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Contamination and Pollution of Soil, Water and Edible Plant by the Concentration of ^{40}K, ^{226}Ra and ^{232}Th and Associated Radiological Parameters of Jos East and Jos South, Plateau State, Nigeria.

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Abstract: Naturally occurring radioactive materials (NORMs) refers to all the radionuclides that exist in the environment naturally, which are the primordial radionuclides ^{40}K, ^{232}Th and ^{226}Ra, and their decay products which are present in varying amounts within the earth crust. This study reports the extent of contamination and pollution of soil, water and edible plant by the concentration of ^{40}K, ^{226}Ra and ^{232}Th and associated radiological parameters of Jos East and Jos South artisanal tin mining areas in Plateau State, Nigeria. The results showed that the contamination factors of Soil in Jos East have the total values in trend with ^{232}Th (1.145) > ^{40}K (0.779) > ^{226}Ra (0.729) while that of Jos South have the total values in trend with ^{226}Ra (0.914) > ^{232}Th (0.914) > ^{40}K (0.816). The contamination factors of water in Jos East have the total values in trend with ^{232}Th (1.116) > ^{40}K (0.756) > ^{226}Ra (0.696) while that of Jos South has the total values in trend with ^{232}Th (0.890) > ^{226}Ra (0.889) > ^{40}K (0.791). The contamination factors of Edible Plants in Jos East have the total values in trend with ^{232}Th (1.088) > ^{40}K (0.731) > ^{226}Ra (0.662) while that of Edible Plants in Jos South have the total values in trend with ^{226}Ra (0.925) > ^{232}Th (0.870) > ^{40}K (0.859). The pollution load index of radioactive trace elements from soil samples of Jos East is in decreasing order trend with ^{232}Th (3.985) > ^{40}K (0.023) > ^{226}Ra (0.013) with the total value of 1.340, on the other hand, that of Jos South is in decreasing order trend with ^{226}Ra (0.328) > ^{232}Th (0.172) > ^{40}K (0.043) with the total value of 0.181. The pollution load index of radioactive trace elements from water samples of Jos East is in decreasing order trend with ^{232}Th (2.910) > ^{40}K (0.015) > ^{226}Ra (0.007) with the total value of 0.977, on the other hand, that of Jos South is in decreasing order trend with ^{226}Ra (0.130) > ^{232}Th (0.077) > ^{40}K (0.018) with the total value of 0.120. The pollution load index of radioactive trace elements from edible plant samples of Jos East is in decreasing order trend with ^{232}Th (2.107) > ^{40}K (0.009) > ^{226}Ra (0.004) with the total value of 0.707, on the other hand, that of Jos South is in decreasing order trend with ^{226}Ra (0.130) > ^{232}Th (0.077) > ^{40}K (0.018) with the total value of 0.075. Based on the results presented, the soil, water and edible plants in Jos East is moderately contaminated and highly polluted with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated soil for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended limit of CF < 1. Therefore, it can be concluded that the soil, water and plants in the Jos East are moderately contaminated and highly polluted, which calls for serious concern and regulatory control.

Keywords: Potassium; Thorium; Radium; Soil; Water; Edible Plants.

1 Introduction

Naturally occurring radioactive materials (NORMs) refers to all the radionuclides that exist in the environment naturally, which are the primordial radionuclides ^{40}K, ^{232}Th and ^{226}Ra, and their decay products which are present in varying amounts within the earth crust [1]. In most cases, the concentration of NORMs in any substance in the environment is negligible, but disposal of large quantities

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of certain minerals (mining) containing ^{40}K and other radionuclides in the decay series of ^{232}Th and ^{238}U from the earth crust results in the radionuclides concentrations becoming elevated [2]. In the studied area, miners and the members of the public may be exposed to radiation during extraction, transportation and processing of the mineral ores, they may also experience internal exposures from radon, and its short-lived decay products that are airborne or ingestible dust from their surroundings [3]. Reconnaissance survey indicated that there was high incidence of small-scale artisanal tin mining activities in some villages under Jos East and Jos South local governments of Plateau State [4]. The communities surrounding the mines depend on surface water, wells and boreholes as their sources of water in addition to farming of edible plants being their major occupation. Mining in the studied area is carried out by illiterate artisans across all the age range [5]. The crude methods of obtaining the minerals may expose the miners, immediate and adjourning environments to high levels of radionuclides [6]. The miners brought soil and stones rich in tin mineral to the surface for processing, the tailings generated are exposed to wind and the prevailing weather conditions resulting in transportation of the particles containing radionuclides to once uncontaminated areas [7]. The populace relies on untreated ground water (shallow wells and boreholes) for drinking, edible plants as their daily food and other household activities which may contain high radon concentrations [8]. This work may call the attention of the stakeholders to give more attention to the environmental impacts of NORMs and motivate further research into controlling NORMs radiation levels in the country [9]. Therefore, this study will also allow us to analyze how much health hazards the natural radionuclides the tin mining poses to the public and the environment using the indices called contamination factor and pollution load index. The results of this study will benefit academicians, the local community, regulatory authorities, health sector, water treatment agencies, mining industry, environmental protection agency and geological survey sectors. The objective of the present paper is to report the extent of contamination and pollution of soil, water and edible plant by the concentration of ^{40}K, ^{226}Ra and ^{232}Th and associated radiological parameters of Jos East and Jos South artisanal tin mining areas in Plateau State, Nigeria.

2 Materials and Methods

2.1 Materials

The materials that were used in carrying out this research are;

i. Hand trowel
ii. Plastic containers
iii. Hand gloves
iv. polyethylene sampling bottles
v. Geo-positioning System meter (GPS meter)
vi. Masking tape
vii. Permanent marker and Joter
viii. Sodium Iodide Gamma Spectrometry System (NaI (Tl))

2.2 Method

2.2.1 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 [10, 11].

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 [10, 11].

The geographical coordinates of the data points are tabulated in Table 1 and the map of the sample points are shown respectively in Figure. 1.

Table 1: Geographical Coordinates of the Data Points.

Village	Sample Points	Geographical Coordinates	
		East	North
Jos East	PT01	9° 13' 22.8"	10° 0' 57.6"
	PT02	9° 7' 37.2"	10° 0' 7.2"
	PT03	9° 4' 8.4"	9° 59' 24"
	PT04	9° 0' 46.8"	9° 57' 50.4"
	PT05	9° 3'00.00"	9° 57' 3.6"
	PT06	9° 0' 46.8"	9° 55' 51.6"
	PT07	9° 0' 28.8"	9° 53' 45.6"
	PT08	9° 8' 2.4"	9° 55' 8.4"
	PT09	9° 13' 8.4"	9° 53' 20.4"
	PT10	9° 8' 24"	9° 51' 57.6"
	PT11	9° 13' 1.2"	9° 49' 4.8"
	PT12	9° 6' 21.6"	9° 46' 12"
Jos South	PT01	8° 49' 48"	9° 50' 42"
	PT02	8° 52' 33.6"	9° 49' 37.2"

	PT03	8° 49' 4.8"	9° 47' 34.8"
	PT04	8° 55' 55.2"	9° 46' 51.6"
	PT05	8° 48' 21.6"	9° 45' 10.8"
	PT06	8° 52' 48"	9° 44' 24"
	PT07	8° 53' 34.8"	9° 43' 22.8"
	PT08	8° 51'	9° 43' 1.2"
	PT09	8° 44' 2.4"	9° 42' 54"
	PT10	8° 43' 8.4"	9° 40' 19.2"
	PT11	8° 45' 46.8"	9° 40' 1.2"
	PT12	8° 49' 51.6"	9° 39' 32.4"

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

2.2.2. Population Sample

The population of the study include all the notable towns where mining activities takes place within Jos East and Jos South in Plateau State which include 2 Local Governments (Jos East and Jos South) with 41 villages.

2.2.3. Sample Collection

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 the Mining local government of Plateau State. Seventy-Two (72) (36 from each Local Government) samples in all were analyzed in this study. Vegetables' rooted soil samples were taken at 0-20 cm depth.

2.2.4. Soil Sample Collection

Twelve sample of soil from each of the Jos East and Jos South Local Governments 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.

2.2.5. Edible Plant Sample Collection

Twelve edible plant samples were collected from each of the Jos East and Jos South Local Governments 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.

2.2.6. Water Sample Collection

Twelve water samples were collected from streams of each of the Jos East and Jos South Local Governments 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.

2.2.7. Edible Plant Sample Preparation

Only the edible part of each plant sample was used for analysis. The plant samples were washed with ultrapure water three times. After the water had evaporated, the plant samples were weighed, oven-dried at 65 °C for 48 h, weighed again and then crushed into powder and then taken to CERT Zaria for sodium iodide analysis.

2.2.8. Soil Sample Preparation

All soil samples were naturally air-dried until constant weight is reached. The dried soil samples were homogenized with pestle in a mortar, and then passed through standard sieves 0.9 mm, 0.3 mm, and 0.15 mm for analysis of pH, organic matter (OM) and heavy metal contents, respectively. Soil pH were measured using a pH electrode and the ratio of solid: water was 1:2.5. OM contents of soil samples were determined using the loss on ignition method. The soil sample was taken to CERT Zaria for sodium iodide analysis.

2.2.9. Water Sample Preparation

Water samples for heavy metals determination was acidified with two (2) drops of concentrated HNO_3; Samples for Dissolved oxygen determination was fixed with 2ml each of Manganese (II) sulphate solution (winkler A) and Alkali-iodide Azide reagent (Winkler B) per sample. These operations were carried out on the field. All samples were then placed in an ice-chest and taken to the laboratory on the same day. The digested water sample was then taken to CERT Zaria for sodium iodide analysis.

2.2.10. Method of Data Analysis

Concentrations of trace elements was analyzed by the use of NaI (Tl) Spectrometric Analysis available at Centre for Energy Research and Training (CERT) ABU Zaria. The results obtained was used to evaluate the contamination factor and pollution load index.

2.2.10.1. Contamination factor (CF)

The level of contamination by metals is expressed in terms of a contamination factor (CF) according to [11, 12] as:

$$CF = \frac{C_m \text{Sample}}{C_m \text{Background}} \quad 1$$

Where C_m = Concentration of sample from the flooded farm, C_m Background = Concentration of sample from the control area.

If CF < 1: indicates low contamination

1 < CF < 3: indicates moderate contamination.
3 < CF < 6: indicates considerable contamination.
CF > 6: indicates very high contamination.

2.2.2.1. Pollution Load Index (PLI)

Each sample collection spot was evaluated for the extent of metal pollution by employing the method based on the Pollution Load Index (PLI) developed by [11-13]. as follows:

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

where: n is the number of metals studied and CF is the Contamination factor [11-13].

Where C_m = Concentration of sample from the flooded farm, C_m Background = Concentration of sample from the control area.

If PLI < 1: indicates perfection
PLI = 1: indicates pollutants are present but only at baseline levels.
PLI > 1: indicates deterioration of site quality.

3Results and Discussion

3.1 Results

The results for the concentration levels of three radioactive trace elements (^{40}K, ^{226}Ra and ^{232}Th) was determined using NaI (Tl) method. A total of twelve samples each of water, soil and edible plants were randomly collected from Jos East and Jos South 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 contamination factor of radioactive trace elements in soil, contamination factor of radioactive trace elements in water, contamination factor of radioactive trace elements in edible plants and pollution load index of radioactive trace elements in soil, water and edible plants were evaluated the concentration of the trace elements using Equation (1) and Equation (2) and presented in Table 2, Table 3, Table 4 and Table 5 respectively.

Table 2: Contamination Factor of Soil Samples.

T/E	^{40}K	^{226}Ra	^{232}Th	Total	^{40}K	^{226}Ra	^{232}Th	Total
S/P	**Jos East**				**Jos South**			
P01	0.625	0.513	1.097	**0.745**	1.150	0.873	1.060	**1.028**
P02	0.751	0.720	1.060	**0.844**	0.588	0.937	0.700	**0.742**
P03	0.518	0.980	1.051	**0.850**	0.869	0.983	0.820	**0.891**
P04	1.126	0.443	1.034	**0.868**	0.846	0.633	0.643	**0.707**
P05	0.856	0.410	1.091	**0.786**	0.861	1.300	0.749	**0.970**
P06	1.025	0.890	1.006	**0.974**	0.863	0.870	0.611	**0.782**
P07	0.853	0.710	1.046	**0.870**	1.137	0.913	1.089	**1.046**
P08	0.594	0.693	0.963	**0.750**	0.578	0.963	1.160	**0.900**
P09	0.579	1.060	1.009	**0.882**	0.593	0.793	0.700	**0.696**
P10	0.856	1.063	1.131	**1.017**	0.306	0.900	0.603	**0.603**
P11	1.266	0.653	2.006	**1.308**	1.135	0.913	1.860	**1.303**
P12	0.304	0.610	1.246	**0.720**	0.868	0.993	0.974	**0.945**
Total	**0.779**	**0.729**	**1.145**	**0.884**	**0.816**	**0.923**	**0.914**	**0.884**

T/E = Trace Elements; P = Points; S/P = Sample Points; ^{40}K = Potassium-40; ^{226}Ra = Radium-226; ^{232}Th = Thorium-232.

It was observed from Table 2 that the contamination factors of Soil in Jos East have the total values in trend with ^{232}Th (1.145) > ^{40}K (0.779) > ^{226}Ra (0.729).

It was also observed from Table 2 that the contamination factors of Soil in Jos South have the total values in trend with ^{226}Ra (0.914) > ^{232}Th (0.914) > ^{40}K (0.816).

It was observed from Table 3 that the contamination factors of water in Jos East have the total values in trend with ^{232}Th (1.116) > ^{40}K (0.756) > ^{226}Ra (0.696).

It was also observed from Table 3 that the contamination factors of water in Jos South has the total values in trend with ^{232}Th (0.890) > ^{226}Ra (0.889) > ^{40}K (0.791).

Table 4: Contamination Factor of Edible Plant Samples.

T/E	^{40}K	^{226}Ra	^{232}Th	Total	^{40}K	^{226}Ra	^{232}Th	Total
Edible Plants	**Jos East**				**Jos South**			
Zogale	0.575	0.447	1.040	**0.687**	1.100	0.807	1.003	**0.970**
Kuka	0.701	0.653	1.003	**0.786**	0.538	0.870	0.643	**0.684**
Rama	0.476	0.913	0.994	**0.794**	0.819	0.917	0.763	**0.833**
Yateya	1.076	0.377	0.977	**0.810**	0.796	0.567	0.586	**0.650**
Alayyahu	0.806	0.343	1.034	**0.728**	0.811	1.233	0.691	**0.912**
Shuwaka	0.975	0.823	0.949	**0.916**	0.813	0.803	0.554	**0.724**
Yakuwa	0.803	0.643	0.989	**0.812**	1.087	0.847	1.031	**0.988**
Karkashi	0.544	0.627	0.906	**0.692**	0.531	0.897	1.103	**0.843**
Ugu	0.529	0.993	0.951	**0.824**	0.543	0.727	0.643	**0.638**
Rogo	0.806	0.997	1.074	**0.959**	0.256	0.833	0.574	**0.555**
Water Leaf	1.229	0.587	1.949	**1.255**	1.085	0.847	1.803	**1.245**
Kabeji	0.254	0.543	1.189	**0.662**	0.818	0.927	0.917	**0.887**
Total	**0.731**	**0.662**	**1.088**	**0.827**	**0.859**	**0.925**	**0.870**	**0.885**

T/E = Trace Elements; P = Points; ^{40}K = Potassium-40; ^{226}Ra = Radium-226; ^{232}Th = Thorium-232.

Table 5: Pollution Load Index of Soil, Water and Plant Samples.

T/E	^{40}K	^{226}Ra	^{232}Th	Total	^{40}K	^{226}Ra	^{232}Th	Total
Sample Type	**Jos East**				**Jos South**			
Soil	0.023	0.013	3.985	**1.340**	0.043	0.328	0.172	**0.181**
Water	0.015	0.007	2.910	**0.977**	0.028	0.209	0.124	**0.120**
Edible Plants	0.009	0.004	2.107	**0.707**	0.018	0.130	0.077	**0.075**

Where T/E = Trace Elements; ^{40}K = Potassium-40; ^{226}Ra = Radium-226; ^{232}Th = Thorium-232.

It was observed from Table 5 that the pollution load index of radioactive trace elements from soil samples of Jos East is in decreasing order trend with ^{232}Th (3.985) > ^{40}K (0.023) > ^{226}Ra (0.013) with the total value of 1.340, on the other hand, that of Jos South is in decreasing order trend with ^{226}Ra (0.328) > ^{232}Th (0.172) > ^{40}K (0.043) with the total value of 0.181.

It was also observed from Table 5 that the pollution load index of radioactive trace elements from water samples of Jos East is in decreasing order trend with ^{232}Th (2.910) > ^{40}K (0.015) > ^{226}Ra (0.007) with the total value of 0.977, on the other hand, that of Jos South is in decreasing order trend with ^{226}Ra (0.130) > ^{232}Th (0.077) > ^{40}K (0.018) with the total value of 0.120.

It was similarly observed from Table 5 that the pollution load index of radioactive trace elements from edible plant samples of Jos East is in decreasing order trend with ^{232}Th (2.107) > ^{40}K (0.009) > ^{226}Ra (0.004) with the total value of 0.707, on the other hand, that of Jos South is in decreasing order trend with ^{226}Ra (0.130) > ^{232}Th (0.077) > ^{40}K (0.018) with the total value of 0.075.

3.1.1. Comparison of Results with World Health Organization (WHO)

The results presented on Table 2, Table 3, Table 4 and Table 5 were used to plot charts in order to compare the results of the present study with World Health Organization (WHO) as seen in Figure 2, Figure 3, Figure 4 and Figure 5.

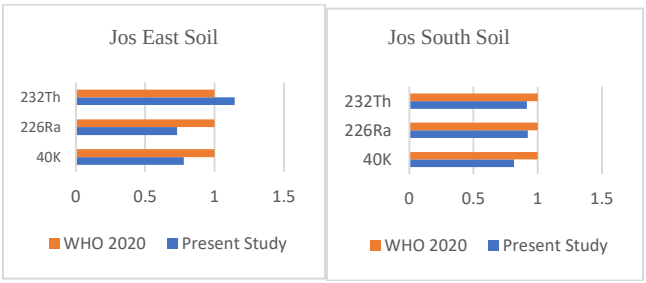

Figure 2: Comparison of Contamination Factor of Soil in Jos East and Jos South with World Health Organization

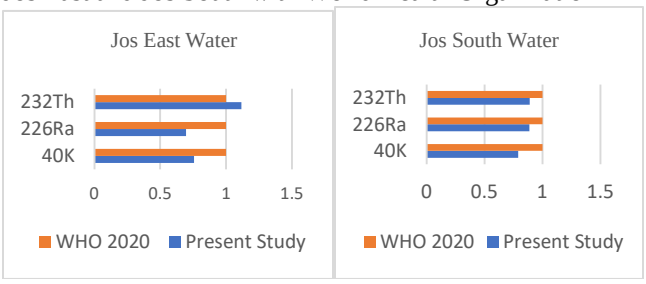

Figure 3: Comparison of Contamination Factor of Water in Jos East and Jos South with World Health Organization

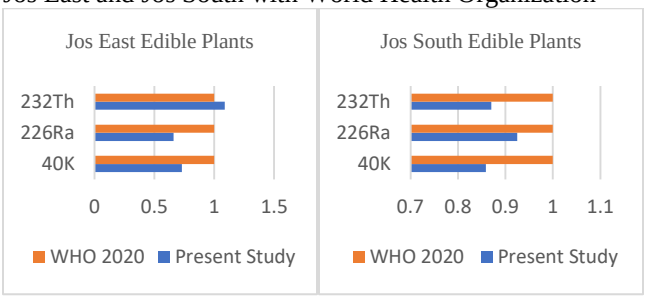

Figure 4: Comparison of Contamination Factor of Edible Plants in Jos East and Jos South with World Health Organization

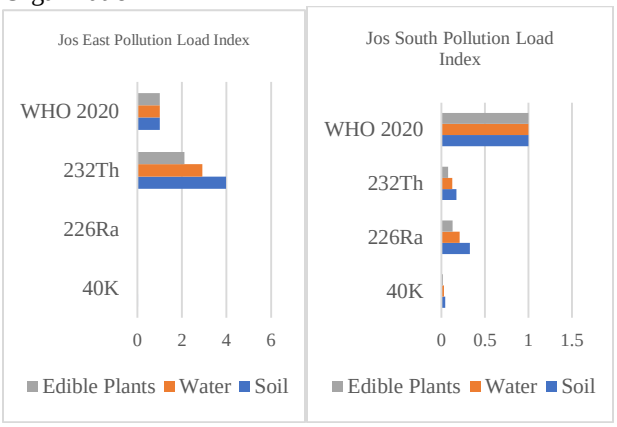

Figure 5: Comparison of Pollution Load Index of Soil, Water and Edible Plants in Jos East and Jos South with World Health Organization

Based on the chart presented in Figure 2, the soil in Jos East is moderately contaminated with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated soil for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended value of CF < 1 as low contamination, 1 < CF < 3 as moderate contamination, 3 < CF < 6 as considerable contamination and CF > 6 as very high contamination.

Based on the chart presented in Figure 3, the water in Jos East is moderately contaminated with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated soil for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended value of CF < 1 as low contamination, 1 < CF < 3 as moderate contamination, 3 < CF < 6 as considerable contamination and CF > 6 as very high contamination.

Based on the chart presented in Figure 4, the edible plants in Jos East is moderately contaminated with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated soil for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended value of CF < 1 as low contamination, 1 < CF < 3 as moderate contamination, 3 < CF < 6 as considerable contamination and CF > 6 as very high contamination.

Based on the chart presented in Figure 5, the soil, water and edible plants in Jos East for Thorium-232 (^{232}Th) indicated deterioration of site quality, but indicated perfection for Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South indicated perfection for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) when compared with the recommended limit of World Health organization of PLI ≤ 1. **[** 14-18**].**

4 Conclusion

Based on the results presented, the soil in Jos East is moderately contaminated with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated soil for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended value of CF < 1 as low contamination, 1 < CF < 3 as moderate contamination, 3 < CF < 6 as considerable contamination and CF > 6 as very high contamination. The water in Jos East is moderately contaminated with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated water for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended value of CF < 1 as low

contamination, 1 < CF < 3 as moderate contamination, 3 < CF < 6 as considerable contamination and CF > 6 as very high contamination. The edible plants in Jos East is moderately contaminated with Thorium-232 (^{232}Th) but less contaminated with Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South have less contaminated edible plants for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) considering the World Health Organization recommended value of CF < 1 as low contamination, 1 < CF < 3 as moderate contamination, 3 < CF < 6 as considerable contamination and CF > 6 as very high contamination. The soil, water and edible plants in Jos East for Thorium-232 (^{232}Th) indicated deterioration of site quality, but indicated perfection for Radium-226 (^{226}Ra) and Potassium-40 (^{40}K). Meanwhile, Jos South indicated perfection for both Thorium-232 (^{232}Th), Radium-226 (^{226}Ra) and Potassium-40 (^{40}K) when compared with the recommended limit of World Health organization of PLI ≤ 1.

Based on the findings of this study, it can be concluded that the soil, water and plants in the study area are moderately contaminated and call for serious concern and regulatory control.

Reference

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