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Human Health Risk Assessment of Heavy Metals Contamination and Accumulation in Maga-Pouss Rice Fields, Far North Region of Cameroon

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Abstract

Accumulation of heavy metals in foodstuffs is a matter of concern for human health. In this sense, the present study was conducted in Maga-Pouss rice fields, the major rice-cultivated area in Cameroon, in order to assess the concentrations of iron (Fe), zinc (Zn), copper (Cu), mercuric (Hg), cadmium (Cd) and lead (Pb) in rice grains and their possible human health risks. Metals were measured by atomic absorption spectrophotometer (AAS) in irrigation water, paddy soils and rice plants and grains gathered from Maga, Ziam, Bakasaraï and Pouss villages. All selected heavy metals were detected in different samples, except Hg. The mean concentrations of heavy metals were in this order: Cu < Zn < Cd < Pb < Fe in water, Cd < Zn < Cu < Pb < Fe in the soil, Cd < Pb < Zn < Cu < Fe in rice plants and Cu < Cd < Pb < Fe < Zn in rice grains. The concentrations of Pb and Cd were alarmingly high in edible part of rice and excessively surpassing allowable values in rice grain. Thus, estimate daily intake, target hazard quotient, total hazard index and cancer risk values for Cd and Pb were greater than 1 for children and adults. These results showed that adults and children are at high risk of cancer and non-carcinogenic health risks through ingestion of rice grown in Maga-Pouss rice fields. Our finding shows the necessity to adopt mitigation measures to protect food from rice-growing area in Northern Cameroon.

Keywords

Heavy Metals, Health Risk Assessment, Rice Field, SEMRY II, Bioaccumulation, Far North-Cameroon

1. Introduction

The food safety and environmental pollution are interlinked and considered to be important issues in today's world. Food safety is historically impacted by soil and water pollution (Hakimi, 2015; Lu et al., 2015; Shahriar et al., 2023a) and the situation is very challenging in many countries where the pollution and risks of increasing food safety have affected large part of population. The factors like over application of chemicals (pesticides and fertilizers) in the environment and scarcity of water are the most important factors which affect food safety in drastic conditions. Pan et al. (2010) reported that water and soil pollution are very serious threats to human health as they regularly come in contact with food grown in the soil. In fact, when plants absorb water and essential nutrients as manganese (Mn), zinc (Zn), magnesium (Mg) and iron (Fe) during photosynthesis, they can also uptake non-essential chemicals as heavy metals (copper Cu, lead Pb, cadmium Cd, mercury Hg, chrome Cr) and metalloids (arsenic As) which are very poisonous and even cause cancer and major harm to the internal organs of people (Ihedioha et al., 2016; Wen et al., 2022; Huda et al., 2024). Water and soil are polluted by sewage, excessive utilization of pesticides and fertilizers in agriculture, oil spills and industrial wastages (Hakimi, 2015; Yadav et al., 2016; Zhang & Wang, 2020; Ranjbar et al., 2022; Madomguia et al., 2023; Rehman et al., 2023; Bala et al., 2024; Huda et al., 2024).

Heavy metals are toxic in nature and are omnipresent in the environment today where they can alterate atmosphere, soil, water and plants (Ahmed et al., 2015). Their contamination in foodstuff is a matter of concern for human health because chronic exposure to high levels of organometallic or ionic form of heavy metals can have serious human health implications. Humans are exposed daily through ingestion of contaminated water and foods such as fish, fruits and crops grown in polluted environments (Ihedioha et al., 2016; Proshad et al., 2018; Chang et al., 2019; Ngweme et al., 2020; Delanoy et al., 2022; Madomguia et al., 2023; Huang et al., 2023; Madomguia et al., 2024; Shaibur et al., 2024; Guadie et al., 2022). Their long-term ingestion from diverse origins can seriously cause depletion of some essential nutrients in the human body, which in turn induces a decrease in immunological defenses, psychosocial dysfunctions, intra-uterine growth retardation (caused by Cd, Mn, and Pb), disabilities associated with malnutrition and upper gastrointestinal cancer (Iyengar & Nair, 2000; Türkdoğan et al., 2003; Hakimi, 2015; Proshad et al., 2018). For example, long-term exposure to cadmium through soil ingestion can lead to prostatic proliferative lesions, hypertension, bone fractures, pulmonary adenocarcinomas, kidney dysfunction and lung cancer (James et al., 2020). Arsenic, cadmium, mercury and lead are carcinogenic (Ihedioha et al., 2016; Yadav et al., 2016; Proshad et al., 2018; Ezeofor et al., 2019; Wen et al., 2022) and cause a variety of adverse effects in human being (IARC, 2006). Copper, Zinc and iron are necessary up to a certain defined allowable concentrations below which they cause malnutrition and above which they become toxic (Delanoy et al., 2022). For example, high concentrations of Cu and Zn in rice, vegetables and other foods are related to high prevalence of upper gastrointestinal cancer (Islam et al., 2015). It has been shown that dermal, oral and nasal route are the possible routes of heavy metals exposure to human (Zakaria et al., 2021) but oral route is the main path of the majority of non-occupational exposure of the general populations to heavy metals (Mao et al., 2019).

Transfer from agricultural soil to plant is the major pathway of human exposure to heavy metals, as soil is an important resource in food production (Yadav et al., 2016). However heavy metals are natural compounds in the environment, the accelerated pace of urbanization, mining, industrialization and infrastructural development has considerably contributed to the anthropogenic release of massive amounts of heavy metals into soil, water and plants (Ahmed et al., 2015). Heavy metal pollution of agricultural fields and crops is one of the most severe ecological problems in the world (Ahmad & Goni, 2010; Mahmud et al., 2021; Aboubakar et al., 2021). One of the major concerns regarding heavy metal pollution is the potential for bioaccumulation in crops (Aziz et al., 2023) and their toxicity for plants, human and animals because of their low biodegradability (Zhuang et al., 2009 voir Proshad et al., 2018). Non-biodegradable, bio-accumulative and persistent nature of heavy metals make them extremely poisonous even at trace concentrations because of their solubility in water and lack of proper mechanism in the body for their elimination (Alloway, 2009). Weldegebriel et al. (2012) stated that excess amounts of heavy metals from anthropogenic activities that enter into the ecosystem may lead to geo-accumulation and bioaccumulation that pollute the environment and also affect the food chain and pose serious human health risks. Heavy metal concentrations in different foods depend on soil and water composition, nutrient balance, metal permissibility, metal selectivity and absorption ability (Ahmad & Goni, 2010). The harmful effects of heavy metals on humans depend on their dosage, rate of emission and period of exposure (Shahriar et al. 2023b). Heavy metals intake in food diet may cause carcinogenic and non-carcinogenic risks (Yadav et al., 2016; Zakaria et al., 2021; Didier et al., 2023; Shaibur et al., 2024). Therefore, regarding food safety issues, maximum permitted levels of toxic heavy metals in foodstuffs are strictly defined by many regulatory agencies like the United States Environmental Protection Agency (US EPA), the World Health Organization (WHO), American Society for Testing and Materials (ASTM), China Environmental Quality Standard for Soil (GB 15618-1995), Canadian Council of Ministers of Environment (CCME) and the Food and Agriculture Organization (FAO). Because of their ability to cause long-term irreversible damages to human being and animal health, many heavy metal elements as Hg, As, Cu, Zn, Pb, Cr, Cd, and Ni have been registered as priory control pollutants by the State Environmental Protection Administration of China and the United States Environmental Protection Agency (USEPA, 1998; 2010; 2011).

Rice is a staple food in many countries and it is the one of the best ways for human heavy metals contamination. Rice is especially prone to heavy metal contamination due to being cultivated in inundated conditions with extensive root systems (Proshad et al., 2018). It has been identified as one of the major sources of cadmium (Cd) and lead (Pb) in rice consuming countries as China, Bangladesh, Iran. In Cameroon where rice plays a critical role in fighting food insecurity, no study in our knowledge has been taken on human health risks due to the production and consumption of rice growth in national territory whereas rice cultivated nations are mobilizing for food safety associated with heavy metal contamination. Madomguia et al. (2023) evaluated the accumulation of heavy metals (Zn, Pb, Cu, Cd) and the health safety of three highly consumed fish (*Alestes baremoze*, *Clarias gariepinus* and *Tilapia niloticus*) caught in rice-farms' channels of Pouss in the Far-North Region. They found that the concentration of Pb in *Clarias gariepinus* was 60 times more than the concentration allowed by the World Health Organization and their danger ratio was greater than 1 for children, synonym of Pb toxicity. Madomguia et al. (2024) studied the accumulation of heavy metals Hg, Cd, Pd, Zn, Cu and Fe in Maga-Pouss rice fields and their transfer to rice grains. They reported that pH and electrical conductivity favored the uptake of lead, copper and cadmium by rice grains and water is more harmful than soil. Nde et al. (2025) evaluated the human health risks associated with potential toxic elements (Cd, Cr, Hg, Cu, As, Zn, and Ni) contamination in agricultural soil and rice grains from different cultivated paddy soils of four localities of Mayo-Danay (Far North, Cameroon). They found that carcinogenic risk factor of chrome is higher than threshold value for children.

The present study aimed to assess the potential human health risks linked to the bioaccumulation of heavy metals in rice fields, plants and rice grains from Maga-Pouss basin located in Mayo Danay Division, Far North Region of Cameroon.

2. Materials and Methods

Study area

The present study was carried out in Maga-Pouss rice's basin also called SEMRY II (Society for the Expansion and Modernization of Rice Cultivation in Yagoua, Sector II). This rice basin is located in Mayo-Danay Division belonging to the Far-North Region of Cameroon (**Figure 1**). The area of SEMRY II rice field is 6200 ha and the soil is a mix of clay and alluvial deposit. With the semiarid climate, temperature and rainfall varied respectively from 13 to 45˚C and from 400 to 796 mm (L'hôte, 1999; Eone et al., 2019). The region is characterized by a belonging to the Far-North Region of Cameroon (**Figure 1**). The area of SEMRY II rice field is 6200 ha and the soil is a mix of clay and alluvial deposit. With the semiarid climate, temperature and rainfall varied respectively from 13 to 45˚C and from 400 to 796 mm (L'hôte, 1999; Eone et al., 2019). The region is characterized by a long dry season (October - May) and short rainy season (June - September) (L'hôte, 1999). Rice cultivation is favoured in Maga-Pouss areas thanks to the huge dam named Maga Dam constructed since 1972. Then, rice and fish are the staple foods in the localities situated in this basin.

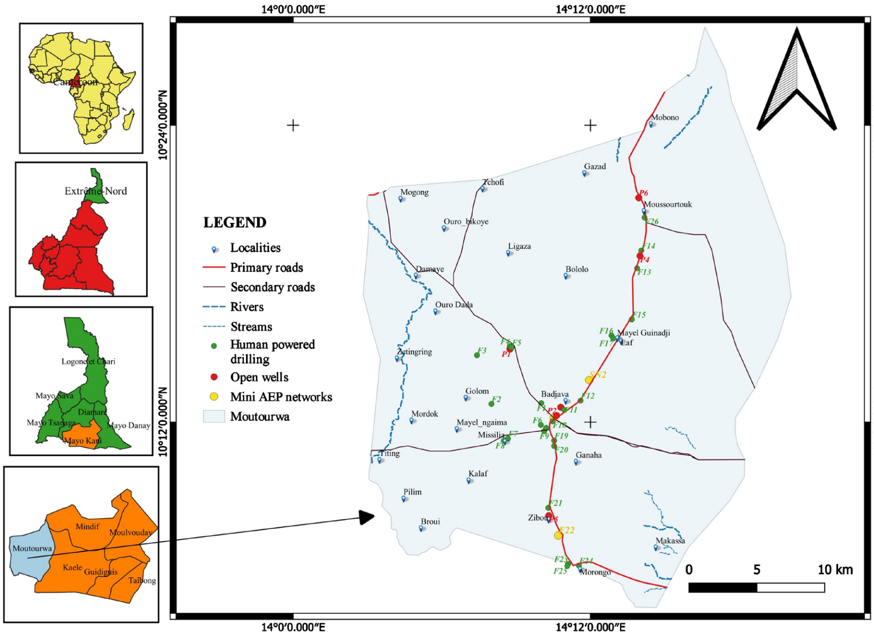

Figure 1. Location of the study site.

For this study, 8 sites were selected in 4 localities: Maga, Ziam, Bakasaraï and Pouss. Geographical coordinates and soil type of each site are shown in Table 1. IR46 is the variety of rice cultivated in Maga-Pouss basin. It is by far the best of all the rice varieties consumed in Cameroon (MINADER, 2020).

Table 1. Geographical coordinates and soil types of sampling points during study.

Localities	Sampling points	Codes	Latitude	Longitude	Altitude	Soil types
Maga	Maga 1	MG1	10˚52'15"N	14˚55'35"E	311 m	Flooding clay soil
	Maga 2	MG2	10˚51'17"N	15˚56'42"E	311 m	Flooding clay soil
Ziam	Ziam 1	ZM1	10˚54'25"N	14˚56'50"E	311 m	Alluvial deposits
	Ziam 2	ZM2	10˚53'49"N	14˚57'46"E	311 m	Alluvial deposits
Bakasaraï	Bakasaraï	BK1	10˚50'35"N	14˚59'36"E	312 m	Alluvial deposits
	Bakasaraï	BK2	10˚49'58"N	15˚00'09"N	312 m	Alluvial deposits
Pouss	Pouss 1	PS1	10˚48'43"N	15˚01'56"E	313 m	Flooding clay soil
	Pouss 2	PS2	10˚52'36"N	15˚1'11"E	313 m	Flooding clay soil

Gathering of irrigation water, soils, rice Plant and Grain

In each site, irrigation water, soil, rice plants and grains were gathered in February 2023 corresponding to the end of the culture season. Irrigation water was collected in rice rack using 500 mL polyethylene bottle, stored in a cooler and frozen during three days. Soils, rice plants and grains samples were collected at the same sites in each village. Soil samples were taken from the 0 - 20 cm surface layer with the hoe. Rice grains were collected by hand with a handle of plants. At least six subsamples of plants, grain and soil were collected per site and finally, each type of samples was placed separately in sealed plastic bags. Paddy soils, rice grains and plants were air-dried during three days and transported in dark with frozen irrigation water to the National Laboratory of Analysis of Agricultural Inputs and Products (LNAD) located in capital city of Yaoundé for further analysis.

Sample Preparation and analysis

In the laboratory, 1 CC of nitric acid HNO_3 1N was added in 10 CC of defrosted irrigation water for digestion. When digestion was complete, the solution was filtered through 110 mm WHATMANN type 598/1 filter. Shelled rice grains were naked, dried in ECOCELL dried-oven at 105˚C during one day (24 hours), powdered and stored in dark until next step. For each sample, 1 g of rice powder was pre-calcinated with SELECT-HORN muffle furnace at 105˚C and gradually calcinated from 200˚C to 450˚C during at least 2 hours until complete mineralization of the sample marked by the formation of the gray ash. Afterwards, ash was cooled at room temperature and digestion was performed on hot plate during 30 min with 10 CC of HNO_3 1N. Digested solution was filtered through 110 mm WHATMANN type 598/1 filter paper. The filtrate was collected in a 50 mL volumetric flask, diluted with deionized water until the mark and stored at room temperature until analysis.

Plants and soils samples were dried, pre-calcinated and calcinated in the same conditions as the rice grains. Dried soils were ground and sieved through 2 mm mesh sieve. Digestion, dilution and storage of plant samples were made also in the same conditions as rice grains. Digestion of soils was performed during 30 min on the agitator with 100 CC of HNO_3 0.05N on 20 g of each soil sample. The mixture was filtrated through a membrane paper (110 mm WHATMANN type 598/1) and the filtrate solution was stored in dark for further analysis.

Measurements of the Pb, Cd, Zn, Hg, Cu and Fe concentrations were realized using an atomic absorption spectrophotometer (Agilent Technologies, 55 AA series). Results were expressed in mg/kg of heavy metals. pH and electrical conductivity (μS/cm) of soil and irrigation water samples were also determined, directly in 100 CC of defrosted water and in a mixture of 10 g of soil and 100 CC of distilled water agitated during 1 hour. Equipment were VOLTCRAFT PH-100 ATC pH-meter and VOLTCRAFT PH-100 ATC conductimeter respectively.

Uptake and translocation of heavy metals in rice plants and grains

Knowing that soil-to-plant transfer factor is an important component of human exposure to metals through the food chain (Rai et al., 2019), heavy metal uptake and translocation in grains were calculated using the bioconcentration factor (BCF) and the bioaccumulation factor (BAF) respectively. BCF is defined as the ratio of metal concentration in plant tissues to that in the field (water and soil) and BAF as the ratio of metal concentration in edible part to that in the field. BCF was calculated with these relations:

$$\mathrm{BCF}_{\mathrm{plant/water}} = \mathrm{C}_{\mathrm{plant}}/\mathrm{C}_{\mathrm{water}} \qquad \mathrm{BCF}_{\mathrm{plant/soi}} = \mathrm{C}_{\mathrm{plant}}/\mathrm{C}_{\mathrm{soi}}$$

When BCF > 1, it suggests that plant can absorb and accumulate heavy metals in their tissues (Yan et al., 2020) i.e. plant can uptake more metals than what is available in the soil, indicating that it has the ability to hyperaccumulate heavy metals (Aziz et al., 2023). BCF < 1 stipulates that plants can only absorb metals in proportion to their availability in the field.

BAF which is an important index for understanding the potential of plants to accumulate heavy metals from soil into their edible parts (Aziz et al., 2023). It was calculated using following equations:

$$\mathrm{BAF}_{\mathrm{grain/soil}} = \mathrm{C}_{\mathrm{grain}} / \mathrm{C}_{\mathrm{soil}} \qquad \mathrm{BAF}_{\mathrm{grain/water}} = \mathrm{C}_{\mathrm{grain}} / \mathrm{C}_{\mathrm{water}}$$

Ma (2001) stated that a BAF ≤ 1 indicates that the plant is able to absorb the heavy metal but do not accumulate whereas BAF > 1 denotes that heavy metal is accumulate in plant after absorption. This may pose risks to human health when consumed.

Human health risk assessment

Evaluation of heavy metals exposure through ingestion

Rice consumption was considered to be the major pathway of human exposure to heavy metals (Huang et al., 2013) For estimation of human exposure to heavy metals in general population, estimate daily intake (EDI) or chronic daily intake (CDI) were calculated in rice grain following U.S Environment Protection Agency (USEPA) methodology. It expresses the mass of the metal per unit body weight per unit time, averaged over lifetime (U.S. EPA, 2010). In fact, the rate of consumption of rice per day could influence the tolerance of metal contaminants. The formula was:

$$EDI = \frac{FIR \times C}{BW}$$

FIR refers to Food ingestion rate of rice per person and per day (g/person/day) and BW to average body weight of consumer (in kg). in Cameroon, FIR equals to 68 g/person/day (MINEPAT/PROMIKA, 2024) and BW to 70 kg for adult and 28 kg for child (FAO, 2007a). EDI were expressed in mg/kg/day.

Non-carcinogenic health risk assessment

Non-carcinogenic health risks due to the consumption of rice were also estimated with the target hazard quotient (THQ) and total hazard index (THI). THQs is the ratio of a single substance exposure level over a specified time period (e.g.: sub-chronic) to a reference dose (RfD) for that substance derived from a similar exposure period (US EPA, 1989). They were estimated using the following equation:

$$THQ = \frac{EF \times EDtot \times FIR \times Crice}{BW \times RfD \times AT} \times 0.001$$

With EF corresponding to the exposure frequency (350 days/year), EDtot to the exposure duration (62 years), FIR is food ingestion rate (68 g/person/day); Crice is mean concentration of metal in rice grain (mg/kg), BW is the average body weight of consumer (28kg/70 kg), AT is averaging time for non-carcinogens (365 days/year × number of exposure years). RfD is the oral reference dose of heavy metal (mg/kg/day): Pb = 0.004; Cd = 0.001; Zn = 0.3; Cu = 0.04 and Fe = 0.7 (USEPA, 2000). If THQ ≤ 1, it is assumed that non-carcinogenic risks have no substantial impact. If THQ > 1, the potential non-carcinogenic effects would occur (Al-Saleh et al., 1999; Copat et al., 2013).

Total hazard index (THI) was calculated in order to assess the overall potential for non-carcinogenic effects from more than one heavy metal. Silins and Hogberg (2011) suggested that cumulative trace element and heavy metal exposures will increase the health risks more than individual exposure of trace element and heavy metals. THI is the sum of THQ of all heavy metals present in samples (Pb, Cd, Fe, Zn and Cu).

$$THI = THQ(\mathrm{Pb}) + THQ(\mathrm{Cd}) + THQ(\mathrm{Cu}) + THQ(\mathrm{Fe}) + THQ(\mathrm{Zn})$$

With a THI > 1, non-carcinogenic impacts might occur in the residents, while a THI ≤ 1 indicates no risk to human health (Guerra et al., 2012).

Carcinogenic health risks assessment

Carcinogenic health risks (CR) were assessed in order to evaluate the likelihood of an individual to develop cancer due to exposure to the potential carcinogen over a lifetime. It uses the cancer slope factor (CSF) to convert the EDI of the heavy metals over a lifetime exposure to the risk of an individual developing cancer (Zakaria et al., 2021).

$$CR = EDI \times CSF$$

If multiple carcinogenic elements are present, the cancer risks from all carcinogen are summed (assuming additive effects). Risks in the range of 1.0×10^{-6} to 1.0×10^{-4} are acceptable (Cao et al., 2015). CSF equals to 0.042 mg/kg/day and 6.30 mg/kg/day for Pb and Cd respectively. If CR ≥1, there may be a concern about potential human health risks caused by exposure to non-carcinogenic elements, whereas, if CR <1, there is no concern about potential human health risks caused by exposure to non-carcinogenic elements (European Commission, 2007).

3. Results

Physicochemical characteristics of paddy soils and irrigation water

Collected data on physicochemical parameters of Maga-Pouss rice fields (**Table 2**) displayed that the pH of irrigation water ranged from 6.8 (Bakasaraï) to 7.1 (Ziam) and its electrical conductivity (EC) ranged from 154.2 $\mu S \cdot cm^{-1}$ (Ziam) and 204.2 $\mu S \cdot cm^{-1}$ (Pouss). In paddy soil, pH ranged from 6.75 (Bakasaraï) to 7.60 (Ziam) and EC ranged from 232.1 $\mu S \cdot cm^{-1}$ (Maga) to 400.4 $\mu S \cdot cm^{-1}$ (Bakasaraï).

The pH values between 6.5 and 7.5 and electrical conductivity values (between 232.1 and 400.4 μS·cm^{-1}) indicated the neutrality (Wen et al., 2022) and low mineralization of Maga-Pouss rice fields. The low conductivity suggests the scarcity of dissolved inorganics matters essential for plant growth and, consequently, the necessity to employ fertilizers to increasing crop's production. Knowing that pH impacts the availability of nutrients and heavy metals in the environment (Ahmed et al., 2019; Huda et al., 2024) and irrigation water outside recommended values may cause nutritional concerns due to the presence of undesirable substances (Zhang & Wang, 2020), it is easy to say that the study site is appropriated for agricultural uses. Knowing also that the abuse of fertilizers and pesticides in farmland led to soil acidification (Ihedioha et al., 2019; Xu et al., 2020) and rice cultivation with chemical agricultural inputs is practiced in Maga-Pouss area since 75+ years, we can say that alluvial deposit and the clay soil type of Maga-Pouss rice fields trends to equilibrate temporal variability of pH (Madomguia et al., 2023; 2024).

Table 2. Physicochemical characteristics of paddy soils and irrigation water from Maga-Pouss rice fields.

Parameters	Samples	Maga	Ziam	Bakasaraï	Pouss	Standard limits
pH	Water	6.80	7.10	6.90	7.00	6.5 - 8.4
	Soil	7.30	7.60	6.75	6.90	-
EC (μS·cm^{-1})	Water	168.6	154.2	110.8	204.2	0 - 3000
	Soil	232.1	307.8	400.4	658.6	-

Metal concentrations in water and soil from Maga-Pouss rice fields

Heavy metals concentrations in Maga-Pouss rice basin are shown in **Table 3**. However, mercury (Hg) is classified between the major heavy metals found worldwide (Wen et al., 2022), it was not detected in any sample. Nde et al. (2025) have not also found mercuric in 100 samples collected in four localities of Mayo Danay Dision. Madomguia et al. (2024) linked the lack of mercuric to the absence of Hg-based molecules or the unfavorable environmental conditions for the solubility of mercuric complexes in the soil and water in Maga-Pouss. Wen et al. (2022) have already stated that the soil pH involve the accumulation of Cd, Pb and Hg in alkaline conditions (7.5 < pH < 8.5) and those for Cu and Zn under neutral soil conditions. This assertion is not justify in Maga-Pouss rice basin because Cd and Pb are well-accumulated in neutral conditions while Cu and Zn are less concentrated in soil in the same conditions. But, Wen et al. (2022) also said that the heavy metals accumulation in soils relies on the farmland pattern use: Cd, Hg, Pb and Zn accumulate severely in upland cropping soils, Cd and Pb are major heavy metals in paddy soils and Cu and Zn in the vegetable-growing soils.

In the soil, the concentrations of necessary micronutrients for rice (Soleimani et al., 2023) were within allowable values in all sites, excepted Fe (**Table 4**). Cu concentrations fluctuated between 39.60 mg/kg (Ziam) to 66.65 mg/kg in Pouss

Table 3. Heavy metals contents (in mg/kg) in irrigation and paddy soils of Maga-Pouss rice basin.

Sites	Samples	Cd	Cu	Fe	Hg	Pb	Zn
Maga	Water	2.95	0.10	298.25	Trace	65.25	Trace
	Soil	3.52	48.6	281.05	Trace	79.00	15.11
Ziam	Water	2.70	1.55	Trace	Trace	60.25	0.35
	Soil	4.25	39.3	284.55	Trace	86.5	11.05
Bakasaraï	Water	2.40	Trace	153.85	Trace	72.75	1.84
	Soil	3.15	45.93	72.18	Trace	105.5	22.52
Pouss	Water	2.33	0.75	113.70	Trace	56.25	Trace
	Soil	3.40	66.65	64.20	Trace	89	33.24
Standard limits	Water	0.01	0.2	0.3	0.006	5	2
	Soil	1	100	5**	0.3	60	200

*FAO (1985); **DPR target value for soil (2002), Maximum Allowable concentration, China Environmental Quality for Soil (GB 15618-1995).

Table 4. Concentrations in mg/kg of heavy metals in rice plants and grains.

Sites	Samples	Cd	Cu	Fe	Hg	Pb	Zn
Maga	Rice plants	1.72	Trace	297.62	Trace	19.32	22.39
	Rice grains	2.17	2.30	Trace	Trace	12.57	13.33
Ziam	Rice plants	2.22	Trace	159.11	Trace	10.85	39.01
	Rice grains	4.27	2.70	21.20	Trace	7.54	16.40
Bakasaraï	Rice plants	0.79	Trace	100.19	Trace	1.01	8.67
	Rice grains	2.22	1.51	15.78	Trace	Trace	35.03
Pouss	Rice plants	3.32	27.26	154.44	Trace	47.33	24.23
	Rice grains	1.82	0.54	Trace	Trace	5.00	10.63
Mean	Rice plants	2.01	27.26	177.84	-	19.63	23.58
	Rice grains	2.02	27.20	188.01	-	19.50	23.61
Standard limits	Rice plants	-	-	-	-	-	-
	Rice grains	0.4	10	48	0.004	0.2	60

and Zn concentrations between 11.05 mg/kg in Ziam to 33.24 mg/kg in Pouss. Fe contents varied from 64.20 mg/kg (Pouss) to 284.55 mg/kg (Ziam). The classification of measured elements using their mean values (Table 5) is as follow: Cd < Zn < Cu < Pb < Fe. The finding that zinc is the highest and cadmium is the lowest concentrations of heavy metals in paddy soils (Salpathy et al., 2014) is not verified here. Toxic elements Cd and Pb contents surpassed standard limits with 3.15 mg/kg (Bakasaraï) to 4.25 mg/kg in Ziam for Cd and 79.00 mg/kg in Maga to 105.50 mg/kg in Bakasaraï for Pb. Most studies revealed that high use of chemical fertilizers and pesticides causes pollution of cultivated soil worldwide. For this

Table 5. Mean of heavy metals in different sample types.

	Cd	Cu	Fe	Pb	Zn
Water	2.59	0.80	188.60	63.63	1.10
Soil	3.58	50.12	175.49	90.00	20.48
Plant	2.01	27.26	177.84	19.63	23.58
Grain	2.62	1.76	18.49	8.37	18.85

purpose, Soleimani et al. (2023) stated that continuous application of chemical fertilizers to the soil can upset soil metal balance, leading to increase toxic metals like cadmium, lead and arsenic (not measured in this study). Huda et al. (2024) bound soil pollution to their strong buffer capacity. In fact, the utilization rate of pesticides is generally just 10% and residual pesticides remaining in water, soil, plants and air (Bose et al., 2021). Direct effect of the pollution of farmland by pesticides is financial losses and indirect impact is the transfer of hazards to human via the food chain, thus causing the degradation of human health (Shi et al., 2019; Weng et al., 2024; Huda et al., 2024). Ecologically, improper use of chemical agricultural inputs affects the activities of soil microorganisms, reduces the organic matter of soil, changes the soil structure, thus reducing the porosity of soil moisture, making crops short of bad growth and low yield (Wang et al., 2019; Zhen et al., 2019).

In water, zinc (Zn) and copper (Cu) concentrations in all sites and iron (Fe) at Ziam village were found to be within standards limits (Zn varied from trace in Maga and Pouss to 1.84 mg/kg in Bakasaraï and Cu ranged from trace in Bakasaraï to 1.55 mg/kg in Ziam). The levels of cadmium (Cd), iron (Fe) and lead (Pb) exceeded the permissible thresholds (**Table 3**): Cd varied from 2.33 mg/kg in Pouss to 2.95 mg/kg in Maga, Fe from 113.70 mg/kg (Ziam) to 298.25 mg/kg (Maga) and Pb from 56.25 mg/kg (Pouss) to 72.75 mg/kg (Bakasaraï); Cd was 2.33 - 295 times, Pb 11.25 - 14.55 times and Fe 568.5 - 1491.25 times (in all sites except Ziam) higher than allowable values. The probable and foremost reason of high Fe contents both in the soil and irrigation water could be the dissolution of iron from embankment supporting Maga dam constructed for rice cultivation and the anaerobic conditions due by annual flooding. Colombo et al. (2014) showed that the availability of Fe ion (Fe^{2+}) is enhanced during inundated period because flooding reduces ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}). But, atmospheric deposition and agricultural practices as organic amendments and using of iron-rich fertilizers can also increase the amount of iron in the field (Liu et al., 2025) As from the soil, high levels of heavy metals in irrigation water pose severe risks, including crop contamination and soil toxicity, which can weaken soil fertility and impact food safety through dietary intake (Soleimani et al., 2023; Shahriar et al., 2023b). In fact, metals like Cd reduce the photosynthesis and uptake of nutrient when the plants are exposed (Di Toppi, & Gabbrielli, 1999). The use of lead-contaminated water for irrigation could potentially affect adjacent aquatic ecosystems, harming aquatic life and fauna (Sultana et al., 2023).

Kruskal-Wallis test showed that there was no significant difference between environmental variables levels and heavy metals contents between localities at α = 0.05 (pH: 0.971; electrical conductivity: 0.984; Pb: 0.988; Cd: 0.764; Zn: 0.901; Cu: 0.634; Fe: 0.129). Concerning samples types, there was no significant difference between irrigation water and soil for iron (p = 0.794) but there was significant difference for pH (0.20), electrical conductivity (0.06), Pb (0.07), Cd (0.31), Zn (0.024) and Cu (0.19) at α = 0.05. Madomguia et al. (2024) have already reported that irrigation water in Maga-Pouss rice fields is more harmful than the soil, notably for cadmium, copper and lead.

Heavy metals concentrations in rice plant and grain samples

Data on the concentrations of heavy metals analyzed in rice plants and grains collected in Maga-Pouss rice farms (**Table 4**) showed that, in rice plants, Cu was detected only in Pouss at the level of 27.26 mg/kg while Cd varied between 0.79 mg/kg (Bakasaraï) and 3.32 mg/kg (Pous), Fe between 100.19 mg/kg (Bakasaraï) and 297.62 mg/kg (Maga), Pb between 1.01 mg/kg in Bakasaraï and 47.33 mg/kg in Pouss and Zn between 8.67 mg/kg in Bakasaraï and 39.01 mg/kg in Ziam. In rice grains, Cd oscillated between 1.82 mg/kg in Pouss and 4.27 mg/kg in Ziam, Cu between 0.54 mg/kg in Pouss and 2.70 mg/kg in Ziam, Fe between trace (Maga and Pouss) and 21.20 mg/kg in Ziam, Pb between trace (Bakasaraï) and 19.32 mg/kg (Pouss) and Zn between 10.63 (Pouss) and 35.03 mg/kg (Bakasaraï).

Mercury was not also detected during the present work into plant parts. The detection of heavy metals in plants indicating substantial uptake of metallic elements present in the soil and irrigation water and their translocation within the rice plants and grains cultivated in Maga-Pouss rice farms (Zakaria et al., 2021; Huda et al., 2024). Plant organs have different abilities to adsorb, translocate and accumulate heavy metals, and the speed and magnitude of these processes vary between plant species and cultivars (Yu et al., 2006). Following the mean of all metallic elements in this site (**Table 5**), the concentrations of Pb and Cd were alarmingly high in edible part of rice (their mean were 8.37 mg/kg and 2.62 mg/kg respectively) and excessively surpassing allowable values in rice grain. Cd and Pb were already reported exceeding the maximum permissible limits in China (Wen et al., 2022), in Malysia (Aziz et al., 2023) and Iran (Eslamizad & Alehashem, 2025). High levels of cadmium and may pose serious health risks (carcinogenic and/or non-carcinogenic), particularly in Maga Subdivision where rice is a staple food. Lead has neurotoxic damage in children and affecting renal function and hemoglobin even at low exposures (Beuckels et al., 2015; Khanam et al., 2020). Cadmium causes leg and spinal pain with other complications, including coughing, anemia and kidney failure (this disease is called itai-itai) (Aoshima, 2012). Swaddiwudhipong et al. (2010) have already reported that Cd exposure might cause severe tubular damage and/or glomerular permeability to larger proteins. Knowing that about 70% in hemodialysis unit in Maroua Regional Hospital coming from Mayo-Danay Subdivision (HRM, 2021) which is the most rice cultivated area in Cameroon, our finding could be the trail for understanding the origin of renal dysfunction in general population of this area. The consumption of milk and meat of animals feed with contaminated plants represents indirect way to the health of this population (Huda et al., 2024). In addition, the consumption of fish caught in Maga-Pouss rice channels is another contamination route of toxic elements to inhabitants (Madomguia et al., 2023). Cd also reduced the photosynthesis and uptake of nutrient when the plants are exposed (Di Toppi, & Gabbrielli, 1999). This could be one of reason of inhabitant complaints about rice yield.

The mean concentrations of heavy metals in manifold samples were in this order: Cu < Zn < Cd < Pb < Fe in water, Cd < Zn < Cu < Pb < Fe in the soil, Cd < Pb < Zn < Cu < Fe in rice plants and Cu < Cd < Pb < Fe < Zn in rice grains (**Table 5**). Cadmium, copper and lead were more concentrated in soil, iron in water and zinc in plants. Ahmed et al. (2019) also found Zn, Cu, Cd and Pb in irrigation water, soils and vegetables in Bangladesh but Zn had the highest concentration and Cd the lowest in all samples. Singh et al. (2003) stated that Zn, Pb, Cu and Cd are higher metals in the cropped soils while Zn, Fe, Cu, Pb and Cd are the highest metals uptake by rice plants. Zinc, copper and iron are the micronutrients required in various enzyme activities for photosynthesis and growth of the plants (Jarvis et al., 1976). Then, it is not surprising that these heavy metals were present in all parts of the sampled rice plants.

Absorption of heavy metals and translocation in rice

The evaluation of the transferability of heavy metals from fields to plants showed that BCF of Cu and Zn in irrigation water and the BCF of Fe and Zn in the soil are greater than 1 (**Table 6**). These results mean that rice plants from study site are able to absorb and accumulate Cu and Zn more than they are available in the water and Fe more than available concentration in the soil (Yan et al., 2020; Aziz et al., 2023). High iron uptake in paddy soil is unusual since iron is generally less available at high pH due to its tendency to form insoluble Fe^{3+} compounds. Our finding can be explain by the poor drainage maintaining anaerobic conditions (FAO, 2007b), the flooded conditions which promotes microbial Fe reduction and plant/microbial iron chelation (Colombo et al., 2014) and the influence of clay soil type on the pH. The plants require the Zn element as an important nutrient in order to synthesize proteins, hormone growth, and reproductive processes of plants (Zakaria et al., 2021). Concerning the BAF, it was greater than 1 only between water and rice grains for Cd, Cu and Zn (**Table 6**). These values denote that Zn, Cu and Cd bioavailability was very high in the water than the soil (Madomguia et al., 2024). Our results called to the great importance of water quality in rice-growing activities in the world, notably in Asia where researchers are especially focused on the toxicity and bioaccumulation of rice by heavy metals from soils while nutrients for rice come both from irrigation water and soil. Rice is a hyper accumulator plant with high potential to absorb metals from soil (Xie, & Huang 1998) and irrigation water in paddy field often causes loads of Cd in soil (Zakaria et al., 2021).

Table 6. Bioconcentration and bioaccumulation factors.

		Cd	Cu	Fe	Pb	Zn
BCF	Water-plant	0.78	34.08	0.94	0.31	21.43
	Soil-plant	0.56	0.54	1.01	0.22	1.15
BAF	Water-grain	1.01	2.20	0.10	0.13	17.13
	Soil-grain	0.73	0.04	0.11	0.09	0.92

Human health risk due to dietary intake of metals through rice grain ingestion

Heavy metals intake in food diet may cause carcinogenic and non-carcinogenic health risks (Duruibe et al., 2007). Major non-carcinogenic health problems caused by heavy metals include hepatic, renal, hematological, developmental, neurological, respiratory, gastrointestinal, cardiovascular, reproductive and immunological dysfunction (Zakaria et al., 2021). In the present work, carcinogenic health risk was assessed with cancer risk (CR) and non-carcinogenic risk with estimate daily intake (EDI), the hazard quotient (THQ) and total hazard index (THI).

Estimate daily intake of heavy metals via consumption of rice from Maga-Pouss basin

Chronic daily intake (CDI) or estimate daily intake (EDI) of Fe, Cu and Zn were below permissible limits for child and adult (**Table 7**). Yadav et al. (2016) in their study in Northern India, Mao et al. (2019) in Yangtze River Delta in China and Nde et al. (2025) the Mayo Danay Division in Cameroon reported EDI mean values lower than 1 for Zn, Cu and Fe, both for children and adults. CDIs values of Cd and Pb in this study were higher than threshold values both for children and adults (**Table 7**). EDI of Cd was estimated at 6.4 mg/kg/day to children and at 2.5 mg/kg/day to adults. For Pb, CDI value was evaluated at 20.3 mg/kg/day and 8.1 mg/kg/day to children and adults respectively. The perennial intake of contaminated rice crops is likely to induce adverse health effects from heavy metal exposures (Zakaria et al., 2021). EDIs values of Cd and Pb were higher than 2.52×10^{-4} mg/kg/day of Cd and 2.94×10^{-3} mg/kg/day found by Yadav et al. (2016). They were also greater than 0.339/0.387 µg/kg/day for Cd and 0.522/0.596 µg/kg/day for Pb to children/adults found by Mao et al. (2019). Our CDI values of Cd were very greater than those of Nde et al. (2025) obtained in another localities belonging to Mayo-Danay Division of Cameroon. Knowing that Nde et al. (2025) worked in SEMRY I and our study was made in SEMRY II, our finding raises questions about the harmonization of agricultural practices within all rice-growing basins of the SEMRY.

Non-carcinogenic risk assessment

The THQ values of individual metal to target population via consumption of rice grains were less than unity for Cu, Fe and Zn and greater than 1 for Cd and Pb (**Table 7**). These results indicate that the daily intake through rice ingestion is likely to cause non carcinogenic effects to inhabitants of Maga-Pouss only for cadmium and lead. Although adults consume more rice than children, the target hazard quotient (THQ) values of heavy metals for children were slightly higher than those for adults. THQ for Pb and Cd was found > 1 in China (Zeng et al., 2015; Fan et al., 2017) and in Nigeria (Ihedioha et al., 2019). The total hazard index (THI) value which measures the potential risk of adverse health effects from a combination of chemical elements in rice is also greater than unity, both for adults and children (**Table 7**). It reaches 11.28 and 4.51 for children and adults respectively. Children and adults consuming rice from Maga-Pouss will undergo high non-carcinogenic effects in study sites due to the biomagnification over a long period of time. Our results are similar to those of Zeng et al. (2015) found in China with seven elements (Cd, Cr, As, Ni, Pb, Mn, and Hg) from brown rice. THI and THQ were greater than those published by Nde et al. (2025) in four localities of Mayo-Danay Division (Vele, Djogoidi, Droumka and Zoulla). They reported that the THI value for children ranged from 1.01E−06 and 4.49E+02, while the THI value for adults ranged from 1.01E−06 and 9.60E−07 while in the studied area. By consuming rice grown at the Maga-Pouss rice basin, adults and children are at high risk of cancer and non-carcinogenic health risks. The values of THI and THQ support the fact that heavy metals, notably lead and cadmium, are responsible of the high prevalence of kidney dysfunction observed in general population of Mayo Danay Division.

Table 7. Estimate daily intake (EDI), cancer risk (CR), hazard quotient (THQ), total hazard index (THI) of the measured metals via ingestion of rice grains.

	EDI		THQ		CR	
	Infant	**Adult**	**Child**	**Adult**	**Infant**	**Adult**
Cd	6.4	2.5	6.10	2.44	40,09	16,03
Cu	4.3	1.7	0.10	0.04		
Fe	44.9	18.0	0.06	0.02		
Pb	20.3	8.1	4.87	1.95	0,85	0,34
Zn	45.8	18.3	0.15	0.06		
	THI		**11.28**	**4.51**	**40.94**	**16.37**

Carcinogenic risk assessment

The carcinogenic risk assessment (CR) and its implication for human health risk of the heavy metals (Cd, Fe, Cu, Zn, Pb) through ingestion pathway were performed for both adults and children in the study site only for lead and cadmium due to the lack of information on the cancer slope factor of iron, zinc and copper. With respectively 40.09 and 16.03 mg/kg/day (**Table 7**), the incremental probability of children and adults to develop a cancer cause by cadmium over a lifetime living in Maga-Pouss his very high. Nde et al. (2025) also observed that CR is much higher in children than adults in four localities of Mayo-Danay Division however its values were deep lower than that found in this study. The sum of cancer risk of all carcinogen identified in Maga-Pouss rice fields (**Table 7**) was much widely higher than acceptable values (1.0×10^{-6} to 1.0×10^{-4}) proposed by Cao et al. (2015). The International Agency for Research on Cancer (IARC, 2011) has categorized Cd as carcinogenic to humans whereas Pb, Cu, Fe and Zn are non-carcinogenic to human.

4. Conclusion

The present study investigated the human health risk due to the concentrations of heavy metals such as Cd, Hg, Cu, Fe, Zn and Pb in irrigation water, soils, rice plants and grains in Maga-Pouss basin which is one of the major rice producer areas in Cameroon Country. The results are critically serious necessitating a prompt response to preserve the health of populations. Agricultural inputs have led to serious environmental pollution, with critical concentrations of lead, cadmium and iron. Irrigation water is the major source of heavy metals for rice plants and grains. Accumulation of toxic elements (Cd and Pb) in rice grain is significantly important, as it will be processed for human consumption. The carcinogenic risk (CR) for Cd was 40.09 mg/kg/day and 16.03 mg/kg/day for children and adults respectively. These values showed the high probability to develop a cancer by inhabitants of Maga-Pouss rice field areas whose consuming rice as staple food. The non-carcinogen risk factor assessment indicated a higher THQ and THI values of Cd and Pb for children and adults, showing a very potential health threat. Our finding could be the trail for understanding the origin of renal dysfunction in general population of Mayo-Danay Division which represents about 70% in hemodialysis unit in Maroua Regional Hospital. The values of THI and THQ support the fact that heavy metals, notably lead and cadmium, are responsible of the high prevalence of kidney dysfunction observed in general population of Mayo Danay Division. All human health risk assessment factors reveled that children are most affected by heavy metals through rice ingestion in Maga-Pouss rice-growing basin.

5. Declarations

Ethical Approval: We declare that this research is an original of our research. We hereby declare that this research represents our own work and has not been submitted for any journal.

Consent to Participate: The authors declare their participation in the paper and maintain a record of their consent.

Consent to Publish: The authors give the Publisher the permission to publish the Work

Availability of Data and material: The data will be available upon request.

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Author Contributions

Diane Madomguia: Writing—review & editing, Writing—original draft, Investigation, Conceptualization. Bello Basokdou G.: Writing—review & editing, Writing—original draft, Methodology, Investigation, Conceptualization. Kalieu W.I.A.: Writing—review & editing, Writing—original draft, Investigation, Conceptualization. Kuitekam Dongo P.: Supervising, Methodology, Conceptualization. Nya E.: Supervising, Methodology, Conceptualization. Zébazé Togouet S.H: Supervising, Methodology, Conceptualization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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