Pollution Load Index of Radioactive Trace Elements in Bassa, Barkin Ladi and Mangu, Plateau, Nigeria

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Abstract

Pollution of trace elements in soil are enhanced by industrial and human activities like mining. Plants received these elements from soils through ionic exchange, precipitation-dissolution, and so on. This work intends to evaluate the extent of water, soil and plants pollution in parts of Plateau through an index called pollution load index. The results revealed that, the pollution load index of trace elements in Bassa, Barkin Ladi and Mangu have their values in trend with $^{232}Th(0.509) > {}^{40}K(0.041) > {}^{226}Ra(0.037)$ *for water,* $^{232}Th(0.764) > {}^{40}K(0.271) > {}^{226}Ra(0.165)$ *for soil and* $^{232}Th(0.056) > {}^{40}K(0.017) > {}^{226}Ra(0.009)$ *for plant. It can therefore be concluded that the soil, water and plants in the study area are not significantly polluted. Even though there may still be moderate accumulation and transfer, which may call for serious concern and regulatory control. This research can serve as reference data for the regulatory bodies like NNRA and the rest.*

Keywords: *Radioactive Trace Elements; Soil; Edible Plant; Water; Pollution Load Index.*

Introduction

Accumulation of trace elements in agricultural soils is instigated by industrial and other human activities such as mining, smelting, cement-pollution, energy and fuel production, power transmission, traffic activities, intensive agriculture, sludge dumping and melting operations (Balabanova *et al.*, 2014; Bi *et al.*, 2006; Filipović-Trajković *et al.*, 2012; Freitas *et al.*, 2004; Guala *et al.*, 2001). Plants received trace elements from soils through ionic exchange, redox reactions, precipitation-dissolution, and so on. Which implies that the solubility of trace elements based on factors like minerals in the soil (carbonates, oxide, hydroxide etc.), soil organic matter (humic acids, fulvic acids, polysaccharides and organic acids), soil pH, redox potential, content, nutrient balance, other trace elements concentration in soil, physical and mechanical characteristics of soil, soil temperature and humidity, etc. (Ibrahim *et al.*, 2014; Waida *et al.*, 2022a; Waida *et al.*, 2022b; Waida *et al.*, 2022c). The bioavailability of elements in soil is a variable process which is based on specific combinations of chemical, biological, and environmental parameters (Waida *et al.*, 2022d; Waida *et al.*, 2022e). Elements distribution in plants is very heterogeneous and is governed by genetic, environmental and toxic factors. The variation of trace elements in plant-soil association is based mainly on the levels of soil contamination and plant species (Jolly *et al.*, 2013; Kouamé *et al.*, 2013; Krstic *et al.*, 2007). Plants traps trace elements from the soil through the root and from the atmosphere through over ground vegetative organs (Mmolawa *et al.*, 2011). Some plants species have lower tolerance to toxic elements absorption in polluted mine soil as they accumulate high concentrations of ^{40}K, ^{226}Ra and ^{232}Th (Moore *et al.*, 2013). More so, different plant species grown in the same soil may have different concentration of the same element (Naser *et al.*, 2011). Some authors have reported the existence of differences in accumulation of trace elements in plant cultivars, age of plants, plant organs and tissues (Ogunkunle *et al.*, 2013; Panuccio *et al.*, 2009; Rangnekar *et al.*, 2013; Rilwan *et al.*, 2021). The same trace elements can contaminate water through erosion, where trace elements are flushed to our rivers and streams and we consume them. Pollution Load Index of trace elements in water, soil and edible plant tissues is studied using an index called Pollution Load Index (Shamuyarira and Gumbo, 2014; Tarradellas *et al.*, 1996). In this work, we intend to evaluate the extent to which the water, soil and plants in parts of Plateau State are polluted through a factor known as pollution load index.

Materials and Methods

Materials

The materials that were used in carrying out this research include Geo-positioning System meter (GPS meter) and Sodium Iodide Thallium Gamma Spectrometry (NaI (Tl)).

Method

The Study Area

Plateau is the twelfth-largest state in Nigeria. Approximately in the centre of the country, it is geographically unique in Nigeria due to its boundaries of elevated hills surrounding the Jos Plateau which is its capital, and the entire plateau itself (Waida *et al.*, 2022f).

Plateau State is celebrated as "The Home of Peace and Tourism". With natural formations of rocks, hills and waterfalls, it derives its name from the Jos Plateau and has a population of around 3.5 million people. Plateau State is located at North Central Zone out of the six geopolitical zones of Nigeria. With an area of 26,899 square kilometers, the State has an estimated population of about three million people. It is located between latitude 08°24'N and longitude 008°32' and 010°38' east. The state is named after the picturesque Jos Plateau, a mountainous area in the north of the state with captivating rock formations. Bare rocks are scattered across the grasslands, which cover the plateau. The altitude ranges from around 1,200 metres (3,900 ft) to a peak of 1,829 metres (6,001 ft) above sea level in the Shere Hills range near Jos. Years of tin and columbite mining have also left the area strewn with deep gorges and lakes (Waida *et al.*, 2022g).

Though situated in the tropical zone, a higher altitude means that Plateau State has a near temperate climate with an average temperature of between 13 and 22 °C. Harmattan winds cause the coldest weather between December and February. The warmest temperatures usually occur in the dry season months of March and April. The mean annual rainfall varies between 131.75 cm (52 in) in the southern part to 146 cm (57 in) on the Plateau. The highest rainfall is recorded during the wet season months of July and August. The average lower temperatures in Plateau State have led to a reduced incidence of some tropical diseases such as malaria. The Jos Plateau makes it the source of many rivers in northern Nigeria including the Kaduna, Gongola, Hadeja and Damaturu rivers. The Jos Plateau is thought to be an area of younger granite which was intruded through an area of older granite rock, making up the surrounding states. These "younger" granites are thought to be about 160 million years old. This creates the unusual scenery of the Jos Plateau. There are numerous hillocks with gentle slopes emerging from the ground like mushrooms scattered with huge boulders. Also, volcanic activity 50 million years ago created numerous volcanoes and vast basaltic plateaus formed from lava flows. This also produces regions of mainly narrow and deep valleys and pediments (surfaces made smooth by erosion) from the middle of rounded hills with sheer rock faces. The phases of volcanic activities involved in the formation of Plateau State have made it one of the mineral rich states in the country. Tin is still mined and processed on the plateau (Waida *et al.*, 2022g).

The geographical coordinates of the data points are tabulated in Table 1 and the map of Nigeria showing Plateau state, the map of Plateau state showing the mining Local Governments and map of mining Local Government showing the sample points are shown respectively in Figure. 1, 2 and 3.

Table 1: Geographical Coordinates of the Data Points

Village	Sample Points	Geographical Coordinates	
		East	East
Bassa	PT01	8°44'34.8"	10°09'39.6"
	PT02	8°40'58.8"	10°06'50.4"
	PT03	8°41'49.5"	10°06'00.00"
	PT04	8° 46' 4.8"	10° 4' 30"
	PT05	8° 51' 7.2"	10° 6' 57.6"
	PT06	8° 54' 3.6"	10° 7' 55.2"
	PT07	8° 50' 56.4"	10° 3' 57.6"
	PT08	8° 48' 3.6"	10° 0' 32.4"
	PT09	8° 41' 52.8"	9° 57' 21.6"
	PT10	8° 46' 37.2"	9° 56' 2.4"
	PT11	8° 43' 4.8"	9° 51' 46.8"
	PT12	8° 39' 3.6"	9° 44' 42"
Barkin Ladi	PT01	9° 4' 55.2"	9° 40' 33.6"
	PT02	9° 1' 30"	9° 37' 55.2"
	PT03	8° 58' 1.2"	9° 36' 39.6"
	PT04	8° 55' 26.4"	9° 34' 19.2"
	PT05	9° 0' 25.2"	9° 30' 36"
	PT06	8° 59' 31.2"	9° 27' 25.2"
	PT07	8° 55' 8.4"	9° 28' 33.6"
	PT08	8° 48' 25.2"	9° 29' 20.4"
	PT09	8° 53' 13.2"	9° 23' 13.2"
	PT10	8° 43' 55.2"	9° 22' 55.2"
	PT11	8° 42' 57.6"	9° 21' 10.8"
	PT12	8° 44' 13.2"	9° 20' 34.8"
Mangu	PT01	9° 9' 57.6"	9° 42' 21.6"
	PT02	9° 6' 21.6"	9° 34' 19.2"
	PT03	9° 13' 8.4"	9° 33'
	PT04	9° 11' 52.8"	9° 31' 30"

PT05	9° 12' 36"	9° 29' 34.8"
PT06	9° 17' 20.4"	9° 28' 22.8"
PT07	9° 15' 21.6"	9° 25' 40.8"
PT08	9° 11' 20.4"	9° 25' 58.8"
PT09	9° 4' 1.2"	9° 25' 12"
PT10	9° 8' 6"	9° 7' 55.2"
PT11	9° 16' 30"	9° 6' 57.6"
PT12	9° 12' 18"	9° 4' 1.2"

Figure 1: Map of Nigeria Showing Plateau State

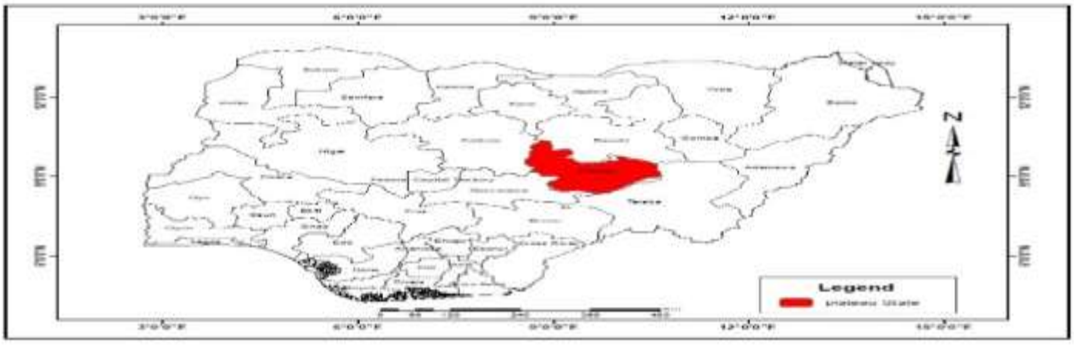


Figure 2: Map of Plateau State Showing Mining Local Government Areas

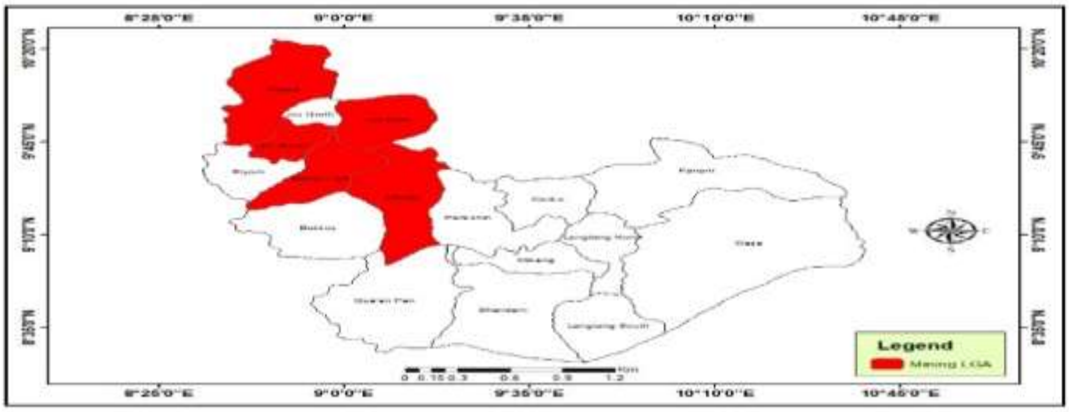
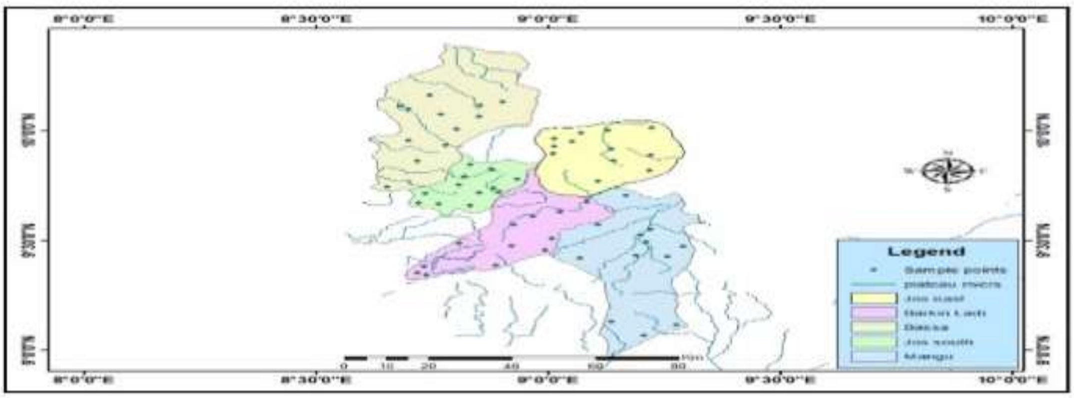


Figure 3: Map of Mining Local Government Areas Showing Sample Points



Population Sample

The population of the study include all the notable towns where mining activities takes place within Plateau State which include 3 local governments (Bassa, Mangu and Barkin Ladi) with 65 villages.

Soil, water and vegetable samples were pair collected. A simple systematic random sampling technique was used to select twelve (12) soil sample, twelve (12) edible plant sample, and twelve (12) water samples from each of the three (3) Mining local government of Plateau State. One hundred and Eight (108) samples in all (36 per local government) were analyzed in this study. Vegetables' rooted soil samples were taken at 0-20 cm depth. A composite sample composed of three (3) subsamples at each sampling site for water, vegetables and soils.

Sample Collection and Preparations

Soil Sample Collection

Twelve sample of soil from the Mining local government of Plateau State was collected. The sample was collected by coring tool to a depth of 5 cm or to the depth of the plough line. The collected samples each of approximately 4 kg in wet weight was immediately transferred into a high-density polyethylene zip lock plastic bag to prevent cross contamination. Each sample was marked with a unique identification number (sample ID) for traceability and its position coordinates were recorded for reference purposes using GPS meter.

Edible Plant Sample Collection

Twelve edible plant samples were collected from the Mining local government of Plateau State. The collected samples were immediately transferred into a high-density polyethylene zip lock plastic bag to prevent cross contamination. Each sample was marked with a unique identification number (sample ID) for traceability.

Water Sample Collection

Twelve water samples were collected from streams from the Mining local government of Plateau State. The collected samples were immediately transferred into plastic containers and was well covered to avoid cross contamination. Each sample was marked with a unique identification number (sample ID) for traceability.

Soil and Edible Plant Sample Preparation

The collected samples (soil and edible plants) were brought into the laboratory and left open (since wet) for a minimum of 24 hours to dry under ambient temperature. They were grounded using mortar and pestle and allowed to pass through 5mm-mesh sieve to remove larger object and make it fine powder. The samples were packed to fill a cylindrical plastic container of height 7cm by 6cm diameter. This satisfied the selected optimal sample container height. Each container accommodated approximately 300g of sample. They were carefully sealed (using Vaseline, candle wax and masking tape) to prevent radon escape and then stored for a minimum of 24 days. This is to allow radium attain equilibrium with the daughters.

Water Sample Preparation

The collected water Sample Preparation at the instrumentation laboratory, the beakers will be properly washed and rinsed with distil water, after which they will be sterilized using Acetone. Each beaker will again be rinsed twice with a little quantity of the water sample to be analysed, then 1000ml of the water sample will be poured into the beaker, which will in turn set on a hot plate in a fume cupboard and allowed to evaporate at a temperature of 50^0C to 60^0C. The beaker will be left open without stirring to avoid excessive loss of the residue. When the water in each beaker remained about 50ml, it will be transferred to a pre-weighed ceramic dish where the sample will be finally evaporated to dryness using a hot plate. The ceramic dish will be weighed again after cooling and the weight of the residue will be obtained by subtracting the previous weight of the empty dish. A few drops of Acetone will be added to the dry residue in order to sterilize it. It will then be stored in a desiccator and allowed to cool, thereby prevented from absorbing moisture.

The volume of water which gave the total residue was obtained from the equation (1) as pointed out by Waida *et al*. (2022g) and WHO (2017):

$$V = \frac{V_w}{TR \times RP} \quad 1$$

Where V_w is the volume of water evaporated, TR is the total residue obtained, RP is the residue transferred to the planchet.

Method of Data Analysis

Activity Concentrations of elements was analyzed by the Sodium Iodide Thallium Gamma Spectrometry (NaI (Tl)) Analysis available at Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The results obtained was used to evaluate the pollution load index.

Pollution Load Index (PLI)

Each sample from the collection spot was evaluated for the extent of trace elements pollution by employing the method based on the Pollution Load Index (PLI) developed by Yan *et al.* (2012); Usman *et al.* (2020a); Rilwan *et al.* (2020); WHO (2017) as follows:

$$PLI = (CF_1 x CF_2 x CF_3 x \dots x CF_n) \quad 2$$

where: n is the number of metals studied and CF is the Contamination factor as calculated in Equation (2) according to WHO (2017); Waida *et al*. (2022e); Waida *et al*. (2022f).

$$CF = \frac{C_m Sample}{C_m Background} \quad 3$$

Where C_m = Concentration of sample from the flooded farm, C_m Background = Concentration of sample from the control area (Usman *et al.* 2020).

If PLI < 1: indicates perfection

PLI = 1: indicates pollutants are present but only at baseline levels.

PLI > 1: indicates deterioration of site quality.

Results and Discussion

Results

The results for the activity concentration levels of three radioactive trace elements (^{40}K, ^{226}Ra and ^{232}Th) was determined using Sodium Iodide Thallium Gamma Spectrometry (NaI (Tl)) method. A total of twelve samples each of water, soil and edible were randomly collected from some Bassa, Barkin Ladi and Mangu mining sites of Plateau State, Nigeria. The coordinates (Latitudes and Longitudes) of the sample points were also measured and recorded with the aid of a Global Positioning System (GPS). The results which include radioactive trace elements concentration in water, radioactive trace elements in soil and radioactive trace elements in edible plants are further used to evaluate the pollution load index of these radioactive trace elements in soil, water and edible plants, and presented in Table 2.

Table 2: Pollution Load Index of radioactive trace elements in Water, Soil and Edible Plant Samples.

T/E	^{40}K	^{226}Ra	^{232}Th	Total
			Water	
Bassa	0.073	0.016	0.036	**0.041**
Barkin Ladi	0.036	0.012	1.372	**0.473**
Mangu	0.014	0.083	0.119	**0.072**
Total	**0.041**	**0.037**	**0.509**	**0.195**
			Soil	
Bassa	0.711	0.293	0.089	**0.364**
Barkin Ladi	0.059	0.024	1.973	**0.685**
Mangu	0.042	0.178	0.230	**0.112**
Total	**0.271**	**0.165**	**0.764**	**0.527**
			Edible Plants	
Bassa	0.026	0.013	0.054	**0.031**
Barkin Ladi	0.015	0.001	0.588	**0.201**
Mangu	0.009	0.013	0.026	**0.009**
Total	**0.017**	**0.009**	**0.056**	**0.080**

It was observed from Table 2 that the total pollution load index of radioactive trace elements from water samples is in decreasing order trend with Barkin Ladi (0.473) > Mangu (0.072) > Bassa (0.041) with ^{232}Th having the highest value (0.509) followed by ^{40}K with (0.041) then ^{226}Ra having the lowest value (0.037).

It was also observed from Table 2 that the total pollution load index of radioactive trace elements from soil samples is in decreasing order trend with Barkin Ladi (0.685) > Bassa (0.364) > Mangu (0.112) with ^{232}Th having the highest value (0.764) followed by ^{40}K with (0.271) then ^{226}Ra having the lowest value (0.165).

It was similarly observed from Table 2 that the total pollution load index of radioactive trace elements from edible plant samples is in decreasing order trend with Barkin Ladi (0.201) > Bassa (0.031) > Mangu (0.009) with ^{232}Th having the highest value (0.056) followed by ^{40}K with (0.017) then ^{226}Ra having the lowest value (0.009).

Comparison of Results with World Health Organization (WHO)

The results presented on Table 2 were used to plot charts in order to compare the results of the present study with World Health Organization (WHO) as seen in Figure 4, Figure 5 and Figure 6.

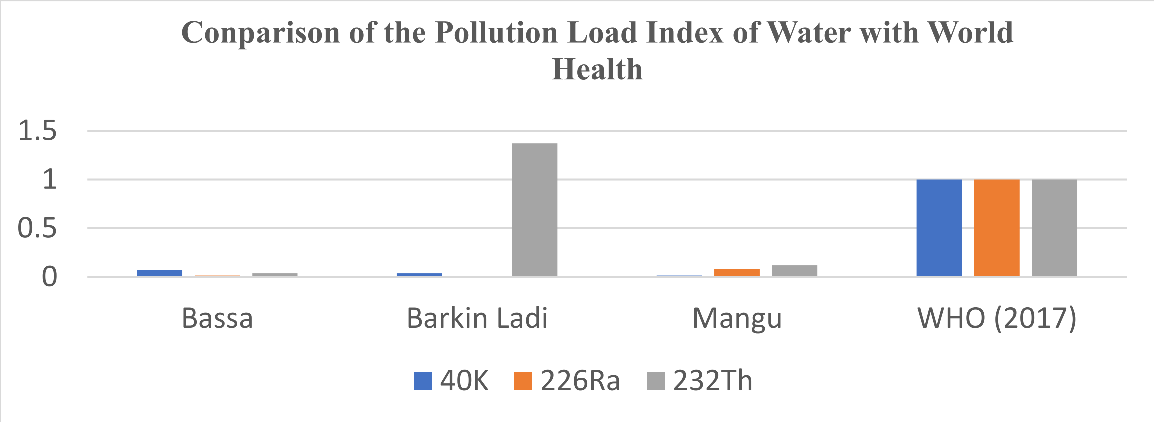


Figure 4: Comparison of Pollution Load Index of Water with World Health Organization

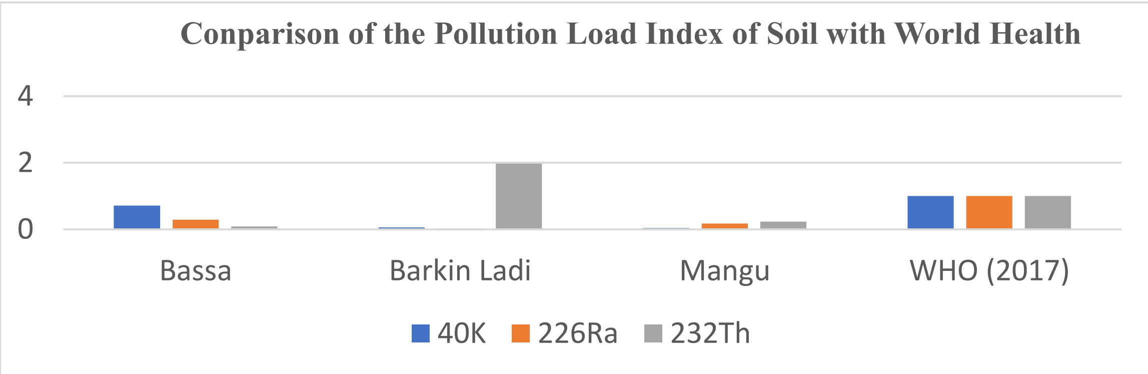


Figure 5: Comparison of Pollution Load Index of Soil with World Health Organization

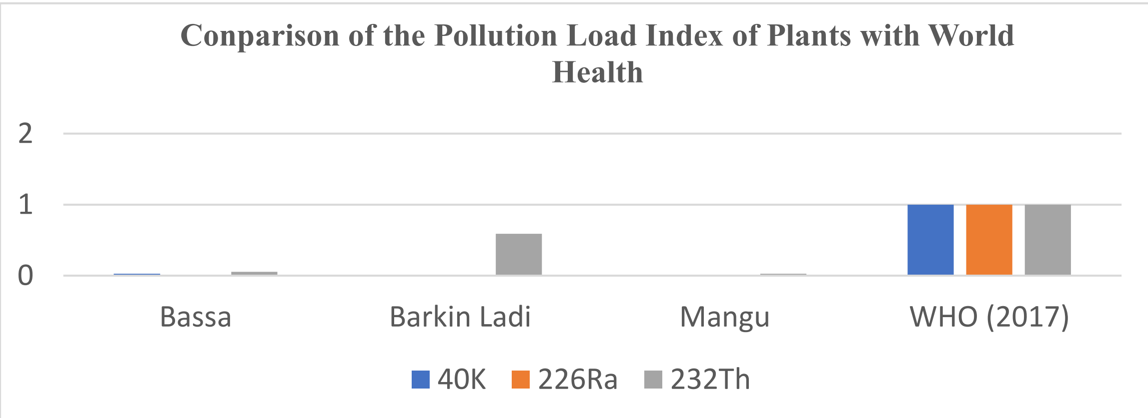


Figure 6: Comparison of Pollution Load Index of Edible Plants with World Health Organization

Discussion

Pollution of different radioactive trace elements in water and plants depends on their relative level of exposure to the contaminated soil as well as the deposition of toxic elements in the polluted air by sedimentation. In this study, the Pollution Load Index (PLI) for various radioactive trace elements showed that the PLI values differed slightly between the locations.

The total pollution load index of radioactive trace elements from water samples is in decreasing order trend as Barkin Ladi (0.473) > Mangu (0.072) > Bassa (0.041) with ^{232}Th

having the highest value (0.509) followed by ^{40}K with (0.041) then ^{226}Ra having the lowest value (0.037).

Based on the chart presented in Figure 4, the water in all the villages for all the radioactive trace elements are found below the recommended limit of World Health organization of PLI≤ 1 except ^{232}Th in Barkin Ladi which was found to be above the recommended limit of World Health organization of PLI≤ 1.

It was also observed that the total pollution load index of radioactive trace elements from soil samples is in decreasing order trend as Barkin Ladi (0.685) > Bassa (0.364) > Mangu (0.112) with ^{232}Th having the highest value (0.764) followed by ^{40}K with (0.271) then ^{226}Ra having the lowest value (0.165).

Based on the chart presented in Figure 5, the soil in all the villages for all the radioactive trace elements are found below the recommended limit of World Health organization of PLI≤ 1 except ^{232}Th in Barkin Ladi which was found to be above the recommended limit of World Health organization of PLI≤ 1.

It was similarly observed that the total pollution load index of heavy metal from edible plant samples is in decreasing order trend as Barkin Ladi (0.201) > Bassa (0.031) > Mangu (0.009) with ^{232}Th having the highest value (0.056) followed by ^{40}K with (0.017) then ^{226}Ra having the lowest value (0.009).

Based on the chart presented in Figure 6, the edible plants in all the villages for all the radioactive trace elements are found below the recommended limit of World Health organization of PLI≤ 1.

Conclusion

Based on the results presented, the findings indicate indicates perfection of site quality with exception of 232Th in Barkin Ladi for water and soil, which indicates that pollutants are present but only at baseline levels. It can therefore be concluded that the soil, water and plants in the study area are not significantly polluted. Even though there may still be moderate accumulation and transfer, which may call for serious concern and regulatory control. This research can serve as reference data for the regulatory bodies like NNRA and the rest.

Acknowledgement

Praise is to our creator, Lord of the worlds, the Eternal Guardian of the heavens and earths, Disposer of all created beings. Whom through His blessings upon us, we were able to successfully complete this work. It is also necessary to acknowledge the Center for Energy Research and Training (CERT) for their effort towards the achievement of this work during the sample analysis.

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