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Accumulation of Heavy Metals in Maga-Pouss Rice Fields (Far-North Region, Cameroon) and Transfer to Rice Grains

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Abstract

Monitoring of heavy metals contamination of agricultural products and their transfer and bioaccumulation in crops like rice has become a hot topic worldwide over the last two decades. The present study was carried out to determine the accumulation of heavy metals in rice fields and their transfer to rice grains. Soil, irrigation water and rice grains samples were gathered in Maga-Pouss, Far-North, Cameroon. Concentrations of six heavy metals (lead, cadmium, zinc, copper, iron and mercury) were evaluated by Atomic Absorption Spectrophotometer (AAS). Mercury was not detected in this study. Average concentrations of metals were in this order (in mg/kg): Fe (188.60 ± 97.06) > Pb (63.63 ± 7.11) > Cd (2.59 ± 0.29) > Zn (1.10 ± 1.05) > Cu (0.80 ± 0.73) in water and Pb (105.50 ± 31.11) > Fe (105.50 ± 31.11) > Cu (45.93 ± 14.39) > Zn (22.52 ± 6.40) > Cd (3.15 ± 0.49) in soil. Water in Maga-Pouss rice fields appears to be more harmful than the soil, notably for lead, cadmium and copper. In rice grains, heavy metals were found in this order (mg/kg): Fe (188.01 ± 82.62) > Cu (27.20 ± 0.00) > Zn (23.61 ± 12.42) > Pb (19.50 ± 19.91) > Cd (2.02 ± 1.05). The mean bioconcentration factor (BCF) of metals from soil to rice grains was in the following order: Fe (2.60) > Zn (1.05) > Cd (0.64) > Cu (0.59) > Pb (0.18). From water to rice grains, the order is: Cu (37.26) > Zn (22.49) > Cd (6.97) > Pb (2.74) > Fe (1.94). Rice field pH and electrical conductivity favored the uptake of lead, copper and cadmium by rice grains. The findings of this study will be good documentation for risk assessment, and decision-making by environmental managers in this region.

Keywords

Heavy Metals, Rice Field, Bioconcenration Factor, Maga-Pouss, Accumulation

1. Introduction

Rice is the most important foods on the planet [1] and it ranks second in the worldwide production of cereals after wheat [2] [3]. Rice and its products are the source of 60% to 70% of calories for more than 2 billion people in Asia [4]. In Africa, it is the most rapidly growing source of food and is significant importance for food security and food self-sufficiency in an increasing number of low-income food deficit countries [5]. Unfortunately, rice is nowadays implicated as the main source of heavy metal exposure for inhabitants worldwide since its consumption has been closely associated with some health concerns, especially human renal dysfunction in China and Japan [6]. [7] defined heavy metals as metallic elements with a relatively high density compared to water or the metals whose density is five times greater than the density of water [8]. Potential toxic metals occur naturally in the earth crust and they tend to concentrate more in agricultural soil due to regular and indiscriminate applications of commercial agricultural inputs (fertilizers and pesticides), biosolids, sewage sludge, smelting, refining and burning of fossil fuel which contains these toxic elements in large proportions [9]. Soil and water are thus the most important reservoirs of heavy metals in the Earth; their concentrations are used as an indicator of pollution status of the environment and of the quality of crops [10].

The concentrations of heavy metals in rice are closely related to their levels in water and soils [11] [12] [13] [14]. In fact, heavy metals usually find their way to agricultural soils through diverse irrigation practices [15] and the bio-available portion of elements in soil gets transferred to food and fodder crops, so introducing risk to human and animal health. Rice plants may accumulate undesirable and toxic metals such as nickel (Ni), chromium (Cr), mercury (Hg), arsenic (As), lead (Pb) and cadmium (Cd) when they acquire the necessary nutrients like azote (N), phosphorus (P), potassium (K), molybdenum (Mo), manganese (Mn), selenium (Se), iron (Fe), zinc (Zn) and copper (Cu) from the polluted soil [16]-[31]. [32] stated that crops irrigated with heavy metal-contaminated water can lead to serious health hazards to humans and animals. In fact, heavy metals can accumulate in human tissues and cause diverse damage on health through direct ingestion of contaminated food or drinking of contaminated water, through contact with contaminated soil or via the food chain (soil/water-plant-human or soil/water-plant-animal-human) [33]. Toxic metals such as Cd, Cu, Zn, Pb, Cr and Ni are transferred from the rice fields and stored in cereal grains [3] [15] [23] [31] [34]. Among these metals, Cr and Cd are the most accumulated in rice [23].

In Cameroon, rice plays a critical role in fighting food insecurity both in rural and urban areas. The national average per capita rice consumption was estimated at 25.7 kg per inhabitant (37.3 kg in urban areas and 19.4 kg in rural areas [35]). Although Cameroon is an import-dependent country (it imports more than 80% of its nationally consumed rice; [36]), rice is cultivated in five main areas in the Northern, Central and Western regions with a production capacity of 313,084 tons of paddy rice and 208,827 tons of milled rice on 268,408 ha [37]. The Far-North Region represents 2/3 of national rice production [35]. Most of the production is exported in its raw form to African Central Republic, Nigeria and Chad [37]. Knowing that heavy metal contamination was reported in rice grain after their transfer from rice field in the world due to weather and cultivation conditions [38], it is important to evaluate the quality of rice produced in Cameroon in terms of its heavy metal contents. The present work aimed to study the accumulation of 6 heavy Metals (Pb, Cu, Cd, Zn, Fe, Hg) in rice fields of Maga-Pouss (Far North Region, Cameroon) and their transfer to rice grains.

2. Material and Methods

2.1. Study Area

Rice grain and soil were sampled from four localities (Bakasaray, Maga, Pouss and Ziam) belonging to Maga-Pouss rice's field basin (Mayo-Danay Division, Far-North Region) also called SEMRY II (**Figure 1**). SEMRY (from the French Société d'Expansion et de Modernisation de la Riziculture de Yagoua) is the main rice field of Cameroon with 6200 ha of cultivated area. In fact, in Cameroon, the rice-growing sector currently covers 18,420 ha of irrigated perimeters with 13,820 ha developed in the Far-North Region with SEMRY [39]. Maga-Pouss basin belongs to the Sudano-Sahelian ecological zone of Cameroon where annual rainfall ranges from 400 to 796 mm and the atmospheric temperature lies between 13˚C - 45˚C with the annual average equals to 29˚C [40] [41]. It is characterized by a long dry season from October to May) and very short rainy season from June to September [42]. Geographical coordinates of 8 sampled points (2 per locality) and their soil types were shown in **Table 1**. The only rice variety grown in these areas is called IR46.

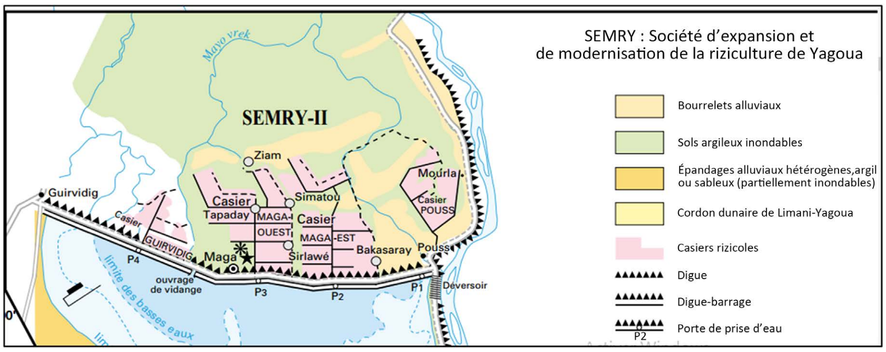

Figure 1. Maga-Pouss rice field basin showing sampled locality.

Table 1. Geographical coordinates of sampling points during study.

Localities	Sampling points	Geographical coordinates	Soil types
Maga	Maga 1	10˚52'15"N; 14˚55'35"E; 311 m	Flooding clay soil
	Maga 2	10˚56'33"N; 14˚59'42"E; 311 m	Flooding clay soil
Ziam	Ziam 1	10˚54'25"N; 14˚56'50"E; 311 m	Alluvial deposits
	Ziam 2	10˚53'49"N; 14˚57'46"E; 311 m	Alluvial deposits
Bakasaray	Bakasaray	10˚50'35"N; 14˚59'36"E; 312 m	Alluvial deposits
	Bakasaray	10˚49'58"N; 15˚00'09"N; 312 m	Alluvial deposits
Pouss	Pouss 1	10˚48'43"N; 15˚01'56"E; 313 m	Flooding clay soil
	Pouss 2	10˚53'06"N; 14˚59'08"E; 313 m	Flooding clay soil

2.2. Sample Collection

Eight samples of rice grains were collected in June 2022 from selected points. In each point, rice grains were collected by hand from several locations in the rice fields. Soil samples were also taken from the surface layer (0 - 20 cm) at the same point using the hoe. At least six replicates of rice grain and soil were collected per sample and final samples were placed separately in sealed plastic bags. Samples of water were also collected in rice rack in all the points with 500 mL polyethylene bottle and cooled during 3 days. Rice grains, soil and water samples were transported in dark to the National Laboratory of Analysis of Agricultural Inputs and Products, Ministry of Agriculture and Rural Development, located in Yaoundé.

2.3. Samples Preparation and Heavy Metal Analysis

In the laboratory, rice grains were shelled and naked grains were dried at 105˚C/24 hours (ECOCELL oven). Dried rice grains were powdered and stored in dark until the control of the metallic quality. Accurately 1 g of each rice powder was placed into a porcelain crucible and pre-calcined at 105˚C with SELECT-HORN muffle furnace. This was followed by gradually calcination from 200˚C to 450˚C for at least 2 hours until complete mineralization of the sample marked by the formation of the gray ash. The ash was removed from the muffle furnace and cooled at room temperature far away from dust and draughts. Afterwards, for dilution, 10 mL of nitric acid (HNO_3 1N) were added on the ash placed into beaker. After homogenization with a glass rod, the beaker was covered with a watch glass and the solution was digested on a hot plate during 30 min. At the end, the digested solution was filtered through 110 mm WHATMANN type 598/1 filter paper and the obtained filtrate was collected in a 50 mL volumetric flask. This last solution was diluted with deionized water until the mark and stored at room temperature until analysis. For soil samples in the laboratory, all debris were manually removed and they were dried in the same conditions as the rice grains. Then, the dried soils were ground and sieved through 2 mm meshes sieve. Nitric acid (100 mL of HNO_3 0.05N) was added in 250 mL flask containing 20 g of each soil sample and agitated during 30 min. The mixture was filtrated through a membrane paper (110 mm WHATMANN type 598/1) and the filtrate solution was stored for further analysis. For water samples, 1 mL of HNO_3 1N was added in 10 mL of defrosted water and the solution was filtered in the same conditions.

The concentrations of these followed heavy metals were detected in water, soil and rice grains using an atomic absorption spectrophotometer (Agilent Technologies, 55 AA series). The concentrations of lead (Pb), mercury (Hg), copper (Cu), zinc (Zn), cadmium (Cd) and iron (Fe) were measured. All the results were expressed in mg/kg of each metal.

2.4. Determination of Environmental Characteristics of the Soil and Water

Electrical conductivity and pH of soil and water were also assessed. They were measured directly in 100 mL of defrosted water respectively with VOLTCRAFT PH-100 ATC pH-meter and VOLTCRAFT PH-100 ATC conductimeter. For the soil, 100 mL of distilled water were added in 10 g of sieve sample of soil and the mixture was agitated during 1 hour. After 16 hours, pH and electrical conductivity were measured with the same equipment.

2.5. Data Analysis

Bioconcentration Factor (BCF) of heavy metals from soil and water to rice grain was calculated in order to assess the bioavailability of heavy metals from the environment to rice grains [43]. Metals with high BCF are more available for crops [19]. The following formula was used:

$$\text{BCF}(\text{soil}-\text{rice}) = \frac{\text{Concentration of heavy metal in rice grain}}{\text{Concentration of heavy metal in soil}}$$

$$\text{BCF}(\text{water}-\text{rice}) = \frac{\text{Concentration of heavy metal in rice grain}}{\text{Concentration of heavy metal in water}}$$

Microsoft Excel 2019 and SPSS software (SPSS Inc. Version 25, 2007) were used 1) to compare the concentrations of heavy metals between water and rice grains and between soil and rice grains; 2) to find correlations (Pearson's correlation) between the concentrations of heavy metals in the soil or water and rice grains.

3. Results and Discussion

3.1. pH and Electrical Conductivity of Maga-Pouss Rice Fields

Field physicochemical parameters, including pH and electrical conductivity, are presented in **Table 2**. Physicochemical properties are important parameters to evaluate the quality of environment used to growing crops. The pH values of irrigation water from Maga-Pouss rice farms varied from 6.8 to 7.1, with an average

Table 2. pH and electrical conductivity of Maga-Pouss rice fields.

Samples	Item	pH	EC (µS/cm)
Water	Max	7.1	204.2
	Min	6.8	110.8
	Mean	6.9	159.5
	SD	0.1	38.6
	Permissible limits **[44]**	**6.5 - 8.4**	**0 - 3000**
Soil	Max	7.6	658.5
	Min	6.8	232.1
	Mean	7.1	399.7
	SD	0.4	185.8
	Permissible limits **[44]**	**-**	**-**

value of 6.9 ± 0.1. These values of pH were within allowable irrigation water recommend by [44]. This result is in accordance with 6.30 - 7.24 found by [31] in periurban areas in Kinshasa, Democratic Republic of Congo (DRC) and 6.82 - 7.26 (7.05 ± 0.15) found by [45] in rice farm channels of Pouss, Far-North, Cameroon. Following [46], irrigation water outside recommended values may cause many problems to the development of some crops and cause nutritional concerns due to the presence of undesirable substances. Soil pH varied from 6.8 to 7.6 with an average of 7.1 ± 0.4. This scheme suggests a neutral soil type with the trend to basicity. This result is in contrasts with the works of [23] and [12] who reported respectively an average soil pH ranged from 4.55 to 5.48 in paddy field from eight counties of Jiangxi province, China and an acidic soil type from Abakaliki, Nigeria. The difference may be due to clay-sand type of soil in Maga-Pouss rice fields [47]. [19] also found pH of the paddy fields' soil varied from slightly neutral (6.9) to alkaline (8.9) in Fatehabad district, (Haryana, India). [20] obtained 4.24 to 8.27 (average value = 6.32) in industrial region of China. Increase in soil pH leads to a decrease availability in heavy metals to plants [48] [49] but alkaline soil and areas with less rainfall faced higher pollution levels [50].

Electrical conductivity (EC) of irrigation water of Maga-Pouss rice farms varied from 110.8 to 204.2 µS/cm (159.5 ± 38.6 µS/cm) and it is within permissible limits allowed by [44]. [31] found an electrical conductivity of irrigation water ranging from 18.8 until 1458.0 µS/cm in periurban areas in Kinshasa, Democratic republic of Congo (DRC). In the soil, electrical conductivity ranged from 232.1 to 658.5 µS/cm (399.7 ± 185.8 µS/cm). The low variation of electrical conductivity in Maga-Pouss environment can be linked to the rural nature and savannah type of the study site with low presence of human activities and organic matter releasing soluble elements in water. The entrance of heavy metals through human activities causes pollution of water, soil, and plants [51]. Our result is lower than 77.7 to 1021.5 ms/cm reported by [19] in Fatehabad district, Haryana, India with similar environment characteristics as Maga-Pouss rice fields: semi-arid area with low rainfall and alluvial clay and sandy soil types. The difference can be due to the irrigation practices and types of agricultural applications [19].

3.2. Heavy Metal Concentration in Maga-Pouss Rice Fields

Of the six heavy metals assessed during the present study, only mercury was not found in water and soil samples (**Table 3**). [20] found Hg in the rhizosphere soil of rice in the Yangtze River delta region of China and linked it to industrial activities. [50] classified Hg between the eight major heavy metals found in agricultural soil in China with Cd, Pb, Cu, Nickel (Ni), Arsenic (As), chromium (Cr) and Zn. [51] also reported mercury in water and soil samples at the edge of Kashaf Roud River, Mashhad, Iran. Our study reveals that agricultural inputs used in Maga-Pouss rice fields did not contain Hg-based molecules or environmental conditions were not favorable for the solubility of mercuric complexes in the soil and water. Pb, Cd, Zn, Cu and Fe concentrations ranged respectively 55.50 - 88.00 (63.63 ± 7.11), 1.95 - 3.15 (2.59 ± 0.29), 0.35 - 1.84 (1.10 ± 1.05), 0.10 - 1.55 (0.80 ± 0.73) and 113.7 - 298.25 mg/kg (188.60 ± 97.06 mg/kg) in water. In the soil, they ranged 80.50 - 127.50 (105.50 ± 31.11), 2.80 - 4.80 (3.15 ± 0.49), 6.67 - 34.66 (22.52 ± 6.40), 35.40 - 72.10 (45.93 ± 14.39) and 9.15 - 333.2 mg/kg (72.18 ± 61.84 mg/kg). The mean concentrations of the detected heavy metals gathered in Maga-Pouss rice fields were found to be in the order: Fe > Pb > Cd > Zn > Cu in water; Pb > Fe > Cu > Zn > Cd in soil. This means that iron and lead are the predominant heavy metals in Maga-Pouss rice farms. [45] has reported the absence of Cd and the presence of Cu, Pb and Zn in irrigation water from Pouss locality belonging to Maga-Pouss rice farms. However iron is an essential micronutrient for rice plants and for human well-being [17], its average value was 628.67 times in water and 14.43 times in soil higher than acceptable limits in Maga-Pouss rice fields (**Table 3**). The presence of high concentrations of iron in the soil (iron II notably) can cause nutritional imbalance in rice plants [21]. Higher iron concentration in rice fields may be due to its relative abundance in the Earth crust, the reduction of precipitation or excess water in the soil [12]. The value of iron found in water in this study is greater than 30.510 - 34.388 mg/kg and 0.452 - 0.555 mg/kg reported by [3] respectively in soil and water samples of some paddy fields of Iraq. The mean value of iron in soil in this study is lower than 3567.488 ± 1200.28 mg/kg and 6900.537 ± 734.82 mg/kg reported by [12] in two farms of Abakaliki (Nigeria).

Excepted Cu in the soil and Zn both in water and soil, the mean concentrations of Pb, Cd and Cu detected in this study exceeded the allowable values of these elements recommended by [44]. Those of Pb, Cd and Cu were 12.72, 259 and 4 times more than the FAO values in water and those of Pb and Cd were 1.75 and 3.15 times more than the recommended values in the soil. Zinc was

Table 3. Concentrations of heavy metal (mg/kg) in water and soil from Maga-Pouss rice's fields.

Samples	Item	Pb	Cd	Zn	Cu	Fe	Hg
Water	Max	88.00	3.15	1.84	1.55	298.25	Trace
	Min	55.50	1.95	0.35	0.10	113.70	Trace
	Mean	63.63	2.59	1.10	0.80	188.60	Trace
	SD	7.11	0.29	1.05	0.73	97.06	Trace
	[44]*	**5**	**0.01**	**2**	**0.2**	**0.3**	**0.006**
Soil	Max	127.50	4.80	34.66	72.10	333.2	Trace
	Min	80.50	2.80	6.67	35.40	9.15	Trace
	Mean	105.50	3.15	22.52	45.93	72.18	Trace
	SD	31.11	0.49	6.40	14.39	61.84	Trace
	[44]*	**60**	**1**	**200**	**100**	**5****	**0.3**

*[44] permissible limits; **DPR target value for soil = Department of Petroleum Resources (2002), Maximum Allowable concentration, China Environmental Quality for Soil (GB 15618-1995).

abundant in soil than water. Water in Maga-Pouss rice fields appears to be more harmful than the soil, notably for lead, cadmium and copper. Cu is also an essential micronutrient for rice plants [52], but the excessive concentrations of Cu poses potential hazards for soil and rice [21]. [30] and [31] rather reported high levels of copper, lead, cadmium and zinc in the soil than in water in their different work fields. In fact, [30] found Cu, Cd, Pb and Zn concentrations ranged respectively 28.9 - 85.5, 0.17 - 0.34, 29.7 - 36.2 and 145.2 - 169.2 mg/kg in the soil versus 1.40 - 6.15, 0.070 - 0.082, 0.35 - 2.04 and 8.60 - 15.3 mg/kg in water. [31] found respectively 1.58 - 124.8, 0.01 - 0.30, 2.09 - 133.83 and 6.71 - 345.48 mg/kg in the soil versus 0.43 - 3.80, 0.02 - 0.06, 0.06 - 0.90 and 1.57 - 30.85 mg/kg in water. [3] reported higher level of Cu in soil (3.993 - 6.343 mg/kg) than in water in soil versus (0.050 - 0.665 mg/kg), idem for Cd (1.089 - 1.276 in soil versus 0.005 - 0.007 mg/kg in water) and Pb (31.188 - 32.301 mg/kg in soil versus 0.626 - 1.332 mg/kg in water). This suggests that environment conditions in Maga-Pouss rice fields trend to enhance the solubilization of cadmium, lead and copper in water and the accumulation of zinc in the soil. The presence of heavy metals in water and soil indicates the contamination of Maga-Pouss rice fields due to agricultural inputs. This report shows the potential health risk for the inhabitants of these environments, especially because of the fact that they consume polluted water during field works [45] in addition to rice consumption.

3.3. Heavy Metal in Rice Grains of Maga-Pouss Rice Fields

The concentrations of researched heavy metals in rice grains from Maga-Pouss fields are presented in **Table 4**. As in water and soil, Hg was not detected during the study but it was reported in rice samples from Kuwaiti Market in Kuwait [8],

Table 4. Concentrations of heavy metal (in mg/kg) in rice grains from Maga-Pouss rice fields.

Sample	Item	Pb	Cd	Zn	Cu	Fe	Hg
Rice grain	Max	58.00	4.15	42.69	27.20	300.75	Trace
	Min	1.00	0.30	8.34	Trace	62.25	Trace
	Mean	19.50	2.02	23.61	27.20	188.01	Trace
	SD	19.91	1.05	12.42	0.00	82.62	Trace
	Permissible limits	**0.2**	**0.4**	**60**	**10**	**48**	**0.004**

from Ugbawka fields in Enugu-Nigeria [53] and from China [11] [22] [50]. Mercury was not also detected in imported rice grains sale in Kaduna states, Nigeria [53]. Pb, Cd, Zn, Cu and Fe concentrations in rice grains ranged 1.00 - 58.00 (19.50 ± 19.91), 0.30 - 4.15 (2.02 ± 1.05), 8.34 - 42.69 (23.61 ± 12.42), trace - 27.20 (27.20 ± 0.00) and 62.25 - 300.75 mg/kg (188.01 ± 82.62 mg/kg) respectively. These heavy metals were already reported worldwide in rice grains. Their detection in rice grains from Maga-Pouss rice fields revealed that potential toxic metals from agricultural inputs are mixed with soil and finally transferred to rice, resulting in serious health threats for both humans and animals [8] [11] [12] [13] [19] [24] [26] [50] [54] [55]. Following the average values, heavy metals in rice grains were found in this order: Fe > Cu > Zn > Pb > Cd. This frame means that iron, copper and zinc which are essential micronutrients were fortunately more concentrated than lead and cadmium known as the most harmful elements for plants and human beings [21] [56]. Cd and Pb could severely disturb plants' respiration, photosynthesis, transpiration, and nutrient uptake [56] [57] [58]. [59] and [60] also described Pb and Cd as a great threat to human health through the soil-plants system and plants-human being system. Zn concentration was within permissible limit indicated by [44]. Our result was similar to [53] who reported 11.74 ± 3.87 mg/kg of zinc in rice grain. [55] also reported 6.7 ± 0.2 mg/kg of zinc in Ethiopian red rice but 51.6 ± 0.2 mg/kg in Ethiopian white rice and 140 ± 9 mg/kg in NERICA new rice for Africa. Although Fe and Cu are important for human being, their average values were respectively 2.21 and 3.92 times above the permissible limits in rice grains (**Table 4**). Concerning Pb its average value was 97.5 times above allowable value in rice and that for Cd was 5 times above allowable limits (**Table 4**). It indicates that long term consumption of rice from this field could induce high exposure of lead, cadmium, copper and iron to consumers because excessive intake of these heavy metals in rice could cause serious abnormalities in several functions [61].

Pb, Cd and Fe concentrations in this study were higher than 0.60 ± 0.46, 0.45 ± 0.08 and 14.71 ± 0.87 mg/kg respectively found by [53]. Pb concentrations were also higher than 3.3 ± 0.2, 0.8 ± 0.07 and 3.8 ± 0.3 mg/kg reported by [55] in Ethiopian white rice, Ethiopian red rice and NERICA new rice for Africa respectively. Idem for Cd in Ethiopian white and red rice (0.54 ± 0.02 and 0.45 ±

0.01 mg/kg respectively). Fe in Maga-Pouss rice was lower than 108 ± 8 and 113 ± 10 mg/kg respectively reported in Ethiopian white and red rice [56].

Comparison of the concentrations of all detected heavy metals in Maga-Pouss rice fields showed that Pb was higher in water and soil samples than in rice grain. The difference was significant between soil samples and rice grain (Kruskall-Wallis test: p = 0.02 at $\alpha = 0.05$) and very significant between soil and water samples (p = 0.00, $\alpha = 0.05$). In revanche, Zn was more concentrated in soil samples and rice grain than in water (p = 0.03, $\alpha = 0.05$). Cu was least concentrated in water than in soil samples (p = 0.02, $\alpha = 0.05$) and in soil samples than in rice grain (p = 0.02, $\alpha = 0.05$). Concerning iron, there was not significant difference between soil, water and rice grain (p = 0.013, $\alpha = 0.05$). The variation in the distribution of lead, cadmium, zinc and copper in Maga-Pouss rice fields could be considered as a result of weak adsorption properties from the soil or water to other parts of the plants by these metals [53] [62]. Following the average values registered during this study, the state that Cd is the most accumulated heavy metal in rice [23] is not verified here.

3.4. Bioconcentration Factor of Heavy Metals in Maga-Pouss Rice Fields

Based on the heavy metal concentrations obtained during this study in rice grains, water and soil from Maga-Pouss rice fields, the bioconcentration factor (BCF) between rice and soil and between rice and water were presented in **Table 5**. The mean BCF of metals from soil to rice grains was in the following order: Fe (2.60) > Zn (1.05) > Cd (0.64) > Cu (0.59) > Pb (0.18). From water to rice grains, the order is: Cu (37.26) > Zn (22.49) > Cd (6.97) > Pb (2.74) > Fe (1.94). These results confirmed the fact that water in Maga-Pouss rice fields is more harmful than the soil for lead, cadmium and copper. [19] reported a very lowest BCF of Cu (0.08), Zn (0.11), Pb (0.01), Cd (0.009) and Fe (0.003) in Northern India. [63] also reported a BCF of Cu, Pb, Cd and Zn equals to 0.25, 0.05, 0.44 and 0.58 respectively from soil to rice grains grown around Guqiao coal mine area in China. Then, our results showed the stronger capacity of micronutrients and toxic metals to translocate from fields to rice grains in Maga-Pouss basin. It can be explained by the high temperature of the region which varied from 13˚C - 45˚C

Table 5. Transfer factor of heavy metals between rice and soil and between rice and water from Maga-Pouss rice fields.

	Pb	Cd	Zn	Cu	Fe	Hg
Rice	19.50	2.02	23.61	27.20	188.01	ND
Soil	105.50	3.15	22.52	45.93	72.18	ND
Water	7.11	0.29	1.05	0.73	97.06	ND
BCF (soil-rice)	0.18	0.64	1.05	0.59	2.60	ND
BCF (Water-rice)	2.74	6.97	22.49	37.26	1.94	ND

Table 6. Pearson's correlation among the environmental factors and heavy metals in Maga-Pouss rice fields.

	pH	EC	Pb	Cd	Zn	Cu	Fe
pH	1	0.723**	0.870**	1	−0.461	0.386	−0.160
EC	0.723**	1	0.850**	0.553	0.069	0.699*	−0.267
Pb	0.870**	0.850**	1	0.799**	−0.136	0.687*	−0.073
Cd	0.570	0.553	0.799**	1	0.113	0.710**	0.229
Zn	−0.461	0.069	−0.136	0.113	1	0.449	−0.009
Cu	0.386	0.699*	0.687*	0.710**	0.449	1	−0.032
Fe	−0.160	−0.267	−0.073	0.229	−0.009	−0.032	1

*Correlation is significant at 0.05 level (two-tailed). **Correlation is significant at 0.01 level (two-tailed).

with the annual average of 29˚C [40] [41]. Our study showed that iron is easier transferred from soil to grain while copper, zinc, cadmium and lead are easily transferred from water to grain. [21] reported that Pb has the weakest mobile ability from soil to rice and transfer ability of Cd in soil to rice is stronger than other metals. In our knowledge, this study is the first to focus on the heavy metals transfer from water to rice. It revealed that uptake of heavy metals from field to rice is higher through water than soil. Fields pH and electrical conductivity (EC) showed significantly positive correlations with Pb, Cu and Cd (**Table 6**), indicating that pH and EC favored the uptake of lead, copper and cadmium by rice grains. At the same time, these factors were negatively correlated with Zn and Fe, showing that they restrained the uptake of Zn and Fe by rice grains. [21] reported a negative correlation between soil pH and Cd, Cu and Zn. Positive correlation between Pb, Cd and Cu, Cd and Cu indicated that they have the common source (agrochemicals fertilizers) in the field and/or the conditions of their absorption by roots of the rice plants are similar. [53] reported significant correlation for cadmium, lead and copper in rice grain and the fields. Negative correlation observed in Fe and Pb, Zn and Cu showing that an increase in one metal concentration will result to a decrease in the other.

4. Conclusion

The present study carried out in Maga-Pouss rice fields (Far North Region, Cameroon) aimed to study the accumulation of six heavy Metals (Pb, Cu, Cd, Zn, Fe, Hg) and their transfer to rice grains. Mercury was not found. Lead, copper, cadmium and iron were higher than permissible concentrations. Bioconcentration factor revealed that water was more harmful than soil. Environmental conditions (pH and electrical conductivity) favored easily uptake of lead, cadmium and copper. This study permitted to label rice produced in Maga-Pouss basin as a bioindicator of heavy metals in Cameroon.

Conflicts of Interest

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

References

[1] Reiter, E.V., Vouk, F., Böhm, J. and Razzazi-Fazeli, E. (2010) Aflatoxins in Rice—A Limited Survey of Products Marketed in Austria. *Food Control*, **21**, 988-991. https://doi.org/10.1016/j.foodcont.2009.12.014

[2] Pandey, P. and Dubey, R.S. (2019) Chapter 15. Metal Toxicity in Rice and Strategies for Improving Stress Tolerance. In: Hasanuzzaman, M., *et al.*, Eds., *Advances in Rice Research for Abiotic Stress Tolerance*, Elsevier Inc., Amsterdam, 313-339. https://doi.org/10.1016/B978-0-12-814332-2.00015-0

[3] Chyad, A.A., Saeed, A.M. and Alhendi, A.S. (2022) Determination of Heavy Metals in Irrigation Water, Soil, Paddy, and Produced Rice of Some Paddy Fields of Iraq. *Iraqi Journal of Science*, **63**, 4637-4649. https://doi.org/10.24996/ijs.2022.63.11.2

[4] Belayneh, T., Atnafu, Z., Madhusudhan, A. and Sciences, C. (2015) Determinations of the Level of Essential and Non-Essential Metals in Rice and Soil Samples. *International Journal of Modern*, **2**, 65-72.

[5] Deldar, A.N. and Abedi, M. (2017) Determination of Heavy Metals (Cadmium, Arsenic and Lead) in Iranian, Pakistani and Indian Rice Consumed in Khorasan-Razavi Province, Iran by Inductively Coupled Plasma (ICP). *International Journal of Scientific Study*, **5**, 534-536.

[6] Zheng, F., Wei, W., Li, M., Huang, R., Yang, F. and Duan, Y. (2015) Toxic Metal Contamination in Rice-Producing Soils of Hunan Province, China and Potential Health Risks. *International Journal of Environmental Research and Public Health*, **12**, 15584-15593. https://doi.org/10.3390/ijerph121215005

[7] Tchounwou, P.B., Yedjou, C.G., Patlolla, A.K. and Sutton, D.J. (2012) Heavy Metal Toxicity and the Environment. *Experientia Supplementum*, **101**, 133-164. https://doi.org/10.1007/978-3-7643-8340-4_6

[8] Jallad, K.N. (2015) Heavy Metal Exposure from Ingesting Rice and Its Related Potential Hazardous Health Risks to Humans. *Environmental Science and Pollution Research*, **22**, 15449-15458. https://doi.org/10.1007/s11356-015-4753-7

[9] Abrahams, P.W. (2002) Soils: Their Implication to Human Health. *Science of the Total Environment*, **291**, 1-32. https://doi.org/10.1016/S0048-9697(01)01102-0

[10] Li, X.Y. (2013) Heavy Metal Contamination of Urban Soil in an Old Industrial City (Shenyang) in Northeast China. *Geoderma*, **192**, 50-58. https://doi.org/10.1016/j.geoderma.2012.08.011

[11] Mao, C., Song, Y., Chen, L., Ji, J., Li, J., Yuan, X. and Theiss, F. (2019) Human Health Risks of Heavy Metals in Paddy Rice Based on Transfer Characteristics of Heavy Metals from Soil to Rice. *Catena*, **175**, 339-348. https://doi.org/10.1016/j.catena.2018.12.029

[12] Ihedioha, J.N., Ogili, E.O., Ekere, N.R. and Ezeofor, C.C. (2019) Risk Assessment of Heavy Metal Contamination of Paddy Soil and Rice (*Oryza sativa*) from Abakaliki, Nigeria. *Environmental Monitoring and Assessment*, **191**, 1-16. https://doi.org/10.1007/s10661-019-7491-3

[13] Hasan, M.N., Salman, M.S., Islam, A., Znad, H. and Hasan, M.M. (2021) Sustainable Composite Sensor Material for Optical Cadmium (II) Monitoring and Capturing

from Wastewater. *Microchemical Journal*, **161**, 105800.
https://doi.org/10.1016/j.microc.2020.105800

[14] Shahriar, S.M.S., Munshi, M., Zakir, H.M., Islam, M.J., Mollah, M.M.A. and Salam, S. (2023) Assessment of Heavy Metal Pollution in Irrigation Water of Rajshahi City, Bangladesh. *Environmental & Earth Sciences Research Journal*, **10**, 100-110.
https://doi.org/10.18280/eesrj.100303

[15] Chopra, K., Pathak, C. and Prasad, G. (2009) Scenario of Heavy Metal Contamination in Agricultural Soil and Its Management. *Journal of Applied and Natural Science*, **1**, 99-108. https://doi.org/10.31018/jans.v1i1.46

[16] Emumejaye, K. (2014) Heavy and Trace Elements in Some Brands of Rice Consumed in Delta State, Nigeria. *Journal of Applied Physics*, **6**, 1-5.
https://doi.org/10.9790/4861-06220105

[17] Satpathy, D., Reddy, M.V. and Dhal, S.P. (2014) Risk Assessment of Heavy Metal Contamination in Paddy Soil, Plants and Grains (*Oryza sativa* L.) at the East Coast of India. *Biomedical Research International*, **2014**, Article ID: 545473.
https://doi.org/10.1155/2014/545473

[18] Bilo, F., Lodolo, M., Borgese, L., Bosio, A., Benassi, L., Depero, L.E. and Bontempi, E. (2015) Evaluation of Heavy Metals Contamination from Environment to Food Matrix by TXRF: The Case of Rice and Rice Husk. *Journal of Chemistry*, **2015**, Article ID: 274340. https://doi.org/10.1155/2015/274340

[19] Yadav, P., Singh, B., Garg, V.K., Mor, S. and Pulhani, V. (2017) Bioaccumulation and Health Risks of Heavy Metals Associated with Consumption of Rice Grains from Croplands in Northern India. *Human and Ecological Risk Assessment*: *An International Journal*, **23**, 14-27. https://doi.org/10.1080/10807039.2016.1218750

[20] Chen, H., Yuan, X., Li, T., Hu, S., Ji, J. and Wang, C. (2016) Characteristics of Heavy Metal Transfer and Their Influencing Factors in Different Soil-Crop Systems of the Industrialization Region, China. *Ecotoxicology and Environmental Safety*, **126**, 193-201. https://doi.org/10.1016/j.ecoenv.2015.12.042

[21] Gu, Q., Yang, Z., Yu, T., Yang, Q., Hou, Q. and Zhang, Q. (2018) From Soil to Rice—A Typical Study of Transfer and Bioaccumulation of Heavy Metals in China. *Acta Agriculturae Scandinavica*, *Section B—Soil & Plant Science*, **68**, 631-642.
https://doi.org/10.1080/09064710.2018.1455218

[22] Lu, A., Li, B., Li, J., Chen, W. and Xu, L. (2018) Heavy Metals in Paddy Soil-Rice Systems of Industrial and Township Areas from Subtropical China: Levels, Transfer and Health Risks. *Journal of Geochemical Exploration*, **194**, 210-217.
https://doi.org/10.1016/j.gexplo.2018.08.003

[23] Li, D., Wang, L., Wang, Y., Li, H. and Chen, G. (2019) Soil Properties and Cultivars Determine Heavy Metal Accumulation in Rice Grain and Cultivars Respond Differently to Cd Stress. *Environmental Science and Pollution Research*, **26**, 14638-14648.
https://doi.org/10.1007/s11356-019-04727-9

[24] Chang, C., Yin, R., Zhang, H. and Yao, L. (2019) Bioaccumulation and Health Risk Assessment of Heavy Metals in the Soil-Rice System in a Typical Seleniferous Area in Central China. *Environmental Toxicology and Chemistry*, **38**, 1577-1584.
https://doi.org/10.1002/etc.4443

[25] Mahmud, U., Salam, M.T.B., Khan, A.S. and Rahman, M.M. (2021) Ecological Risk of Heavy Metal in Agricultural Soil and Transfer to Rice Grains. *Discover Materials*, **1**, Article No. 10. https://doi.org/10.1007/s43939-021-00010-2

[26] Hasan, G.M.M., Das, A.K. and Satter, M.A. (2022) Accumulation of Heavy Metals

in Rice (*Oryza sativa* L.) Grains Cultivated in Three Major Industrial Areas of Bangladesh. *Journal of Environmental and Public Health*, **2022**, Article ID: 1836597. https://doi.org/10.1155/2022/1836597

[27] Shahriar, S.M.S., Munshi, M., Hossain, M.S., Zakir, H.M. and Salam, S.M.A. (2023) Risk Assessment of Selected Heavy Metals Contamination in Rice Grains in the Rajshahi City of Bangladesh. *Journal of Engineering*, **14**, 29-41. https://doi.org/10.3329/jes.v14i1.67633

[28] Chary, N.S., Kamala, C.T. and Raj, D.S. (2008) Assessing Risk of Heavy Metals from Consuming Food Grown on Sewage Irrigated Soils and Food Chain Transfer. *Ecotoxicology and Environmental Safety*, **69**, 513-524. https://doi.org/10.1016/j.ecoenv.2007.04.013

[29] Alani, E.A. (2015) Economic Analysis of Heavy Metals Pollution on Soil, River and Rice Production in Nigeria. *Journal of Emerging Trends in Economics and Management Sciences*, **6**, 363-366.

[30] Ahmed, M., Matsumoto, M., Ozaki, A., Thinh, N.V. and Kurosawa, K. (2019) Heavy Metal Contamination of Irrigation Water, Soil, and Vegetables and the Difference between Dry and Wet Seasons near a Multi-Industry Zone in Bangladesh. *Water*, **11**, Article No. 583. https://doi.org/10.3390/w11030583

[31] Ngweme, G.N., Atibu, E.K., Al Salah, D.M.M., Muanamoki, P.M., Kiyombo, G.M., Mulaji, C.K. and Poté, J.W. (2020) Heavy Metal Concentration in Irrigation Water, Soil and Dietary Risk Assessment of *Amaranthus viridis* Grown in Peri-Urban Areas in Kinshasa, Democratic Republic of the Congo. *Watershed Ecology and the Environment*, **2**, 16-24. https://doi.org/10.1016/j.wsee.2020.07.001

[32] Ostad-Ali-Askari, K., Shayannejad, M., Eslamian, S., Zamani, F., Shojaei, N., Navabpour, B., Majidifar, Z., Sadri, A., Ghasemi-Siani, Z., Nourozi, H., Vafaei, O. and Homayouni, S.-M.A. (2017) Chapter 18. Deficit Irrigation: Optimization Models. In: Eslamian, S. and Eslamian, F.A., Eds., *Handbook of Drought and Water Scarcity: Management of Drought and Water Scarcity*, CRC Press, Boca Raton, 373-389. https://doi.org/10.1201/9781315226774-18

[33] Cadar, O., Miclean, M., Cadar, S., Tanaselia, C., Senila, L. and Senila, M. (2015) Assessment of Heavy Metals in Cows Milk in Rodnei Mountains Area, Romania. *Environmental Engineering & Management Journal*, **14**, 2523-2528. https://doi.org/10.30638/eemj.2015.269

[34] Hu, X.-F., Jiang, Y., Shu, Y., Hu, X., Liu, L. and Luo, F. (2014) Effects of Mining Wastewater Discharges on Heavy Metal Pollution and Soil Enzyme Activity of the Paddy Fields. *Journal of Geochemical Exploration*, **147**, 139-150. https://doi.org/10.1016/j.gexplo.2014.08.001

[35] ECAM 3 (2008) Rapport de l'enquête de consommation auprès des ménages Au Cameroun 2007. Institut National de la Statistique (INS) Reference ID CMR_2007_ECAM-III_V01_M.

[36] FAO (2010) Base de données relative aux statistiques agricoles pour l'afrique (FAO.Org).

[37] FAO (2019) https://www.fao.org/

[38] Naseri, M., Vazirzadeh, A., Kazemi, R. and Zaheri, F. (2015) Concentration of Some Heavy Metals in Rice Types Available in Shiraz Market and Human Health Risk Assessment. *Food Chemistry*, **175**, 243-248. https://doi.org/10.1016/j.foodchem.2014.11.109

[39] Ministère de L'Agriculture et du Développement Rural (MINADER) (2015) Stratégie nationale de développement de la filière semences de riz (SNDSR). 56 p.

[40] L'Hôte, Y. (1999) Climatologie in Atlas de la Province Extrême Nord Cameroun, Planche 2. République du cameroun, ministère de la recherche scientifique et de la technologie/institut national de cartographie, 32 p.

[41] Eone, N., Bell, J.M., Amougou, J.A., Abossolo, S.A. and Biye, E.H. (2019) Conditions Climatiques et Rentabilité des Outils et Équipements Agricoles Dans la Partie Septentrionale Du Cameroun. *Afrique Science*, **14**, 270-280.

[42] Suchel, J.B. (1972) Les Climats Du Cameroun. Thèse de Doctorat 3eme Cycle, Université de Bordeaux III, Bordeaux, 186 p.

[43] Olguin, E.J. and Sanchez-Galvàn, G. (2012) Heavy Metal Removal in Phytofiltration and Phycoremediation: The Need to Differentiate between Bioadsorption and Bioaccumulation. *NewBiotech*, **30**, 3-8. https://doi.org/10.1016/j.nbt.2012.05.020

[44] FAO (1985) Water Quality for Agriculture. Food and Agriculture Organization, Rome. http://www.fao.org/3/t0234e/t0234e00.htm

[45] Madomguia, D., Mbenda, S.H.N., Basokdou, G.B., Kalieu, W.I.A., Kuitekam Dongo, P. and Nya, E. (2023) Evaluation of Bioaccumulation of Heavy Metals in Some Fish Species from the Far North, Cameroon Rice Farms' Channels of Pouss. In: Babalola, O.O., Ayangbenro, A.S. and Ojuederie, O.B., Eds., *Food Security and Safety*, Springer, Berlin, Vol. 2, 19-32. https://doi.org/10.1007/978-3-031-09614-3_2

[46] Brockwell, J. and Gault, R.R. (1976) Effect of Irrigation Water Temperature on Growth of Some Legume Species in Glasshouses. *Australian Journal of Experimental Agriculture*, **16**, 500-505. https://doi.org/10.1071/EA9760500

[47] Commune de Maga (2012) Plan Communal de Développement. 133 p.

[48] Misra, S.G. and Mani, D. (1991) Soil Pollution. Ashish Publishing House, Punjabi Bagh.

[49] Lu, H., Li, K., Nkoh Nkoh, J., Shi, Y., He, X., Hong, Z. and Xu, R. (2022) Effects of the Increases in Soil PH and PH Buffering Capacity Induced by Crop Residue Biochars on Available Cd Contents in Acidic Paddy Soils. *Chemosphere*, **301**, Article ID: 134674. https://doi.org/10.1016/j.chemosphere.2022.134674

[50] Wen, M., Ma, Z., Gingerich, D.B., Zhao, X. and Zhao, D. (2022) Heavy Metals in Agricultural Soil in China: A Systematic Review and Meta-Analysis. *Eco-Environment & Health*, **1**, 219-228. https://doi.org/10.1016/j.eehl.2022.10.004

[51] Ranjbar, G., Kariminejad, F., Jamali, J., Shams, M, Najafpoor, A.A. and Dehghan, A. (2022) Heavy Metal Concentration in Water, Soil and Cultivated Vegetables at the Edge of Kashaf Roud River, Mashhad, Iran: Ecological Risk Assessment and Bioaccumulation Factor. *International Journal of Environmental Analytical Chemistry*. https://doi.org/10.1080/03067319.2022.2089031

[52] Shahid, M., Shukla, A.K., Bhattacharyya, P., Tripathi, R., Mohanty, S., Kumar, A., Lal, B., Gautam, P., Raja, R., Panda, B.B. and Nayak, A.K. (2016) Micronutrients (Fe, Mn, Zn and Cu) Balance under Long-Term Application of Fertilizer and Manure in a Tropical Rice-Rice System. *Journal of Soils and Sediments*, **16**, 737-747. https://doi.org/10.1007/s11368-015-1272-6

[53] Chidinma, C.E., Ihedioha, J.N., Ujam, O., Ekere, N.R. and Nwuche, C.O. (2019) Human Health Risk Assessment of Potential Toxic Elements in Paddy Soil and Rice (*Oryza sativa*) from Ugbawka Fields, Enugu, Nigeria. *Open Chemistry*, **17**, 1050-1060. https://doi.org/10.1515/chem-2019-0121

[54] Feka, D.P., Anhwange, B.A. and Adie, P.A. (2022) Toxic Metals Contamination of Paddy (*Oryza sativa*) and Imported Rice Sold in Kaduna and Its Human Health Risk Assessment. https://doi.org/10.21203/rs.3.rs-1953036/v1

[55] Hele, A.K. and Moloro, H.B. (2023) Review on Levels of Some Selected Heavy Metals in Commercially Available Rice in Ethiopia. *East African Scholars Journal of Agriculture and Life Sciences*, **6**, 15-28. https://doi.org/10.36349/easjals.2023.v06i01.002

[56] Gorinova, N., Nedkovska, M., Todorovska, E., Simova-Stoilova, L., Stoyanova, Z., Georgieva, K. and Herzig, R. (2007) Improved Phytoaccumulation of Cadmium by Genetically Modified Tobacco Plants (*Nicotiana tabacum* L.) Physiological and Biochemical Response of the Transformants to Cadmium Toxicity. *Environmental Pollution*, **145**, 161-170. https://doi.org/10.1016/j.envpol.2006.03.025

[57] Krystofova, O., Zitka, O., Krizkova, S., Hynek, D., Shestivska, V., Adam, V. and Kizek, R. (2012) Accumulation of Cadmium by Transgenic Tobacco Plants (*Nicotiana tabacum* L.) Carrying Yeast Metallothionein Gene Revealed by Electrochemistry. *International Journal of Electrochemical Science*, **7**, 886-907. https://doi.org/10.1016/S1452-3981(23)13383-9

[58] Zaidi, A., Wani, P.A. and Khan, M.S. (2012) Toxicity of Heavy Metals to Legumes and Bioremediation. Springer, London. https://doi.org/10.1007/978-3-7091-0730-0

[59] Grimm, N.B., Foster, D., Groffman, P., Grove, J.M., Hopkinson, C.S., Nadelhoffer, K.J., Pataki, D.E. and Peters, D.P.C. (2008) The Changing Landscape: Ecosystem Responses to Urbanization and Pollution across Climatic and Societal Gradients. *Frontiers in Ecology and the Environment*, **6**, 264-272. https://doi.org/10.1890/070147

[60] Wang, A., Wang, M., Liao, Q. and He, X. (2016) Characterization of Cd Translocation and Accumulation in 19 Maize Cultivars Grown on Cd-Contaminated Soil: Implication of Maize Cultivar Selection for Minimal Risk to Human Health and for Phytoremediation. *Environmental Science and Pollution Research*, **23**, 5410-5419. https://doi.org/10.1007/s11356-015-5781-z

[61] Yeung, A.T. and Hsu, C. (2005) Electrokinetic Remediation of Cadmium Contaminated Clay. *Journal of Environmental Engineering*, **131**, 298-304. https://doi.org/10.1061/(ASCE)0733-9372(2005)131:2(298)

[62] Mido, Y. and Satake, M. (2003) Chemicals in the Environment. In: Sethi, M.S. and Iqbaeds, S.A., Eds., *Toxic Metals*, Discovery Publishing House, New Delhi, 45-68.

[63] Wang, X., Zhou, C., Liu, G. and Dong, Z. (2013) Transfer of Metals from Soil to Crops in an Area near a Coal Gangue Pile in the Guqiao Coal Mine, China. *Analytical Letters*, **46**, 1962-1977. https://doi.org/10.1080/00032719.2013.777923