Pertanika J. Sci. & Technol. 27 (3): 1091 - 1103 (2019)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Health Risk Assessment of Exposure to Radon in Water of Contaminated Kawo and Magiro Communities, Nigeria

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ABSTRACT

Radon concentration levels in water from lead contaminated Kawo and Magiro communities in Rafi Local Government Area were assessed using RAD-7. The mean radon concentration in the areas ranged from 35.02 to 175.10 Bq L^{-1}; while the weighted mean concentration was 87. 55 Bq L^{-1}. The resulting weighted mean annual effective dose in the two communities for stomach were 30.64 μSv y^{-1}, 23.08 μSv y^{-1} and 18.38 μSv y^{-1} for infant, children and adults respectively. The mean and weighted mean concentrations in all the samples exceeded the maximum contaminant level recommended by International Organization. Forty five (45%) of the samples exceeded 100 Bq L^{-1} recommended by EU and WHO.

Keywords: Contaminated, Kawo, Magiro, radon, water

INTRODUCTION

Anthropogenic activities (fertilizer application in irrigation system in agriculture, industrial waste and mining) and geogenic activities (weathering, leaching, eruptions, floodings and erosions) are factors that affect the quality of drinking water (Li et al., 2016). Radionuclides such ^{226}Ra, ^{234}Th, ^{40}K and ^{222}Rn are natural and widely spread in the environment. They exist in various geological formations such as soils, rocks,

ARTICLE INFO

Article history:
Received: 26 April 2018
Accepted: 27 March 2019
Published: 24 July 2019

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ISSN: 0128-7680
e-ISSN: 2231-8526

water, air and building materials in different levels (UNSCEAR, 2000; Varshney et al., 2010). Uranium is the fundamental source of radium and radon its progeny in soil and rock. Escape radon from these dissolved and incorporated in groundwater flows. The largest percentage of the natural radiation exposure receive by members of public comes from a radioactive gas radon (WHO, 2004). Polonium isotopes such as ^{214}Po and ^{218}Po which are decay products of ^{222}Rn are electrically charged emit alpha radiation. They contribute more than 90 % of the total radiation dose received due to radon exposure (Marques et al., 2004; Badhan et al., 2010; Yalcin et al., 2011). Radon dissolved in water can be transported far away from the original place in short time due to factors such as temperature, pressure, pH of water and aquifer lithology (Facchini et al., 1995). Radon (^{222}Rn) is the second risk factor for lung cancer after smoking (EPA, 2003). A fraction of the charged particles when inhaled is deposited in the lung, emitting alpha particles that are absorbed in the nearby lung tissue damaging the pulmonary epithelium and thereby causing lung cancer (EPA, 2003, Quarto et al., 2016). Radon dissolved in water enters human body through (i) the gastro-intestinal track and deliver a whole body radiation dose and (ii) escape from household water and become a source of the indoor radon which can enter the human body through the respiratory tract to deliver the radiation dose (Prasad et al., 2007). Radon atoms emitted from the soil contaminated with mine tailing and chemical such as cyanides used in process of gold ore could exist in water and soil. Mining activities are increasing considerably and exert a great anthropogenic pressure on the environment as seen in Kawo and Magiro communities in Kagara Districts in Rafi Local Government of Niger State Nigeria. According to WHO (2015), Kawo and Magiro communities experienced lethal lead outbreak where 28 children died between April and May 2015 as a result of extremely high levels of lead between 17 to 22 times (171.5-224 µg Pb/dl) in their blood stream after ingested water poisoned by lead.

Therefore, this study was carried out to ascertain the concentrations of radon in water in the areas. The study (i) examines radon concentration in water in the mining areas (ii) assesses the radiation dose to the residents consuming groundwater from the area (iii) estimates the radiological impact of radon to different ICRP age groups. The findings will add values to only dosage of lead pollutant that has been determined in the blood serum of the children since the outbreak lead poison in the water in the areas that had already been identified with distinct pollution sources.

MATERIALS AND METHODS

The studied areas Kawo and Magiro are agricultural and gold-mining communities that are located in Kagara Districts in Rafi Local Government Area in Niger State with coordinates 10^0 11′ 04″N 6^0 15′12″E (Figure 1) in Nigeria. Kawo and Magiro are underlain by the Basement Complex rocks. The Basement complex rock in the areas is typified by the magmatite-gneiss complex among the three lithofacies such as older granites, the low grade schict belt and the magmatite-gneiss complex that characterized Nigerian Basement complex rock (Olarewaju et al., 1996; Olasehinde, 1999). The state experiences both wet and dry seasons with annual rainfall ranging from 1,100mm (North)-1,600mm (South). The maximum temperature in the state is 94^0F. The rainy season ranges between 120-150 days. The fertile soil and hydrology of the areas permit the cultivation of most Nigeria's staple crops. Based on these aforementioned geographical and climatic conditions, agricultural activities form the mainstay of the people's economy (NSCN, 2016). Rafi is bordered in the south by Kaduna River. According to NPC (2006), the population, Time zone, area and density of Rafi are 181,929, WAT (UTC+1), 3,680 km^2 and 71.06/ km^2. The age distribution and population of Rafi according to NPC are 0-9 yrs 67,862; 10-17 yrs 34,467; 19-29 yrs 30,731; 30-39yrs 20,367; 40-49 yrs 12,449; 50-59yrs 6,712; 60-69 yrs 3,657; 70-79 yrs 2,454 and 80+yrs 2,419 (NPC, 2006). This implies infants and children between ages 0-17yrs are 58 % of the total population. The miners in the areas had engaged in the illegal mining activities for about 50 yrs. Therefore, groundwater and all other sources of water in the areas were contaminated by lead during processing of gold ore.

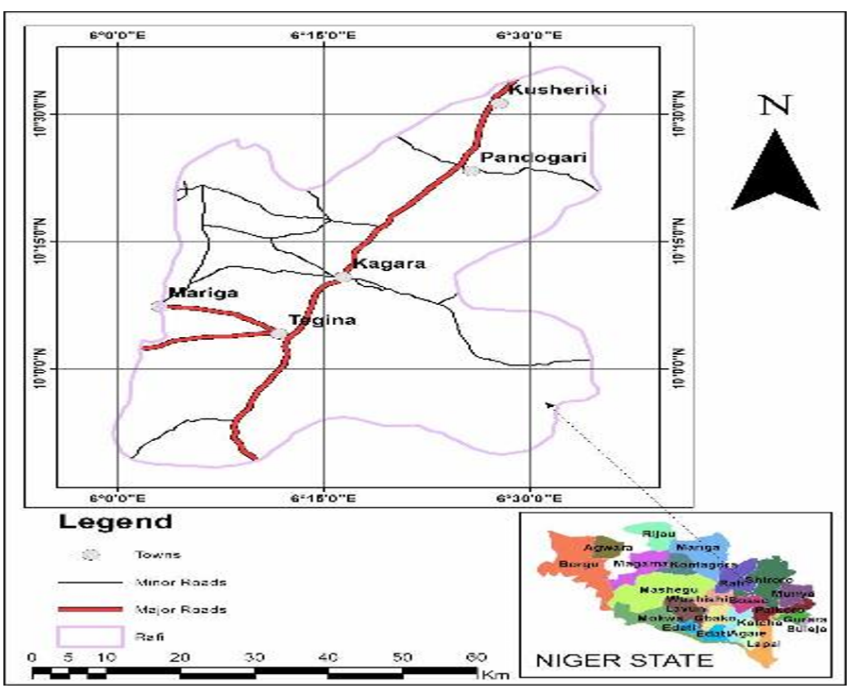

Figure 1. Location map of sampling site in Rafi Local Government, Nigeria.

Sampling

Three samples were taken in twenty sampling points and were analyzed for the presence of dissolved radon. A total of sixty water samples were collected in all; thirty from Kawo and thirty from Magiro. At each point, 250 mL vials designed for radon-in-water activity measurement were filled to edge with the sampled water in various mining pits and then closed immediately to avoid loss of radon by degassing during transportation to the laboratory. Samples were taken to laboratory immediately (WHO, 2004). Radon levels were determined within 6 hrs after sample collection in order to minimize the influence of radioactive decay (Alonso et al., 2015).

Radon Measurement

Radon concentration in water samples was measured using an advanced radon-in-air RAD-7 radon analyzer (Durridge Co., USA) that used alpha spectrometry technique (El-Taher, 2012; Oni et al., 2014). This in turn was connected to RAD H_2O accessory with closed loop aeration concept (Lee & Kim, 2006). The RAD7 radon detector was calibrated at the Durridge radon calibration facility at Billerica Massachusetts, United States. The calibration system was compared to a precision of better than 1 %, with a secondary standard chamber, which was in turn calibrated by comparison with a National Institute of Standards and Technology (NIST) radon standard supplied through the U.S. Environmental Protection Agency. The calibration system's accuracy was also check by making a direct measurement of radon level from activity and emission of a European standard radon source. The calibration achieves a reproducibility of better than ±2 % and an overall calibration accuracy of better than ±5 %. Rad-7 used was maintained between 6- 10 % relative humidity for the efficiency not to decrease due to neutralization of Po ions by water particle (Ravikumar & Somashekar, 2014). In the setup, 250-mL sample bottle was connected to RAD-7 detector via bubbling kit which enables it to degas radon from a water sample into the air in a closed loop (Oni et al., 2014). To ensure the quality control and reliability of the sampling and measurement methods, each sample was assayed for 30 minutes for each run. Five runs were done for each sample. At the end of the run (after the start), the RAD-7 prints out automatically the summary, showing the average radon reading from the five cycles counted.

Radon Health Parameters

Residents of the areas could be exposed to radon through occupational and environmental sources such as illegal gold mining. This results mainly from inhalation of radon during gold ore processing and ingestion of radon in water. In order to quantify the health risk associated with the ingestion and inhalation of radon in the areas, it is imperative to estimate the effective dose that determines how different age groups are exposed to radiation. According to UNSCEAR, (1993) and UNSCEAR, (2000), the following established expressions were used to estimate the annual effective dose from ^{222}Rn ingested and inhaled in water.

$$H_{ing} = C_{water} \times D_{ing} \times L \quad [1]$$

$$H_{inh} = C_{air} \times R \times F \times T \times 9n\,Sv\,(Bq\,hm^{-3})^{-1} \quad [2]$$

From expression 1, H_{ing} is the annual effective dose due to ingestion in $mSv\,y^{-1}$, C_{water} is the radon concentration in water in Bq L^{-1} , D_{ing} is the dose conversion coefficient and L is the annual water intakes by adults, children and infants respectively. The dose conversion coefficients are given as $1x10^{-8}$, $2x10^{-8}$ and $7x10^{-8}$ Sv Bq^{-1} for adults, children and infant respectively (UNSCEAR, 1993). From expression 2, H_{inh} is the annual effective dose due to inhalation in μSv y^{-1}, C_{air} is the radon concentration in Bq L^{-1}, R is air-water concentration ratio given as 10^{-4} (UNSCEAR, 2000), F is the equilibrium factor between radon and its progeny, F is given as 0.4, T is the occupancy factor (7000 hy^{-1}) and $9n\ Sv\ (Bq\ hm^{-3})^{-1}$ is the dose conversion factor. The dose contribution due to ingestion and inhalation to stomach and lung was calculated by multiplying the ingestion and inhalation dose tissue weighting factor for stomach and lung respectively, the tissue weighting factor is 0.12 for both stomach and lung (Eckerman et al., 2013).

RESULTS AND DISCUSSION

The ^{222}Rn concentration in water samples collected from different points in the area was presented in Table 1. It also compiled results of annual effective dose rate to different age groups in μSv y^{-1} and mSv y^{-1} respectively. It was observed that water samples from Kawo and Magiro showed a mean range of activity from 35.02 to 175.10 Bq L^{-1} with weighted average 87.55 Bq L^{-1}. Mean and weighted mean radon concentration in all the samples exceeded the maximum contaminant level (MCL) 11. 1 Bq L^{-1} prescribed by USEPA (1991), while 70 % of the samples exceeded 4 to 40 Bq L^{-1} reference level by UNSCEAR (2008). Forty five (45 %) of the sample exceeded the 100 Bq L^{-1} level recommended by EU (2001) and WHO (2011). This might be due to main boundary trust (MBT) as reported by Kumar et al. (2016) as a result of mining activities and could lead to health risk over long-term exposure.

Table 1

Mean radon activity in water samples from the contaminated areas and annual effective dose rate to different age classification

Sample		R/H %	Radon (BqL^{-1})	AEDR (μSvy^{-1})						AEDR ($mSvy^{-1}$)					
				Age Classification											
				Infant		Children			Adults	Infant		Children			Adults
				1	2	3	4	5	6	1	2	3	4	5	6
				<1yr	1-2yr	2-7yr	7-12yr	12-17yr	>17yr	<1yr	1-2yr	2-7yr	7-12yr	12-17yr	>17yr
1	K_I	6.0	35.02	35.02	45.53	52.53	61.29	105.06	127.82	0.035	0.046	0.053	0.061	0.105	0.128
2	K_2	5.0	70.04	70.04	91.05	105.06	122.57	210.12	255.65	0.070	0.091	0.105	0.123	0.210	0.256
3	K_3	5.0	35.02	35.02	45.53	52.53	61.29	105.06	127.82	0.035	0.046	0.053	0.061	0.105	0.128
4	K_4	5.0	70.04	70.04	91.05	105.06	122.57	210.12	255.65	0.070	0.091	0.105	0.123	0.210	0.256
5	K_5	5.0	70.04	70.04	91.05	105.06	122.57	210.12	255.65	0.070	0.091	0.105	0.123	0.210	0.256
6	K_6	5.0	140.08	140.08	182.10	210.12	245.14	420.24	511.29	0.140	0.182	0.210	0.245	0.420	0.512
7	K_7	5.0	35.02	35.02	45.53	52.53	61.29	105.06	127.82	0.035	0.046	0.053	0.061	0.105	0.128
8	K_8	5.0	140.08	140.08	182.10	210.12	245.14	420.24	511.29	0.140	0.182	0.210	0.245	0.420	0.512
9	K_9	5.0	105.06	105.06	136.58	157.59	183.86	315.18	383.47	0.105	0.137	0.158	0.184	0.315	0.383
10	K_{10}	5.0	175.10	175.10	227.63	262.65	306.43	525.30	639.12	0.175	0.228	0.263	0.306	0.525	0.639
11	M_1	5.0	70.04	70.04	91.05	105.06	122.57	210.12	255.65	0.070	0.091	0.105	0.123	0.210	0.256
12	M_2	5.0	175.10	175.10	227.63	262.65	306.43	525.30	639.12	0.175	0.228	0.263	0.306	0.525	0.639
13	M_3	5.0	105.06	105.06	136.58	157.59	183.86	315.18	383.47	0.105	0.137	0.158	0.184	0.315	0.383
14	M_4	5.0	35.02	35.02	45.53	52.53	61.29	105.06	127.82	0.035	0.046	0.053	0.061	0.105	0.128
15	M_5	6.0	35.02	35.02	45.53	52.53	61.29	105.06	127.82	0.035	0.046	0.053	0.061	0.105	0.128
16	M_6	5.0	70.04	70.04	91.05	105.06	122.57	210.12	255.65	0.070	0.091	0.105	0.123	0.210	0.256
17	M_7	5.0	105.06	105.06	136.58	157.59	183.86	315.18	383.47	0.105	0.137	0.158	0.184	0.315	0.383
18	M_8	5.0	105.06	105.06	136.58	157.59	183.86	315.18	383.47	0.105	0.137	0.158	0.184	0.315	0.383
19	M_9	5.0	140.08	140.08	182.10	210.12	245.14	420.24	511.29	0.140	0.182	0.210	0.245	0.420	0.512
20	M_{10}	5.0	35.02	35.02	45.53	52.53	61.29	105.06	127.82	0.035	0.046	0.053	0.061	0.105	0.128

The weighted mean concentration in this study was almost the same as 88.63 Bq L^{-1} obtained in Islamabad, Pakistan, but less than 207 Bq L^{-1} and 318.20 (maximum) obtained in wells from southern Poland and Sankey India (Ravikumar & Somashekar, 2014) respectively. The radon concentration in 45 % of the samples that exceeded 100 Bq L^{-1} was due to the depth of source, which allowed water to interact with a greater thickness of the aquifer and leading to more radon (Ahmad et al., 2015). Furthermore, the variation of the radon concentration of each water sample may be due to mineral content of the areas.

The annual effective dose rate for different age classifications as classified by ICRP has also been calculated in Table 1. The range of mean annual effective dose rate for age groups 1 (0 to 1yr), 2 (1-2yr), 3 (2-7yr), 4 (7-12yr), 5(12-17yr), 6(> 17yr) ranged from 0.04 to 0.18 mSv y^{-1}, 0.05 to 0.23 mSv y^{-1}, 0.05 to 0.26 mSv y^{-1}, 0.06 to 0.31 mSv y^{-1}, 0.11 to 0.53 mSv y^{-1}, 0.13 to 0.64 mSv y^{-1}, with weighted mean 0.09 mSv y^{-1}, 0.11 mSv y^{-1}, 0.13 mSv y^{-1} respectively for both Kawo and Magiro. Figures 2a, 2b and 3a, 3b show variations in the annual effective dose rate for different age classification. The weighted means dose rate received by all age classifications as classified by ICRP were within 0.1 mSv y^{-1} recommended limit for drinking water and below the UNSCEAR and WHO recommended limit of 1 mSv y^{-1} for public. It was observed that the annual effective dose rate value was increasing with respect to radon activity age and water consumption rates. Annual effective dose rate to different age groups could be arranged in this sequence classification6>5>4>3>2>1.

Radon consumption in water and inhalation in air are basis of radiation dose to internal organs such as stomach and lungs. Therefore, it is imperative to discuss radiation dose received by stomach and lungs as reported in Table 2. Annual effective dose rate values received by stomach were shown in the columns 4, 5, 6 for infant, children and adults. The mean annual effective dose rate for the two communities for stomach varied from 12.26 to 61.29 μSv y^{-1}, 9.19 to 45.96 μSv y^{-1}, 7.36 to 36.77 μSv y^{-1} with weighted mean 30.64 μSv y^{-1}, 23.08 μSv y^{-1} and 18.38 μSv y^{-1} for infant, children and adults respectively. Using the, weighted mean, it was observed that infant and children are 1.67 and 1.26 times that of the adults which could be the reason why they are more vulnerable to illness than adults. Since the areas have been mined for 50 years, dividing cells in infant and children responded faster to radionuclides compared to that of adults.

Table 2

Annual effective dose contribution to lungs and stomach and whole body

Sample	Mean	Ingestion	(μSvy^{-1})	Inhalation	Lungs	Stomach (μSvy^{-1})			Total Effective Dose (μSvy^{-1})				
		(BqL^{-1})	Infant	Children	Adults	(μSvy^{-1})		Infant	Children	Adults	Infant	Children	Adults
1	K_1	35.02	12.26	9.19	7.35	88.25	10.59	1.47	1.10	0.88	12.06	11.69	11.47
2	K_2	70.04	24.51	18.39	14.71	176.50	21.18	2.94	2.21	1.77	24.12	23.39	22.95
3	K_3	35.02	12.26	9.19	7.35	88.25	10.59	1.47	1.10	0.88	12.06	11.69	11.47
4	K_4	70.04	24.51	18.39	14.71	176.50	21.18	2.94	2.21	1.77	24.12	23.39	22.95
5	K_5	70.04	24.51	18.39	14.71	176.50	21.18	2.94	2.21	1.77	24.12	23.39	22.95
6	K_6	140.08	49.03	36.77	29.42	353.00	42.36	5.88	4.41	3.53	48.24	46.77	45.89
7	K_7	35.02	12.26	9.19	7.35	88.25	10.59	1.47	1.10	0.88	12.06	11.69	11.47
8	K_8	140.08	49.03	36.77	29.42	353.00	42.36	5.88	4.41	3.53	48.24	46.77	45.89
9	K_9	105.06	36.77	27.58	22.06	264.75	31.77	4.41	3.31	2.65	36.18	35.08	34.42
10	K_{10}	175.10	61.29	45.96	36.77	441.25	52.95	7.35	5.52	4.41	60.30	58.47	57.36
11	M_1	70.04	24.51	18.39	14.71	176.50	21.18	2.94	2.21	1.77	24.12	23.39	22.95
12	M_2	175.10	61.29	45.96	36.77	441.25	52.95	7.35	5.52	4.41	60.30	58.47	57.36
13	M_3	105.06	36.77	27.58	22.06	264.75	31.77	4.41	3.31	2.65	36.18	35.08	34.42
14	M_4	35.02	12.26	9.19	7.35	88.25	10.59	1.47	1.10	0.88	12.06	11.69	11.47
15	M_5	35.02	12.26	9.19	7.35	88.25	10.59	1.47	1.10	0.88	12.06	11.69	11.47
16	M_6	70.04	24.51	18.39	14.71	176.50	21.18	2.94	2.21	1.77	24.12	23.39	22.95
17	M_7	105.06	36.77	27.58	22.06	264.75	31.77	4.41	3.31	2.65	36.18	35.08	34.42
18	M_8	105.06	36.77	27.58	22.06	264.75	31.77	4.41	3.31	2.65	36.18	35.08	34.42
19	M_9	140.08	49.03	36.77	29.42	353.00	42.36	5.88	4.41	3.53	48.24	46.77	45.89
20	M_{10}	35.02	12.26	9.19	7.35	88.25	10.59	1.47	1.10	0.88	12.06	11.69	11.47

The annual effective dose rate values received by lungs due to inhalation of radon released into the air from water in column 7 varied from 88.25 to 353.00 μSv $y^{-1}$with weighted mean 220.63 μSv y^{-1} in the two communities. Table 2 shows the contribution and effect of dose to lungs and stomach. It was calculated by multiplying the inhaled and ingested doses by a tissue weighing factor 0.12 for both lung and stomach (Eckerman et al., 2013). The annual effective dose rate contribution to lungs ranged from 10.59 to 52.95 μSv y^{-1} with mean value of 26.48 μSv y^{-1} for the two communities. In contrast, the annual effective dose rate contribution to stomach varied from 1.47 to 7.35 μSv y^{-1}, 1.10 to 5.52 μSv y^{-1} and 0.88 to 4.41 μSv y^{-1} with mean value of 3.68, 2.76 and 2.21 μSv y^{-1} for infant, children and adults respectively. The findings revealed that dose contributed to lungs was higher than dose contributed to stomach. The results agreed with that of drinking water in India as reported by Kumar et al. (2017). The estimated effective dose (whole body) due to radon inhalation and ingestion for infant, children and adults ranged from 12.06 to 60.30 μSv y^{-1}, 11.69 to 58.47 μSv y^{-1} and 11.47 to 57.36 μSv y^{-1} with weighted mean 30.15, 29.23 and 28.68 μSv y^{-1} for infant, children and adults respectively. The risk estimate revealed that inhalation of radon accounts for 75 % of the individual risk associated with the used of water in the areas, while the remaining 25 % resulting from the ingestion of radon. The calculated mean of total effective dose values were below 100 μSv y^{-1} recommended by WHO (2004).

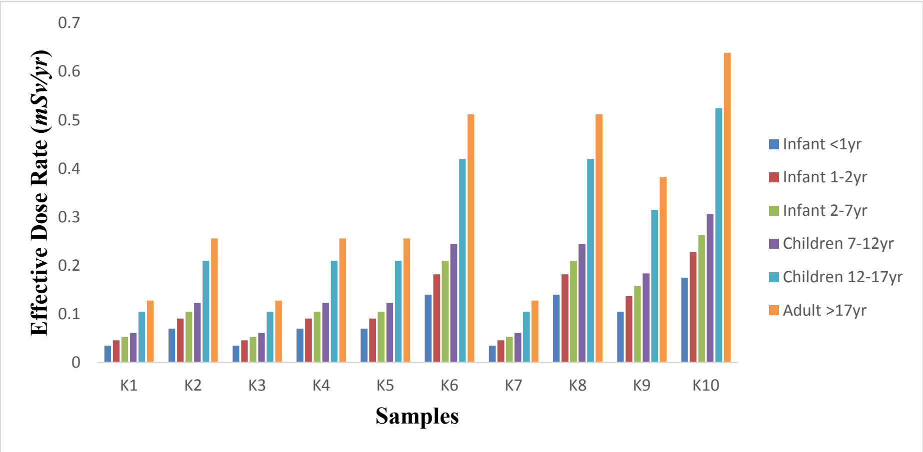

Figure 2a. Variations of effective dose in Kawo for different age classification

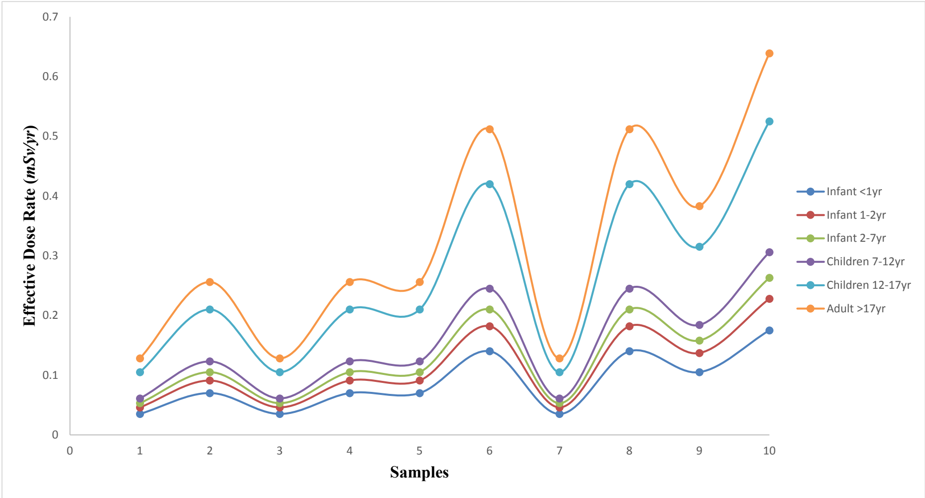

Figure 2b. Spectra of variations of effective dose in Kawo for different age classification

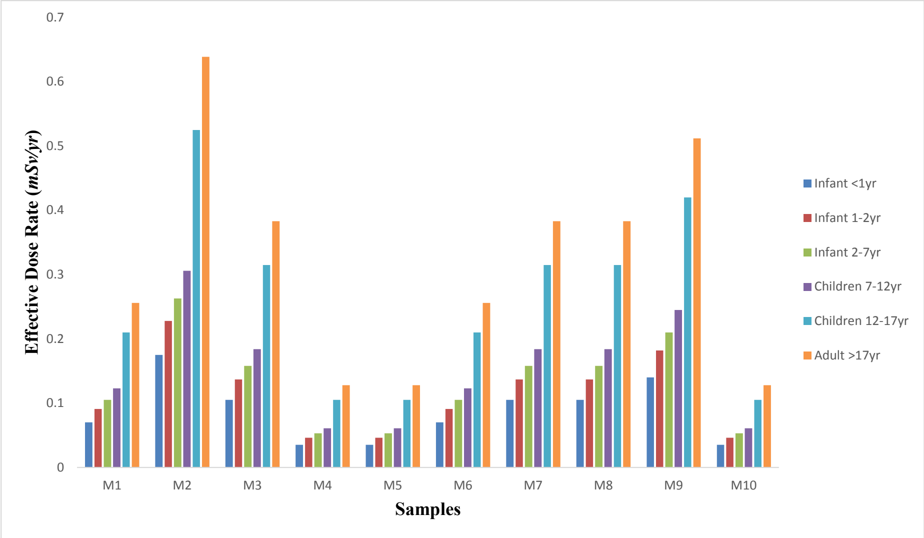

Figure 3a. Variations of effective dose in Magiro for different age classification

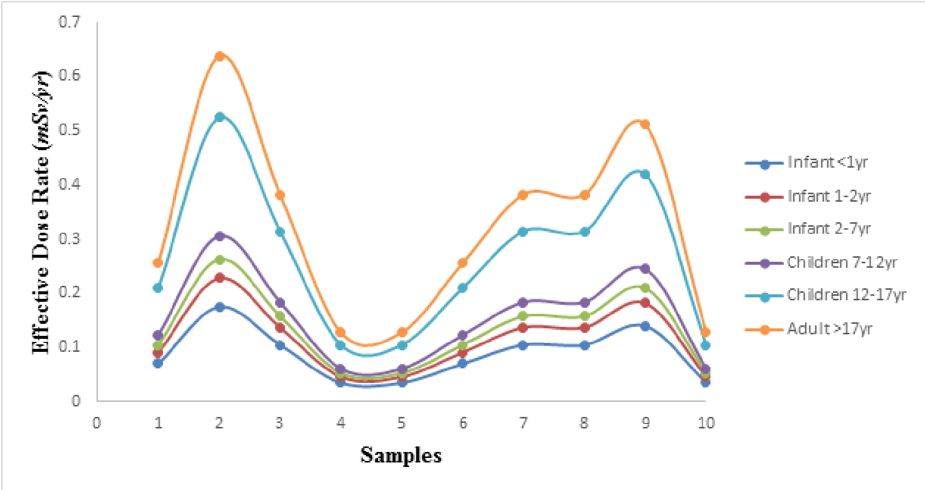

Figure 3b. Spectra of variations of effective dose in Magiro for different age classification

CONCLUSIONS

The observed variations in the radon activity in the water samples may be attributed to the aquifer lithology. The ^{222}Rn concentration in various water samples collected in and around the mined sites in the two communities was comparable with the similar study carried in other parts of the world. Seventy percent (70%) of water samples in the communities recorded ^{222}Rn concentration above the safer limits of 4-40 Bq L^{-1} as per UNSCEAR regulations. Forty five (45%) of the water samples studied recorded values that were higher than the value of Radon concentration in water for human consumption of 100 Bq L^{-1} by EU and WHO. However, two (10%) of the samples in the present study have exceeded the alternative maximum contamination level of 148 Bq L^{-1} suggested by EPA. The results obtained in this study revealed that the doses due to inhalation are higher compared to those from ingestion and contribute to the total effective. As a result of the high mean annual effective dose due to inhalation of radon in some of the sites in the areas, it is therefore recommended that those sites need proper monitoring in order to reduce carcinogenic risks in future.

ACKNOWLEDGMENTS

The authors would like thank Mr. Oso. A, Prof Oni, M.O, Mr. Yinka Ajiboye for the laboratory analysis.

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