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

**Consent for publication** All authors have agreed to publish this manuscript with EMAS Journal.

**Conflicts of interest** The authors declare no competing interests.

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