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ASSESSMENT OF RADIOACTIVITY LEVELS AND TRANSFER FACTOR OF NATURAL RADIONUCLIDES AROUND IRON AND STEEL SMELTING COMPANY LOCATED IN FASHINA VILLAGE, ILE-IFE, OSUN STATE, NIGERIA

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Abstract. *This study assessed the radioactivity levels and transfer factor of natural radionuclides around iron and steel smelting company located in Fashina village, Ile-Ife, Osun State, Nigeria. This was with a view to evaluate the exposure rate of the study area, determine the radionuclides present and activity concentration (238U and 232Th and 40K) in the samples and evaluate the soil-to-food transfer ratio of the radionuclides. A portable survey meter with a Global Positioning System (GPS) were used for in-situ investigation and a well-calibrated NaI(Tl) detector system was used for the radioactivity measurement of the samples. A total of 38 samples comprising soil, food and water were collected at the study area (Fashina) and control area (Opa) in Osun state, Nigeria for spectrometry analysis. The soil and food samples were oven dried, pulverized and sieved while water samples were acidified with 10 mL of 11 M HCl per litre to prevent adsorption of radionuclides with the wall of the container. All the samples were then sealed and kept for at least 28 days in radon impermeable cylindrical container so as to reach secular equilibrium. The mean exposure rates in the study area were 0.14 µSv hr-1 and 0.12 µSv hr-1 for the control environment. The mean radioactivity content obtained for 238U, 232Th and 40K were 12.14 ± 4.17 Bq kg-1, 23.23 ± 7.67 Bq kg-1 and 270.14 ± 61.79 Bq kg-1 respectively in soil samples and 8.56 ± 2.80 Bq kg-1, 13.17 ± 4.48 Bq kg-1 and 89.41 ± 24.15 Bq kg-1 respectively in food samples. Similarly it was 7.64 ± 2.95 Bq L-1, 10.04 ± 3.43 Bq L-1 and 69.04 ± 15.49 Bq L-1 respectively for 238U, 232Th and 40K in water samples. The transfer factor from soil to food for 238U, 232Th and 40K were calculated from the activity concentrations of soil and food, while the means were 0.73, 0.61, and 0.39 respectively in the study area.*

Key words: *radioactivity, scrap metal, transfer factor, gamma spectrometry, gamma-scout*

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1. INTRODUCTION

Iron and steel scrap recycling has been of double advantage to Nigeria in terms of its contribution to secondary steel smelting. The scrap is both a raw material source and a waste management method for handling materials that would have otherwise constituted various forms of environmental hazards into useful forms (Owoade et al., 2015; Orosun et al., 2016b).This rapid growth has not been matched with the required strict regulations for environmental and personnel protection. Most of these industries are yet to invest in facilities necessary for improving their production processes. These industries also lack installed control devices (scrap metal radiation) on their production processes as should be required. Radioactively contaminated scrap threatens human health and the environment, as well as economics of the steel industry. If radioactive scrap contaminate the metal supply, it could expose steel workers, the environment to health hazard and potentially be incorporated into consumer products (EPA, 2015). Emissions, which include a range of air pollutants associated with the iron smelter production processes has remained a great concern (Brook et al., 2004; UNECE, 2006; Pope and Dockery, 2006; Zhang et al., 2009; Owoade et al., 2009; Tai et al., 2010; Orosun et al., 2016b). Contamination of the food chain occur as a result of direct deposition of these radionuclides on plant leaves, fruits, tubers, root uptake from contaminated soil or water, and animals ingesting contaminated plants, soil or water(Velasco et al., 2004).

According to IAEA (2004), radioactive scrap metals is defined as metals that comprise radioactively contaminated scrap metal, activated scrap metal and scrap metal with radioactive source(s) or substances contained within it. Radioactive scrap metal can occur in a number of different ways; demolition or decommissioning of industrial facilities processing raw materials containing naturally occurring radionuclides, decommissioning of nuclear installations (such as nuclear power plants or nuclear fuel cycle facilities) and other facilities, loss of sources, demolition of facilities in which radioactive sources have been used and incorporation of old radioactive devices into scrap. The major naturally occurring radionuclide includes the isotopes of uranium and thorium plus their daughters and potassium (IAEA, 1989) which are categorized into primordial, secondary and cosmogenic radionuclides. The pathways by which people are exposed to radiation result in exposure to different parts of the body which are via inhalation, ingestion and direct exposure.

The iron and steel company along Ife-Ibadan road is involved in the recycling of secondary steel metals which release various particles that may be associated with radioactive contaminants. These emissions do not only degrade the soil, vegetation and water, but also increase the rate of occurrence of some common diseases in the populace. This study is therefore necessary to investigate the activities content and transfer factor of natural radionuclides in soil, food and water samples in the residential areas and farms around the iron and steel smelting company.

2. MATERIALS AND METHODS

2.1. The study area

The study area (Fashina) is located in Ife Central Local Government Area of Osun State, Southwest Nigeria on latitude 7^{o} 27”N and 7^{o} 37”N and longitude 4^{o} 22”E and 4^{o} 29”E where the iron and steel company is located. This company, since January 2011, is specializing in the

use of electric arc furnace in the production of iron bar from the scrap collected from various dumping area across the country. The climate of this area is humid tropical characterized by marked wet and dry season typical south-west of Nigeria. The rainy season covers a period of seven to nine months with two high rainfall peaks and a short dry season. The mean annual rainfall recorded from meteorological station in Teaching and Research Farm of Obafemi Awolowo University, Ile–Ife, for this area is about 1196 mm and may be higher due to orographic effect. The dry season is associated with the tropical continental air mass with a severe harmattan wind that carries a lot of dust towards the end of the dry season and this season covers a period of four to six months. The control area (Opa) was located in the same Local Government on latitude 7^o 32"N and 7^o 34"N and longitude 4^o 32"E and 4^o 35"E under the same climatic conditions and about 12km (7 miles) from the study area.

2.2. Sampling

It has been noted that the selection of an adequate number of properly located sampling sites is of great importance in obtaining meaningful data (Fitzgerald, 1969). At the study area, a total number of thirty (30) samples were collected radially around the factory, especially in the cultivated lands while eight (8) samples were collected in Opa area as controls for this case study. The samples comprise of soil, vegetables, fresh cassava, grains and water of different sources such as well, borehole, stream and rain water during and after the factory production time. All water samples were treated with acidified hydrochloric acid (11M) at the rate of 10 mL per litre of sample to avoid adsorption of radionuclides on the walls of the container. Each soil sample and its derived food product were collected by mapping out 1 by 1 m2 at each sampling point. In each sampling square, five core soil samples were taken (four from all the corners and one from the centre) at the depth of 0-30 cm using a hand towel, while its derived food products were also collected within the same sample square point. All the five core soil samples were mixed together to make a composite sample, labelled appropriately after individual placement in polythene bags in order to avoid any mix-up as well as cross contamination. The collected samples were then transported to the laboratory for further processing. The descriptions of the various samples as well as geological survey of the study area are shown in Figure 1 below. Samples received in the laboratory may not be in the proper physical form for analysis. They may require reduction in size, dryness or some form of homogeneity before aliquots can be taken for analysis. The solid samples were oven-dried at 85 oC until a constant weight is attained, then ground and passed through a mesh size of 2 mm while the larger particles were discarded. All the samples were thoroughly washed with dilute HNO3, rinsed with distilled water, labelled and sealed in cylindrical air tight polyvinylchloride containers and stored for 28 days to attain secular equilibrium. Then the gamma spectrometry measurements of the samples were carried out using a well calibrated Sodium Iodide (NaI(TI)) detector at the Centre for Energy Research Development (CERD), Obafemi Awolowo University, Ile-Ife, Osun state, Nigeria.

2.3. Instrumentations

Measurements were carried out with Gamma-Scout radiation detector with Serial Number: 038439 as a dose meter to measure the exposure rate of the environments of each sample in the study area. Garmin Global Positioning System (GPS) device was used to get the location of each sample point. Waypoints which are the co-ordinates of a specific

location were created base on the locations, recorded and stored on the device. The activity concentration of the natural radionuclides in food, water and soil samples were determined using a well calibrated 76 mm x 76 mm NaI(TI) detector shielded from radiation by a 5 cm thick Lead shield located at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. Accurate energy and efficiency calibrations of the gamma spectrometry system were made using a standard source of radionuclides supplied by the International Atomic Energy Agency (IAEA), Vienna, Austria and the isotope products laboratories, Burbank laboratory, California, U.S.A. The system was preset to 18000 seconds (counting time). When this counting time was reached, the information about the radionuclides at different photo peaks were displayed, recorded and stored in the computer. The gamma spectroscopy analysis was carried out by a spectra-analysis program, SAMPO 90, which matched the gamma energies at various energy levels to a library of possible isotopes. An empty container with the same geometry as that of the sample was counted for background. The net background peak was subtracted from the corresponding net peak area for a particular radionuclide. The activities concentrations for the natural radionuclides in the measured samples were evaluated using the following equation;

$$C_{sm} = \frac{A_{sm} - A_o}{P_\gamma M_{sm}\, t\, \varepsilon} \tag{2.1}$$

where, A_{sm} = the net area of the peak in the sample, A_o = the net area of the background peak, t = the counting time in seconds, M_{sm}= mass of the sample, ε = the detection efficiency at the energy line and P_γ = the gamma yield.

The specific activity of the radioisotope is obtained by direct comparison with the same radionuclide in a given standard. The specific radioactivity "Cx" in the sample and the corresponding specific radioactivity "Cs" in the standard are related by

$$C_x = C_s \frac{M_s A_x}{M_x A_s} \tag{2.2}$$

where, M_s= mass of the standard, M_x = mass of the sample, A_s = area of the standard and A_x= area of the sample.

2.4. Transfer factor evaluation from soil to food

The transfer factor (TF) for food which is an index for the accumulation of radionuclides by plants from soil to plants according to IAEA (1982) is defined as:

$$\text{TF food} = \frac{\text{Activity Concentration in Food (Bq/kg)}}{\text{Activity Concentration in Soil (Bq/kg)}} \tag{2.3}$$

There are two main mechanisms for the contamination of vegetation i.e. by root uptake directly and by aerial deposition of fallout radionuclides on plants.

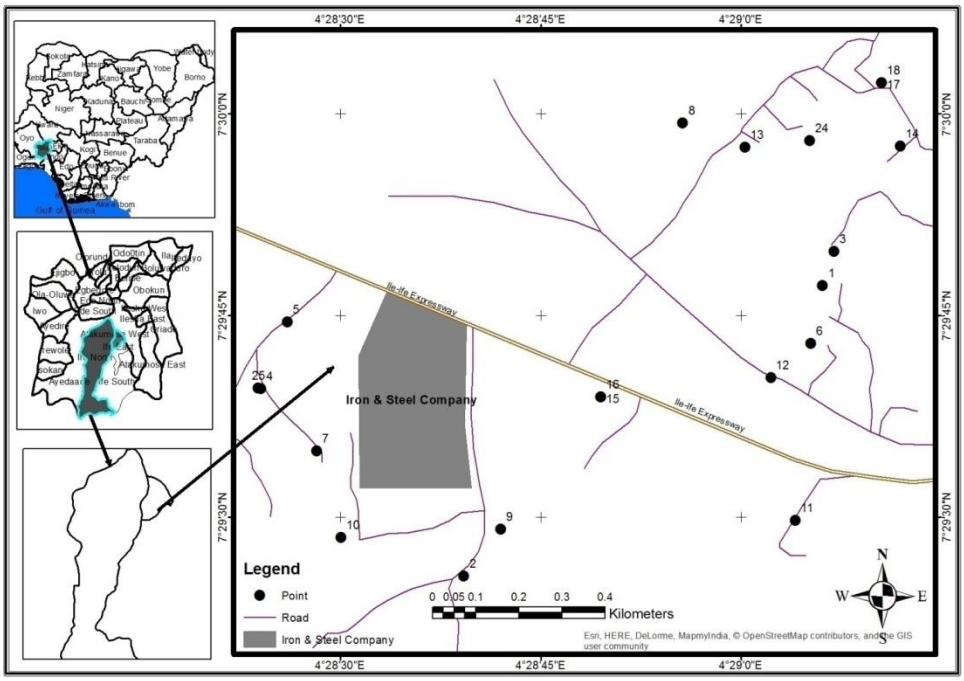

Fig. 1 Samples Locations at Fashina Village.

3. Results And Discussion

3.1 In-situ Measurement

The results of the in-situ survey are presented in Table 1 and illustrated in figure 2 for the study and control environments. The values ranged between 0.11 to 0.16 µSv h-1 with an average of 0.14 µSv h-1 in the study area while the control site have values ranging between 0.10 to 0.14 µSv h-1 with an average value of 0.12 µSv h-1. The average value in study area (Fashina) was higher than the control area; hence this can be as a result of industrial activities present in the study area. Most of the values estimated for the exposure rate in the study area were higher than the recommended limit of 0.11µSv hr-1 (IAEA, 2000). The average value of 0.14 µSv h- in this study is higher than the recommended limit (Larmash, 1983).

Table 1 Radiation level measurement in soil, food and water samples by gamma scout

S/N	Code	Sample points	Exposure rate ($\mu Sv\ hr^{-1}$)	Description
1	VSo1	5	0.15	Water Leaves @ Fashina 1
2	VSo2	6	0.16	Water Leaves @ Fashina 2
3	VSo3	1	0.12	Cassava @ Fashina 1
4	VSo4	2	0.16	Cassava @ Fashina 2
5	VSo5	10	0.16	Cassava for processed Garri @ Fashina
6	VSo6	7	0.14	Jute leaves (Ewedu) @ Fashina 1
7	VSo7	8	0.15	Jute Leaves (Ewedu) @Fashina 2
8	VSo8	3	0.14	African Spinach (Efotete) @ Fashina 1
9	VSo9	4	0.15	African Spinach (Efotete) @ Fashina 2
10	VSo10	9	0.12	Dried Yellow Maize @ Fashina
14	WS01	13	0.12	Borehole Water @ Fashina 1
15	WS02	14	0.14	Borehole Water @ Fashina 2
16	WS03	11	0.11	Stream Water @ Fashina 1
17	WS04	12	0.13	Stream Water @ Fashina 2
18	WS05	24	0.14	Well Water @ Fashina 1
19	WS06	25	0.12	Well Water @ Fashina 2
20	WS07	15	0.14	Rain Water No Production (NP) Fashina 1
21	WS08	17	0.12	Rain Water Production (P) @ Fashina 2
22	WS09	16	0.12	Rain Water Production (P) @ Fashina 1
23	WS010	18	0.12	Rain Water No Production (NP) @ Fashina 2
21	WS08	17	0.12	Rain Water Production (P) @ Fashina 2
22	WS09	16	0.12	Rain Water Production (P) @ Fashina 1
23	WS010	18	0.12	Rain Water No Production (NP) @ Fashina 2
26	Soo1	5	0.15	Sandy soil for water leaves @ Fashina 1
27	Soo2	6	0.16	Sandy soil for water leaves @ Fashina 2
28	Soo3	1	0.12	Sandy soil for cassava plant @ Fashina 1
29	Soo4	2	0.16	Sandy soil for cassava plant @ Fashina 2
30	Soo5	10	0.16	Sandy soil for Cassava processed garri @ Fashina
31	Soo6	7	0.14	Sandy soil for jute leaves (Ewedu) @ Fashina 1
32	Soo7	8	0.15	Sandy soil for jute leaves (Ewedu) @Fashina 2
33	Soo8	3	0.14	Sandy soil for African spinach (Efotete) @ Fashina 1
34	Soo9	4	0.15	Sandy soil for African spinach (Efotete) @ Fashina 2
35	Soo10	9	0.12	Sandy soil for dried yellow maize @ Fashina
	Mean		0.14	
11	VSo11	21	0.14	Water Leaves @ *Opa*
12	VSo12	19	0.10	Dried White Maize @ *Opa*
13	VSo13	20	0.12	Jute leaves (Ewedu) @ *Opa*
24	WS011	22	0.12	Well Water @ *Opa*
25	WS012	23	0.10	Borehole Water @ *Opa*
36	Soo11	21	0.14	Sandy soil for water leaves @ *Opa*
37	Soo12	19	0.10	Sandy soil for dried white maize @ *Opa*
38	Soo13	20	0.12	Sandy soil for jute leaves (Ewedu) @ *Opa*
	Mean		0.12	

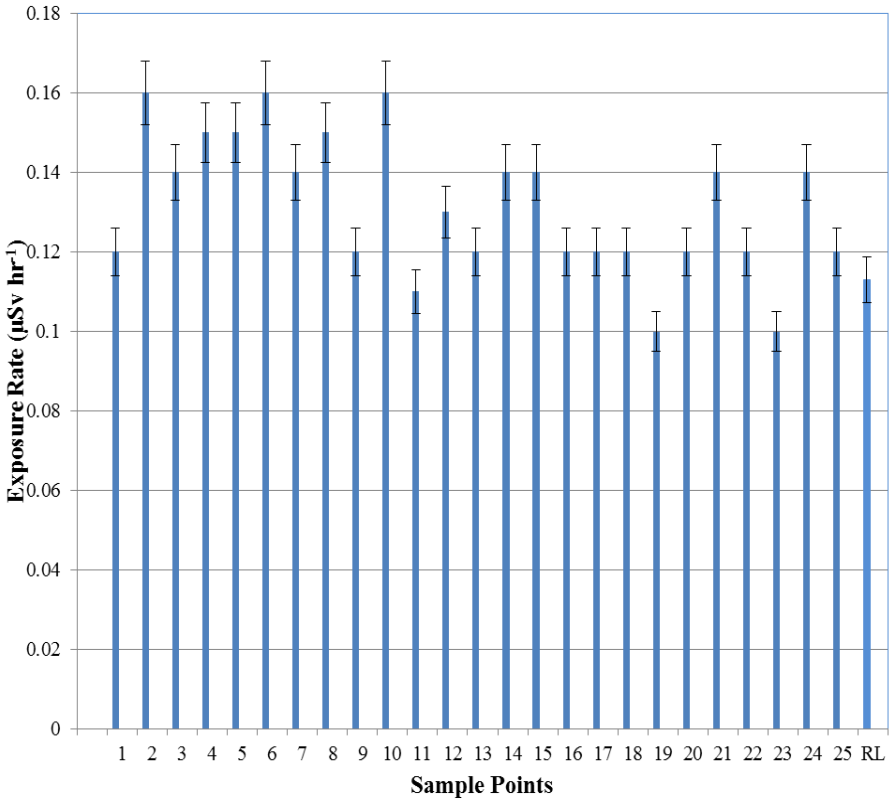

Fig. 2 Exposure rate of the study environment
Key:RL: Recommended limit by IAEA (2000)

3.2 Activity concentrations of natural radionuclides in the samples

3.2.1. Activity concentration in soil

The activity concentrations of the radionuclides in the soil samples collected from the study area and control locations are presented in Table 2 and illustrated in Figure 3 respectively. All radionuclides detected and quantified came from the natural occurring 232Th and 238U decay series, as well as the non series 40K. The specific activity concentration of 40K ranged from 92.85 ± 29.06 to 537.28 ± 99.28 Bq kg-1, with an average of 270.14 ± 61.79 Bq kg-1. The lowest and highest values were obtained in Soo1 and Soo7 locations respectively. Also, specific activity concentration of 232Th ranged from 6.28 ± 2.15 to 41.22 ± 12.60 Bq kg-1, with an average of 23.23 ± 7.67 Bq kg-1, the lowest and highest occurring in locations Soo4 and Soo2 respectively. Similarly, the specific activity concentration of 238U ranged from 7.28 ± 2.10 to 20.18 ± 6.74 Bq kg-1 with an average of 12.14 ± 4.17 Bq kg-1, the lowest and highest occurring in locations Soo5 and Soo1 respectively. In the control area, the specific activity concentration of 40K ranging from 193.86 ± 41.78 to 264.65 ± 51.02 Bq kg-1 with an average of 220.14 ± 42.37 Bq kg-1, with the lowest and highest values in locations Soo13 and Soo12 respectively. Also,

specific activity concentration of 232Th ranged from 18.16 ± 4.58 to 20.31 ± 4.11 Bq kg-1, with an average of 19.13 ± 5.30 Bq kg-1, with the lowest and highest occurring in Soo11 and Soo13 locations respectively. Similarly, the specific activity concentration of 238U ranged from 5.98 ± 1.47 to 11.82 ± 2.11 Bq kg-1 with an average of 8.64 ± 2.46 Bq kg-1, with the lowest and highest occurring in Soo13 and Soo11 locations respectively. The mean concentrations of 40K, 232Th and 238U in the study area are; 270.14 ± 61.79, 23.23 ± 7.67 and 12.14 ± 4.17 Bq kg-1 while in control area they are; 220.35 ± 42.37, 19.38 ± 5.30 and 8.64 ± 2.46 Bq kg-1 respectively. The mean values for the radionuclides concentration in all the samples analyzed were below the International standard limits of 424, 20.5 and 20 Bq kg-1 which have a confidence interval that lies between 417 - 432, 19.2 - 21.9 and 18 - 22 for 40K, 232Th and 238U respectively except 232Th (IAEA, 2000). In some locations, the radionuclides concentrations of 232Th were higher than the International standard limits. This may be as a result of radon gas (220Rn) from the 232Th series originating from the air which might have been deposited on the soil. This thereby increases 232Th concentration (Fasasi et al., 2003; Orosun et al., 2016a). Likewise, the activity concentration of 40K, 232Th and 238U, are averagely lower in Opa environment, this could be as a result of no industrial activity in that environment.

Table 2 Activity concentration of radionuclides in soil samples

S/N	Samples name	Radioactivity content (Bq kg^{-1})		
		^{40}K	^{232}Th	^{238}U
		Study area		
1	Soo1	92.85 ± 29.06	32.01 ± 11.07	20.18 ± 6.74
2	Soo2	352.62 ± 88.34	41.22 ± 12.6	14.62 ± 5.10
3	Soo3	186.62 ± 40.93	19.73 ± 6.47	10.22 ± 3.70
4	Soo4	201.60 ± 51.11	6.28 ± 2.15	12.10 ± 4.36
5	Soo5	429.07 ± 84.63	20.33 ± 5.84	7.28 ± 2.10
6	Soo6	142.62 ± 30.98	21.76 ± 5.46	9.07 ± 2.53
7	Soo7	537.28 ± 99.28	33.26 ± 9.53	8.10 ± 1.84
8	Soo8	253.63 ± 46.47	16.56 ± 4.89	13.52 ± 3.54
9	Soo9	342.84 ± 61.73	20.02 ± 5.63	17.11 ± 6.03
10	Soo10	162.30 ± 35.92	21.15 ± 7.06	9.19 ± 2.55
	Mean	270.14 ± 61.79	23.23 ± 7.67	12.14 ± 4.17
		Control area		
11	Soo11	202.53 ± 32.22	18.16 ± 4.58	11.82 ± 3.11
12	Soo12	264.65 ± 51.02	19.67 ± 6.81	8.11 ± 2.51
13	Soo13	193.86 ± 41.78	20.31 ± 4.11	5.98 ± 1.47
	Mean	220.35 ± 42.37	19.38 ± 5.30	8.64 ± 2.46

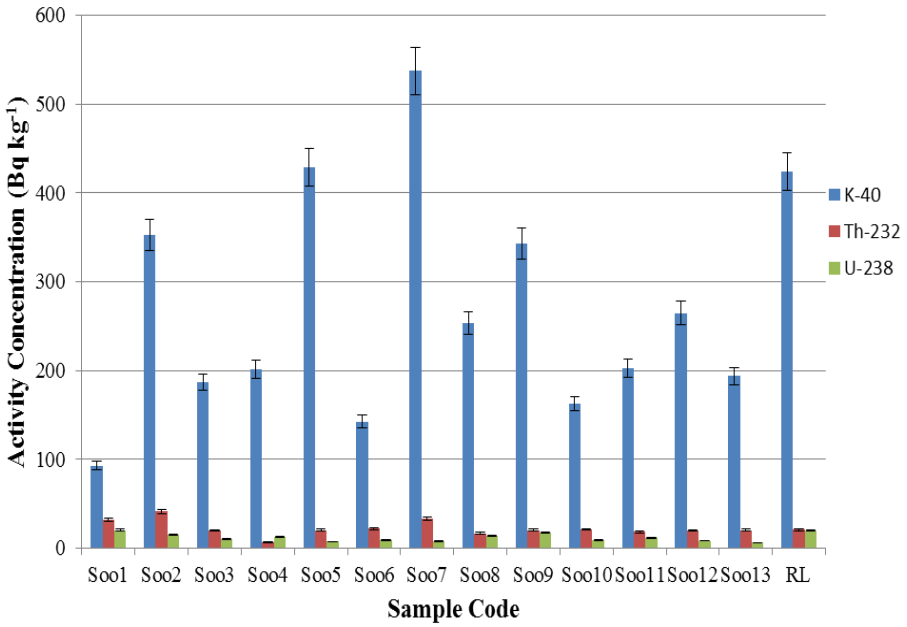

Fig. 3 Activity Concentration in Soil Samples.
Key: RL: Recommended limit by IAEA (2000).

3.2.2. Activity concentration in food samples

The activity concentrations of the radionuclides in the food samples collected from the study area and control locations are presented in Table 3 and illustrated in Figure 4 respectively. All radionuclides detected and quantified are from the natural occurring 232Th and 238U decay series, as well as the non series 40K. For the study area, the specific activity concentration of 40K ranged from 53.27 ± 11.96 to 124.9 ± 29.13 Bq kg-1 with an average of 89.41 ± 24.15 Bq kg-1, the lowest and highest values occurring in jute leaves 1 (Corchorus) and jute leaves 2 (Corchorus) at locations 7 and 8 respectively. Also, the specific activity concentration of 232Th ranged from 5.12 ± 1.15 to 21.15 ± 7.11 Bq kg-1 with an average of 13.17 ± 4.48 Bq kg-1, with the lowest and highest occurring in processed cassava to garri (Manihot esculentun) and jute leaves 2 (Corchorus) in the locations 10 and 8 respectively. Similarly, the specific activity concentration of 238U ranged from 5.27 ± 1.70 to 13.13 ± 4.74 Bq kg-1 with an average of 8.56 ± 2.80 Bq kg-1, with the lowest and highest occurring in dried yellow maize (Zea mays) and jute leaves 1 (Corchorus) in the locations 9 and 7 respectively. For the control area, in the same Table 3, the specific activity concentration of 40K ranging from 46.58 ± 9.38 to 64.34 ± 20.43 Bq kg-1 with an average of 54.36 ± 16.69 Bq kg-1, with the lowest and highest values occurring in water leaves (Talinum triangulae) and jute leaves (Corchorus) locations 21 and 20 respectively. Also, the specific activity concentration of 232Th, ranged from 3.35 ± 2.02 to 9.37 ± 3.26 Bq kg-1, with an average of 6.56 ± 2.52 Bq kg-1, with lowest and highest occurring in jute leaves (Corchorus) and water leaves (Talinum triangulae) locations 20 and 21 respectively. Similarly, the specific activity concentration of 238U ranged from 0 to 10.27 ± 4.26 Bq kg-1 with an average of 8.01 ± 3.45 Bq kg-1, with the lowest and highest

occurring in jute leaves (Corchorus) and water leaves (Talinum triangulae) locations 20 and 21 respectively. The mean concentrations of 40K, 232Th and 238U in the study area are; 89.41 ± 24.15, 13.17 ± 4.48 and 8.56 ± 2.80 Bq kg-1 respectively while in the control area they are; 54.36 ± 16.69, 6.56 ± 2.52 and 8.01 ± 3.45 Bq kg-1 respectively. The mean activity concentration of 40K, 232Th and 238U, are averagely lower in Opa (the control area) environment in comparison with the study area. This could be as a result of no industrial activities in Opa. In this study, it is also noted that the leafy vegetables seem to absorb more radionuclides than other food crops such as maize and roots food product. Potassium recorded the highest overall mean in all the food composites. However, 40K is an essential biological element and its concentration in human tissue is under close metabolic (homeostatic) control (UNSCEAR, 1982). Variation of 40K concentration in dietary composition do not influence significantly the radiation dose received (Makon et al., 2011). The result of this study is in comparison with the values recorded for activity concentration of radionuclides in vegetables, grains and tubers collected in oil and gas areas in the Niger Delta region in Nigeria as reported by Avwiri et al., (2013) and Tchokossa et al., (2013).

Table 3 Activity concentration of radionuclides in food samples

S/N	Sample Names			Radioactivity content (Bq kg^{-1})		
	Sample code	English names	Botanical names	^{40}K	^{232}Th	^{238}U
				Study area		
1	VSo1	Water Leaves @ Fashina 1	*Talinum triangulae*	60.12 ± 21.72	9.82 ± 3.15	9.77 ± 2.83
2	VSo2	Water Leaves @ Fashina 2	*Talinum triangulae*	121.53 ± 30.66	16.72 ± 4.63	6.75 ± 2.66
3	VSo3	Cassava @ Fashina 1	*Manihot esculentun*	78.39 ± 26.73	17.53 ± 5.62	7.22 ± 1.98
4	VSo4	Cassava @ Fashina 2	*Manihot esculentun*	98.66 ± 17.23	13.17 ± 3.84	8.00 ± 2.17
5	VSo5	Cassava Processed garri @ Fashina	*Manihot esculentun*	88.45 ± 12.98	5.12 ± 1.15	10.45 ± 3.77
6	VSo6	Jute Leaves @ Fashina 1 (Ewedu)	*Corchorus*	53.27 ± 11.96	8.16 ± 2.07	13.13 ± 4.74
7	VSo7	Jute Leaves @ Fashina 2 (Ewedu)	*Corchorus*	124.9 ± 29.13	21.15 ± 7.11	11.44 ± 2.88
8	VSo8	African Spinach @ Fashina 1 (Efotete)	*Amaranthus hybridus*	69.93 ± 20.18	14.76 ± 5.24	5.74 ± 1.03
9	VSo9	African Spinach @ Fashina 2 (Efotete)	*Amaranthus hybridus*	111.55 ± 39.31	16.28 ± 6.01	7.86 ± 2.41
10	VSo10	Dried Yellow Maize @ Fashina	*Zea mays*	87.25 ± 17.25	8.99 ± 1.88	5.27 ± 1.70
		Mean		89.41 ± 24.15	13.17 ± 4.48	8.56 ± 2.80
				Control area		
11	VSo11	Water Leaves @ *Opa*	*Talinum triangulae*	46.58 ± 9.38	9.37 ± 3.26	10.27 ± 4.26
12	VSo12	Dried White Maize @ *Opa*	*Zea mays*	52.17 ± 18.17	6.02 ± 2.11	9.42 ± 4.18
13	VSo13	Jute Leaves @ *Opa*	*Corchorus*	64.34 ± 20.43	3.35 ± 2.02	0
		Mean		54.36 ± 16.69	6.56 ± 2.53	8.01 ± 2.45

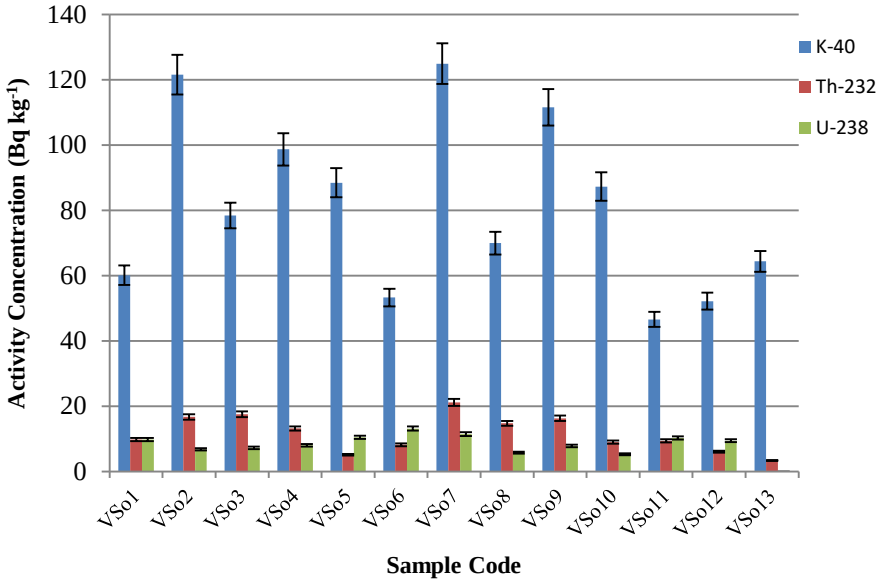

Fig. 4 Activity Concentration in Food Samples

3.2.3. Activity concentration in water samples

The activity concentrations of the radionuclides in the water samples collected from the study and control locations are presented in Table 4 and illustrated in Figure 5. All the radionuclides detected and quantified came from the natural occurring 232Th and 238U decay series, as well as the non series 40K. Generally, the radionuclides concentrations in water samples were a function of geological formation of the area (Strain and Watson, 1979). The specific activity concentration ranged from 65.38 ± 15.67 to 98.62 ± 20.92 Bq L-1 with an average of 82.00 ± 18.48 Bq L-1 for 40K, 4.41 ± 1.34 to 8.12 ± 1.34 Bq L-1 with an average of 6.27 ± 1.84 Bq L-1 for 232Th and 4.15 ± 2.11 to 6.21 ± 2.34 Bq L-1 with an average of 5.18 ± 2.23 Bq L-1for 238U in borehole water. Also it ranged from 46.09 ± 11.28 to 62.91 ± 19.62 Bq L-1 with an average of 54.50 ± 16.00 Bq L-1 for 40K, 9.73 ± 4.02 to 10.11 ± 3.16 Bq L-1 with an average of 9.92 ± 3.62 Bq L-1 for 232Th and from 7.12 ± 3.11 to 8.14 ± 2.21 Bq L-1 with an average of 7.63 ± 2.70 Bq L-1 for 238U in stream water. While in well water, it ranged from 53.82 ±13.27 to 96.58 ± 20.01 Bq L-1 with an average of 75.2 ± 18.90 Bq L-1 for 40K, from 7.78 ± 3.17 to 13.02 ± 2.92 Bq L-1 with an average of 10.4 ± 3.05 Bq L-1 for 232Th and from 5.38 ± 2.27 to 11.02 ± 4.21 Bq L-1 with an average of 8.20 ± 3.38 Bq L-1 for 238U. As for rain water when the factory is not working, the specific activity concentration ranges from 47.08 ± 12.58 to 77.38 ± 9.51 Bq L-1 with an average of 62.23 ± 11.15 Bq L-1 for 40K, from 8.16 ± 3.01 to 13.04 ± 6.02 Bq L-1 with an average of 10.60 ± 4.76 Bq L-1 for 232Th and from 5.28 ± 2.10 to 8.06 ± 3.12 Bq L-1 with an average of 6.67 ± 2.66 Bq L-1 for 238U, while for rain water during the factory working period, it ranged from 55.67 ± 14.34 to 86.89 ± 11.28 Bq L-1 with an average of 71.28 ± 12.90 Bq L-1 for 40K, 9.99 ± 5.01 to 16.05 ± 2.19 Bq L-1 with an average of 13.02 ± 3.87 Bq L-1 for 232Th and from 9.03 ± 4.10 to

12.01 ± 3.41 Bq L-1 with an average of 10.52 ± 3.77 Bq L-1 for 238U. For the control area in the same table, the specific activity of 40K was 69.83 ± 20.14, 11.74 ± 4.18 for 232Th and 11.53 ± 3.87 for 238U in well water, while in borehole water the activity concentration was 61.96 ± 16.20 for 40K, 9.89 ± 2.26 for 232Th and 7.36 ± 3.08 for 238U. From this study, the largest contribution to the overall mean activity in all the various types of water sample came mainly from 40K with the average of 69.04 ± 15.49 Bq L-1 when compared with that 232Th and 238U with the average values of 10.04 ± 3.43 and 7.64 ± 2.95 Bq L-1 respectively. The overall mean radionuclides concentration of 238U was lower than the world average value of 10 Bq L-1, for 232Th was higher than the world average value of 1 Bq L-1 while for 40K no limit is needed as potassium content of the body is under homeostatic control and is not influenced by environmental levels (UNSCEAR, 2000; CNSC, 2011; WHO, 2011 and Orosun et al., 2018). The activity concentration of 40K, 232Th and 238U are averagely lower in Opa environment in comparison with the study area. This could be as a result of lack of industrial activities in the environment. Generally, the concentrations of 232Th and 238U for rain water during the factory working period at the study were higher than other sources of water in the area. This may be as a result of radon gases (222Rn and 220Rn) originating from the air as a result of the iron smelting. Opa environment consist a series of bedrock ridges which may contribute to the activity concentrations in water samples gotten in the area.

Table 4 Activity Concentration of Radionuclides in Water Samples

S/N	Sample Names	Radioactivity content (Bq L^{-1})		
		^{40}K	^{232}Th	^{238}U
		Study area		
1	WSO1	65.38 ± 15.67	4.41 ± 1.34	4.15 ± 2.11
2	WSO2	98.62 ± 20.92	8.12 ± 2.23	6.21 ± 2.34
	Mean	82.00 ± 18.30	6.27 ± 1.79	5.18 ± 2.23
3	WSO3	46.09 ± 11.28	10.11 ± 3.16	8.14 ± 2.21
4	WSO4	62.91 ± 19.62	9.73 ± 4.02	7.12 ± 3.11
	Mean	54.50 ± 15.45	9.92 ± 3.59	7.63 ± 2.66
5	WSO5	96.58 ± 20.01	13.02 ± 2.92	11.02 ± 4.21
6	WSO6	53.82 ± 13.27	7.78 ± 3.17	5.38 ± 2.27
	Mean	75.20 ± 16.64	10.4 ± 3.05	8.20 ± 3.24
7	WSO7	77.38 ± 9.15	13.04 ± 6.02	8.06 ± 3.12
8	WSO8	47.08 ± 12.58	8.16 ± 3.01	5.28 ± 2.10
	Mean	62.23 ± 11.05	10.60 ± 4.52	6.67 ± 2.61
9	WSO9	55.67 ± 14.34	16.05 ± 2.19	12.01 ± 3.41
10	WSO10	86.89 ± 11.28	9.99 ± 5.01	9.03 ± 4.10
	Mean	71.28 ± 12.81	13.02 ± 3.60	10.52 ± 3.76
	Overall mean	69.04 ± 15.29	10.04 ± 3.31	7.64 ± 2.90
		Control area		
11	WSO11	69.83 ± 20.14	11.74 ± 4.18	11.53 ± 3.87
12	WSO12	61.96 ± 16.20	9.89 ± 2.26	7.36 ± 3.08
	Mean	65.90 ± 18.17	10.82 ± 3.22	9.45 ± 3.48

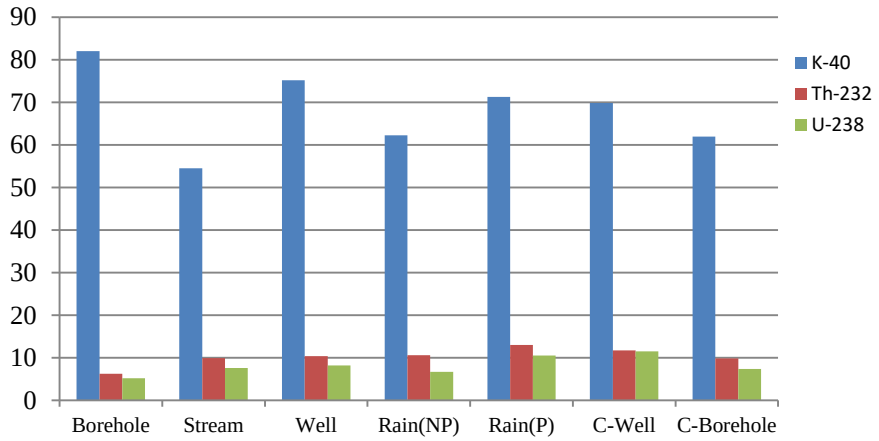

Fig. 5 Activity Concentration in Water Samples

3.3. Transfer factor of the radionuclides

The transfer factors (TF) from soil to food samples in the study and control areas for 238U, 232Th and 40K were obtained using equation 2.3 and presented in Table 5. The TF from soil to plant at the study area ranged from 0.20 to 0.57 with an average of 0.39 for 40K, the highest was recorded in Corchorus and the lowest in Zea mays at location points 7 and 9 respectively. Also, it ranged from 0.26 to 0.84 with an average of 0.61 for 232Th, the highest was in Talinum triangulae and lowest in Corchorus at location points 5 and 7 respectively. For the 238U, it ranged from 0.40 to 0.97 with an average of 0.73, the highest in Amaranthus hybridus and lowest in Talinum triangulae at location points 4 and 5 respectively.

At the control site, the TFs for 40K it ranged between 0.18 to 0.33 with an average of 0.26, the highest in Corchorus and lowest in Talinum triangulae at location points 20 and 21 respectively, while for 232Th it between 0.17 to 0.51 with an average of 0.33 with the highest in Talinum triangulae and lowest in Corchorus at location points 21 and 20 respectively. The TF for 238U were computed for two of the samples (Talinum triangulae and Zea mays) at location points 21 and 19 respectively whose values ranged between 0.80 and 1.27, with average of 1.03. The TF for the other one sample (Corchoru)s at point 20 was not computed because the activity concentration was below detection. This may be as a result of their lower radionuclides absorption from the soil to plant.

It was noted that at study area the mean TFs were very high in comparison with the control area for all the radionuclides, this may due to industrial activities which result in high absorption of radionuclides from the soil and deposit on plants present in such environment. The overalls mean were in the order of 238U >232Th >40K respectively. Care must be taken in some areas where TFs are high as the consumption of such crops or plants have serious health implications, though, the overall assessment of the naturally occurring radionuclides in the soil of the study area does not give a cause for alarm at this stage.

Table 5 Transfer factor soil-food of the radionuclides

S/N	Transfer Code	Transfer Factor		
		^{40}K	^{232}Th	^{238}U
		Study area		
1	Vso1/Soo1	0.24	0.59	0.72
2	Vso2/Soo2	0.36	0.84	0.40
3	Vso3/Soo3	0.48	0.83	0.79
4	Vso4/Soo4	0.53	0.67	0.78
5	Vso5/Soo5	0.44	0.82	0.86
6	Vso6/Soo6	0.57	0.26	0.65
7	Vso7/Soo7	0.35	0.51	0.78
8	Vso8/Soo8	0.49	0.68	0.63
9	Vso9/Soo9	0.21	0.49	0.97
10	Vso10/Soo10	0.20	0.44	0.72
	Mean	0.39	0.61	0.73
		Control area		
11	Vso11/Soo11	0.18	0.48	1.27
12	Vso12/Soo12	0.26	0.33	0.80
13	Vso13/Soo13	0.33	0.17	BDL
	Mean	0.26	0.32	VCN

Keys: BLD: Below Detection Limit.
VNC: Value Not Computed

4. Conclusion and Recommendations

The radionuclides detected in the gamma spectrometry analysis belonged to the naturally-occurring series-decay 238U and 232Th as well as the non-series 40K. 238U and 232Th concentrations in some food and water samples were found to be higher than the recommended limit in the study area. The control area showed a trend of low activity concentrations in all the samples analyzed when compared to the study area. This can be attributed to the industrial activities in the study area. In addition, the transfer factor from soil to plant was found to be higher in 238U and 232Th compare to 40K. This might be attributed to the deposition of airborne radioactive particles of 238U and 232Th series on the surface of plants in the study area.

It is therefore recommended that further research work on the natural occurring radionuclides inside the factory should be done to know the occupational exposure rate of workers.

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PROCENA NIVOA RADIOAKTIVNOSTI I TRANSFER FAKTOR PRIRODNIH RADIONUKLIDA U OKOLINI TOPIONICE GVOŽĐA I ČELIKA U NASELJU FAŠINA, ILE-IFE, DRŽAVA OSUN, NIGERIJA

U studiji je izvršena procena nivoa radioaktivnosti i transfer faktor prirodnih radionuklida u okolini topionice gvožđa i čelika koja se nalazi u mestu Fašina, Ile-Ife, država Osun, u Nigeriji. Cilj ovog rada je procena izloženosti u ispitivanoj oblasti, određivanje prisutnih radionuklida i koncentracija njihovih aktivnosti (238U and 232Th and 40K) u uzorcima, kao i procena transfera radionuklida iz zemljišta u hranu. Za in-situ ispitivanje korišćen je prenosni merač sa sistemom globalnog pozicioniranja (GPS), dok je za merenje radioaktivnosti uzoraka korišćen kalibrisani NaI(Tl) detektorski sistem.Za spektometrijsku analizu korišćeno je 38 uzoraka iz zemljišta, hrane i vode iz ispitivanog području (Fašina) i iz kontrolnog područja (Opa) u državi Osun, Nigerija. Uzorci zemljišta i hrane su sušeni u pećnici, usitnjeni i prosejani dok su uzorci vode zakiseljeni sa 10 mL 11 M HCl po litru kako bi se sprečila adsorpcija radionuklida na zidu posude. Nakon toga, svi uzorci su hermetički zatvoreni i čuvani najmanje 28 dana u nepropusnom radonskom cilindričnom kontejneru kako bi se uspostavila ravnoteža. Srednje stope izloženosti u ispitivanom području su iznosile 0.14 μSv hr-1 i 0.12 μSv hr-1 za kontrolnu sredinu.Srednji nivo radioaktivnosti za 238U, 232Th i 40K bio je 12.14 ± 4.17 Bq kg-1, 23.23 ± 7.67 Bq kg-1 i 270.14 ± 61.79 Bq kg-1 u uzorcima zemljišta respektivno, i 8,56 ± 2,80 Bk kg-1, 13,17 ± 4.48 Bk kg-1 i 89.41 ± 24.15 Bk kg-1 u uzorcima hrane respektivno. Slično tome, u uzorcima vode vrednosti su iznosile 7,64 ± 2,95 Bk L-1, 10,04 ± 3,43 Bk L-1 i 69,04 ± 15,49 Bk L-1 za 238U, 232Th I 40K respektivno. Transfer faktor iz tla u hranu za 238U, 232Th i 40K je izračunat na osnovu koncentracija aktivnosti zemljišta i hrane, dok su srednje vrednosti iznosile 0,73, 0,61 i 0,39 respektivno, u ispitivanoj oblasti.

Ključne reči: *radioaktivnost, otpadni metal, transfer faktor, gama spektrometrija, gamma-scout merač radioaktivnosti*