Asian Journal of Advanced Research and Reports

3(4): 1-8, 2019; Article no.AJARR.47198

Contamination and Pollution Risk Assessment of Heavy Metals in Rice Samples (*Oryza sativa*) from Nasarawa West, Nigeria

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Authors' contributions

This study was carried out in collaboration among all the authors. The authors read and contributed appropriately to the final manuscript.

Article Information

DOI:10.9734/AJARR/2019/v3i430097

Editor(s):

(1) Dr. Sobia Chohan, Assistant Professor, Department of Plant Pathology, Bahauddin Zakariya University, Multan, Pakistan.

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Complete Peer review History: http://www.sdiarticle3.com/review-history/47198

Original Research Article

Received 22 November 2018
Accepted 21 February 2019
Published 13 March 2019

ABSTRACT

Aim: This study was undertaken to assess the heavy metals contamination level in rice grains (*Oryza sativa*) from Nasarawa West, Nigeria.

Study Design: To estimate the contamination factor, degree of Contamination and Pollution load index of rice samples from Nasarawa west using the world health organization/food and agricultural organization acceptable limits of some toxic Heavy Metals in Food as reference heavy metals concentration.

Place and Duration of Study: The research was carried out in the Department of physics, Nasarawa State University, Keffi, from September 2017 to April 2018.

Methodology: Fifteen (15) samples each were taken from various locations from the rice fields in Keffi, Kokona, Karu, Nasarawa, and Toto respectively. Rice grain samples were dried in an open air at an ambient temperature to constant weight. Husks were removed. Then, the grain rice samples were pulverized and were passed through a 2.00 mm sieve and stored in closed polyethylene bags for irradiation using ECLIPSE Ш Energy Dispersive X – Ray Fluorescence (EDXRF) XR–100 CR spectrometer supplied by AMTEK INC. MA; USA.

Results: The values of contamination factor of rice samples from the study area were in the order

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of Zn < Cu < Ni < Cr < Pb and are all less than 1, indicating a 'low risk' of contamination with the value of Cd >> 6 presenting a very high contamination risk of Cadmium. The Pollution Load Index value observed in Nasarawa West were in the order of Nasarawa (0.0683) < Keffi (0.0773) < Toto (0.0972) < Kokona (0.0988) < Karu (0.1389) and are all less than unity (1), indicating that the rice samples were not polluted by Cd, Cu, Cr, Ni, Pb and Zn.

Conclusion: Findings from this study will help in making policies and preferring solution to public health related issues and further studies may be important.

Keywords: Heavy metals; contamination level; pollution load index.

1. INTRODUCTION

The resulting effects of human activities on the earth's surface are devastating to the global ecosystem and man [1]. Activities such as commerce, agriculture, industry, among others, have become a major source of concern to the world, in terms of their effects on the environment and human health. The human society today is faced with so many environmental problems, prominent among which is contamination and pollution. According to Richard [2], contamination and pollution results from human activities and these affect the quality of air, water, land and food. Majority of rice consumers may in turn be exposed to the heavy metals [3]. Heavy metals could be released into the environment either through natural or anthropogenic sources [4]. Anthropogenic inputs are always associated with industrialization and agricultural activated depositions. Some of which include atmospheric deposition, waste disposal, waste incineration, urban effluent, traffic emission, application of fertilizer and long – term application of waste water in our agricultural lands [5]. The deposition of radionuclides and heavy metals in food crops such as rice which could be subsequently transferred to the edible portion of plants are key pathways in a large set of ecological and other surveys [6]. This is one of the first steps in which heavy metals enter our biosphere and thus, the human food chains [6]. Heavy metals become toxic to the plants when it exceeds maximum acceptable limits [7]. Toxic heavy metals could be absorbed and then accumulated by plants which might eventually enter the human body through the normal food intake. Consumption of these foods is the major exposure pathway; with the exposure risk from ingestion exceeding risks from inhalation and dermal contacts [8]. A reduction in crop yield may results from the normal plant growth inhibited by high levels of heavy metal in the soil [9,10]. Exposure to heavy metal sources both from the soil and water may results in contamination of crops such as rice that are grown in submerged conditions.

Consumptions of food (e.g. rice) contaminated with heavy metals is closely related to the negative health impacts. Clear evidence has shown that human renal dysfunction is linked to contamination of rice with heavy metals [11,12]. In view of the recognition of the adverse health implications of heavy metals toxicity, there is a need for up – to – date measures to be taken so as to overcome the potential food contamination in the study area, especially as agrochemical applications such as pesticides, herbicides and fertilizers are now the practice of the day in the study area.

2. MATERIALS AND METHODS

2.1 Materials

Rice Samples were packaged in plastic containers from the rice fields. Samples were grounded using agate Mortar and Pestle, and then Sieved through a 2.00 mm sieve using Methylated spirit and Tissue paper for cleansing. Global Positioning System (GPS) was used in taken the coordinates of the sampling locations. Representative samples were later package in a well labeled Polythene bags and XRF Spectrometry Machine was used to analyze the samples.

2.2 Methods

2.2.1 Study area

Nasarawa west agricultural zone as the study area consisting of Keffi (KEF), Kokona (KKN), Karu (KRU), Nasarawa (NSW), and Toto (TTO) Local Government Areas is bordered by Federal Capital Territory, Abuja, Kogi State and Kaduna state respectively. The study area has an existing network of roads linking all rural areas and major towns. Nasarawa west being part of

Nasarawa State dominated by guinea savannah vegetation has agriculture as the mainstay of its economy with the production of varieties of cash crops such as rice, groundnut, cassava, pepper, cowpea, sesame, sorghum, yam throughout the year by the populace that engage in subsistence farming. It also contains various minerals such as cassiterite, columbit, mica, granite, quartz, iron-ore, and bauxite which are mostly mined by artisanal miners. The Figure below shows the map of Nasarawa West as the study area.

2.2.2 Samples collection and preparation

A purposive sampling technique was used to collect a total of Seventy five (75) samples from the selected rice fields locations in Nasarawa West, Nigeria. A total of fifteen (15) samples were collected from each of the five Local Governments in the study area using knife and the samples were packaged in well labeled plastic containers. A Global Positioning System (GPS) to obtain the coordinates of each location. The samples to be analyzed were air – dried at an ambient temperature, pulverized using agate mortar and pestle, and then sieved with a 2.00mm so as to obtain a uniform representative sample sizes. A 0.8 g samples by mass measured from each sample is pelletized with steel molds, pellets and a hydraulic press, using aluminum foil as the binder to hold the sample particles together after the removal from the molds.

2.2.3 Rice samples analysis

X – Ray Fluorescence (XRF) spectrometric procedure that required little pre-treatment analysis of food samples was employed in this study. Representative samples were irradiated using the ECLIPSE Ш Energy Dispersive X – Ray Fluorescence (EDXRF) spectrometer (XR – 100 CR) supplied by AMTEK INC. MA; USA, with a high performance thermoelectrically cooled Si–PIN photodiode as an X – ray detector and a preamplifier at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile–Ife, Nigeria. The detector is coupled to the pocket MCA 8000A Multichannel Analyzer. The resolution of the detector for the 5.9 keV peak of 55Fe is 220 eV full width half maximum (FWHM) with 12 µS shaping time constant for the standard setting and 186 eV FWHM with 20µs time constant for the optional setting. The quantitative analysis of samples was carried out using the XRF-FP Quantitative Analysis Software package. It converts elemental peak intensities to elemental concentrations and or film thickness. The samples to be irradiated are placed in the sample chamber. The sample chamber has connections to it, which are at angle 45° to it respectively, the source X-ray tube and the Si-PIN photodiode detector. The source X-ray tube is maintained at a voltage of 25 kV and a current of 50 µA and each of the samples is irradiated for 1000 sec. Quality control measure was taken to ensure reliability of results. Samples were handled carefully to avoid contamination. Recovery test was carried out on the XRF machine by spiking analyzes. All samples were irradiated in duplicate and the concentration of the heavy metals by mass was obtained by taken the average values.

2.2.4 Contamination factor (CF)

Contamination factor (CF) is used to assess contamination level in relative to average concentration of the respective heavy metals in the environment i.e. foods to the measured reference values from previous study with similar geological origin or uncontaminated foods [13]. The mathematical expression (1) was used for calculating the Contamination Factor (CF) [14].

$$\mathrm{CF} = \frac{C_m}{C_{ref}} \tag{1}$$

where, C_m= mean concentration of the heavy metal in the rice sample;

C_{ref} = reference concentration of the metal.

If the values of 'CF < 1', '1 ≤ CF< 3', '3 ≤ CF < 6' and 'CF ≥ 6' it indicates 'Low risk', 'Moderate risk', 'Considerable high risk' and 'Very high risk' respectively [15,16].

Table 1. Acceptable limits of some toxic heavy metals in food by WHO/FAO

Heavy Metals	Concentrations (µg/g) [17]
Cd	0.10
Cu	73.00
Cr	2.30
Ni	67.00
Pb	0.30
Zn	100.00

World Health Organization and Food Agricultural Organization standards for some toxic heavy metals in foods were taken as the reference concentration. The values are presented in Table 1.

These metals are called micronutrients and are toxic when taken in excess of requirements.

Information about contamination factor is shown in Table 2.

2.2.5 Contamination degree (CD)

Contamination degree (CD) is sometimes known as degree of contamination. CD is the sum of all contamination factors, which provides information about total contamination in a particular sampling location [18,19] and it is shown in Table 3 below.

Contamination degree is often expressed as:

$$CD = \Sigma \mathrm{CF_{Cd}} + \mathrm{CF_{Cr}} + \mathrm{CF_{Cu}} + \mathrm{CF_{Cu}} + \mathrm{CF_{Ni}} + \mathrm{CF_{Pb}} + \mathrm{CF_{Zn}} \quad (2)$$

Where, CF_{Cd}, CF_{Cr}, CF_{Cu}, CF_{Ni}, CF_{Pb} and CF_{Zn} were the contamination factors for Cadmium, Chromium, Copper, Nickel, Lead and Zinc respectively [17,20]. If ‘CD < 8’, ‘8 ≤ CD< 16’, ‘16 ≤ CD < 32’ and ‘CD ≥ 32’ it indicates ‘Low risk’, ‘Moderate risk’, ‘Considerable high risk’ and ‘Very high risk’ respectively [13,16,17].

2.2.6 Pollution load index (PLI)

The basis of determining the pollution load is to estimate the extent of heavy metals pollution in rice samples in comparison to its reference acceptable limits in foods by WHO/FAO. Pollution load index (PLI) gives information about the toxicity of heavy metals in each respective sample locations in the study area [19,21,22] and it is shown in Table 4.

The expression (3) was used for calculating the pollution load index (PLI) base on the toxic heavy metals detected with a view of determining the suitability of rice for human consumption [14].

$$PLI = (\mathrm{CF_1 x\, CF_2 x\, CF_3 x\, CF_4} \ldots\ldots\ldots \mathrm{x\, CF_n})^{1/\mathrm{n}} \quad (3)$$

where,

n = Number of metals considered in the study;
CF_i= Contamination Factor for each individual metal.

If ‘PLI < 1’, ‘1 < PLI < 2’, ‘2 < PLI < 3’ and ‘PLI > 3’ it indicates ‘No Pollution’, ‘Moderate Pollution’, ‘Heavy Pollution’ and ‘Extremely Heavy Pollution’ respectively [13,14,16,17].

3. RESULTS AND DISCUSSION

3.1 Mean Concentrations of Heavy metals in Rice Samples from Nasarawa West Agricultural Zones

The mean concentrations of cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) [23] were estimated in rice samples from Keffi, Kokona, Karu, Nasarawa and Toto of Nasarawa West agricultural zone. Table 2 shows that the results of the mean concentrations of heavy metals in rice samples from Keffi (KEF) were in the decreasing order of Cd > Ni > Cu > Zn > Pb > Cr with each heavy metal having the mean value of Cd (29.521 µg/g), Ni (0.349 µg/g), Cu (0.287 µg/g), Zn (0.215 µg/g), Pb (0.157 µg/g) and Cr (0.060 µg/g).

In Kokona (KKN), it is observed that the mean concentrations of heavy metals in rice samples were in the increasing order of Cr < Pb < Zn < Cu < Ni < Cd with the value of Cr (0.097 µg/g), Pb (0.181 µg/g), Zn (0.252 µg/g), Cu (0.341 µg/g), Ni (0.420 µg/g) and Cd (33.477 µg/g).

It is shown in Table 2 that the mean concentrations of heavy metals in rice samples from Karu (KRU) were in the order of Cr < Pb < Zn < Cu < Ni < Cd with Cr (0.172 µg/g) presenting the lowest value followed by Pb (0.268 µg/g), Zn (0.380 µg/g), Cu (0.531 µg/g), Ni (0.648 µg/g) and Cd (40.183 µg/g).

The observed mean concentrations of heavy metals in rice samples from Nasarawa (NSW) were in the order of Cr < Pb < Zn < Cu < Ni < Cd with the respective value of 0.085 µg/g, 0.123 µg/g, 0.179 µg/g, 0.241 µg/g, 0.293 µg/g and 25.919 µg/g.

The mean concentrations of heavy metals in rice samples from Toto (TTO) were in order of Cr < Pb < Zn < Cu < Ni < Cd with the value of Cr (0.146 µg/g), Pb (0.168 µg/g), Zn (0.262 µg/g), Cu (0.340 µg/g), Ni (0.410 µg/g) and Cd (31.749 µg/g).

It is observed that Cd has it highest mean concentration value of 40.183 µg/g in rice samples from Karu (KRU) with the lowest value of 25.919 µg/g in rice samples from Nasarawa (NSW) and this is corroborated by the study carried out by Umar et al. [24] with the average concentration values of 260.90 – 524.50 mg/kg for Cd at swampy agricultural soils of Nasaarawa West.

3.2 Contamination Factor, Contamination Degree and Pollution Load Index of Heavy Metals in Rice Samples from Nasarawa West Agricultural Zones

Contamination Factor (CF) which is used in assessing the level of contamination of heavy metals in rice samples from Keffi (KEF) is in the order of Zn < Cu < Ni < Cr < Pb with their values less than 1, indicating 'low risk of contamination' while Cd >> 6 indicating 'a very high risk of contamination by Cadmium' [16,17] as shown in Table 3.

In Kokona (KKN), Table 3 shows that risk level is in the order of Zn < Cu < Ni < Cr < Pb and are less than unity (1), indicating that the contamination of these heavy metals is at 'low risk' while the CF value of Cd >> 6 indicating that the rice samples were highly contaminated with cadmium.

In Karu (KRU), the CF value shows that Zn < Cu < Ni < Cr < Pb < 1 indicating a 'low risk' of contamination by these heavy metals. But the rice samples presented a very high contamination risk of Cd indicating that the value of Cd >> 6.

Table 2. Mean concentrations of heavy metals in rice samples from Nasarawa west

S/N	Sample ID	Sample Size	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Ni (µg/g)	Pb (µg/g)	Zn (µg/g)
1	KEF	15	29.521	0.060	0.287	0.349	0.157	0.215
2	KKN	15	33.477	0.097	0.341	0.420	0.181	0.252
3	KRU	15	40.183	0.172	0.531	0.648	0.268	0.380
4	NSW	15	25.919	0.085	0.241	0.293	0.123	0.179
5	TTO	15	31.749	0.146	0.340	0.410	0.168	0.262

Note; KEF – Keffi, KKN – Kokona, KRU – Karu, NSW – Nasarawa, TTO – Toto, ID – Identity

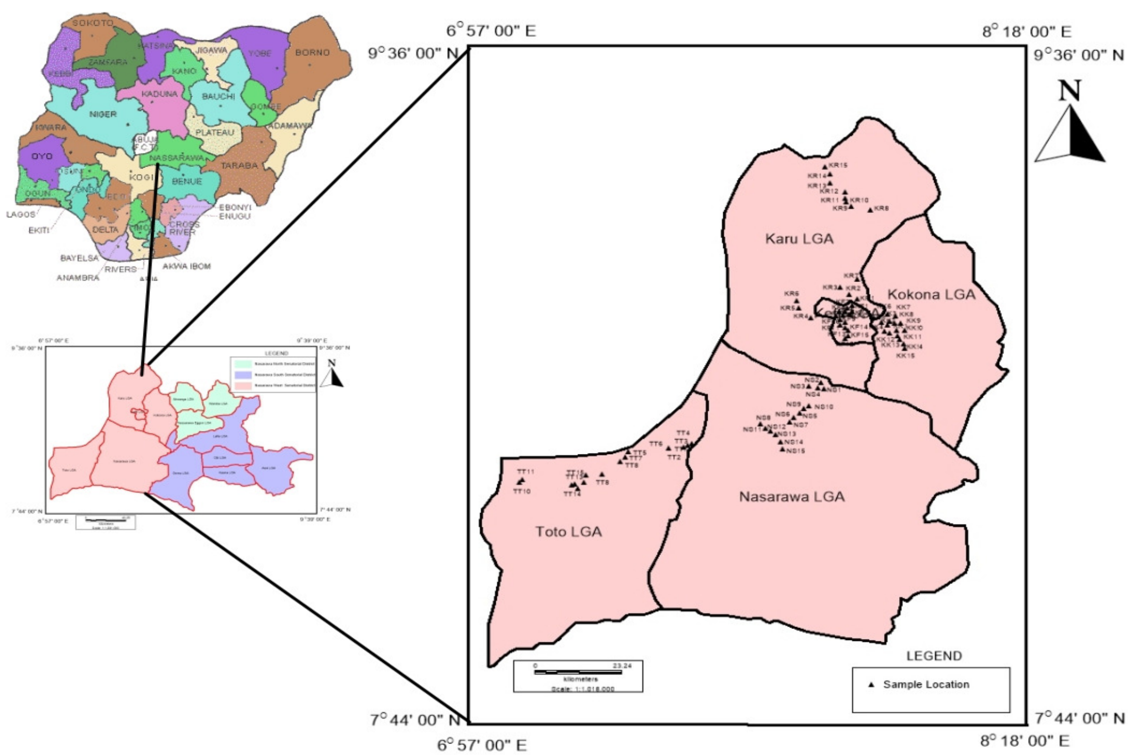

Fig. 1. Map of the study area and sampling locations

Table 3. Contamination factors (CF), degree of contamination (CD), and pollution load index (PLI) of some heavy metals in Nasarawa West using WHO/FAO standard

Sample ID	Contamination factor (CF)						Degree of Contamination (CD) [20]		Pollution Load Index (PLI)	
	Cd	Cu ($x10^{-3}$)	Cr	Ni ($x10^{-3}$)	Pb	Zn ($x10^{-3}$)				
KEF	295.21	3.8784	0.0260	5.2089	0.5233	2.1500	295.7705	Very high risk	0.0773	Unpolluted
KKN	334.77	4.6712	0.0422	6.2687	0.6033	2.5200	334.8254	Very high risk	0.0988	Unpolluted
KRU	401.83	7.2739	0.0748	9.6716	0.8933	3.8000	402.8188	Very high risk	0.1389	Unpolluted
NSW	259.19	3.3014	0.0369	4.3731	0.4100	1.7900	259.6464	Very high risk	0.0683	Unpolluted
TTO	317.49	4.6575	0.0635	6.1194	0.5600	2.6200	318.1269	Very high risk	0.0972	Unpolluted

Rice samples from Nasarawa (NSW) shows that contamination level of Zn < Cu < Ni < Cr < Pb < 1 indicating 'low risk' of of contamination by these heavy metals while the samples presented a very high risk of contamination by Cd with the value of Cd >> 6.

It is observed from Toto (TTO) that the rice samples presented the contamination level of heavy metals in the order of Zn < Cu < Ni < Cr < Pb < 1 indicating 'low risk' of contamination while the value of Cd >> 6 presenting a very high risk of contamination by Cadmium.

The Degree of Contamination by heavy metals in rice samples from KEF, KKN, KRU, NSW and TTO were 295.7705, 334.8254, 402.8188, 259.6464 and 318.1269 respectively.

The Pollution Load Index value observed in Nasarawa West were in order of NSW (0.0683) < KEF (0.0773) < TTO (0.0972) < KKN (0.0988) < KRU (0.1389) and are all less than unity (1), indicating that the rice samples were not polluted by Cd, Cu, Cr, Ni, Pb and Zn.

4. CONCLUSION

The high concentration and contamination levels presented by Cd and the increasing values of CF, CD and PLI for Cu, Cr, Ni, Pb and Zn in rice samples from the study area, may arise from the leaching of the top soils and rocks into the rice fields, and the modern practice of application of mineral fertilizers which is a great concern. Ahmed et al. [25] almost got similar results in a related study, where they found that Cd and Pb concentrations were increased in the cultivated soils and subsequent transfer into foods due to mineral fertilizer applications. In addition, Abbas and Abdelhafez [26] highlighted the negative impacts of pesticide manufacturing due to the presence of Cd and other heavy metals concentrations in the surrounding area. Thus, the unmanaged agricultural practices in terms of mineral fertilizer and pesticide applications might call for greater attention. Furthermore, the quality of water flowing into the rice field thorough leaching of top soils might not satisfy the standard index of water required in agricultural fields. This is an indication of potential health risk among the exposed population. The value of the pollution load index in Nasarawa west were all less than unity (1), indicating that the rice samples were not polluted by Cd, Cu, Cr, Ni, Pb and Zn.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/47198