Radiological Impact Assessment of Activity Concentrations in Soil Samples of Selected Region of Kwara State Nigeria

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Abstract: ***The soil, being a natural source of radiation consists of ^{238}U, ^{232}Th and ^{40}K radionuclides which at elevated levels can pose a radiological health concern to humans as man is continuously exposed to radiation in the environment. Studies on soil activity levels and radionuclide distributions in selected region of Kwara state were carried out to provide a baseline data on gamma radiation due to soil samples. Following standard procedures, Gamma spectroscopy measurements were performed on a total of sixty four (64) collected soil samples from sixteen (16) selected regions using a high-resolution NaI(Ti) detector. Activity concentrations of ^{238}U and ^{232}Th vary from 1.76±1.5 to 16.25±2.1 below 35Bq/kg world limit at ASD location and 2.98±4.8 to 33.9±3.8 below 30 Bq/kg world limit at TK location. The activity of ^{40}K was found significantly higher than 400 Bq/kg limit in 14 sampling regions. From gamma spectroscopy results, radiological hazard indices were estimated to assess the safety of the residents of the study area. In all locations, external and internal hazard indices revealed values significantly lower than "unity" which is the limit set by International Commission on Radiation Protection (ICRP). The average values for annual effective dose falls below 1 mSv/yr limit set by (ICRP). Excess lifetime cancer risk (ELCR) estimated in TK location only showed value (0.4050 ×10^{-3}) higher than the world average(0.29 × 10^{-3}). Overall, average ELCR (0.2564 ×10^{-3}) value in the study area falls below the world average value. This implies that cancer risk of one member of the public in the study area over a 70 years lifetime is high.***

Keywords: radiation, radiological hazard, excess lifetime cancer risk

1. Introduction

Studies on human exposure to naturally occurring radiations have received scientific attention in the last two decades, as about 80% of human exposure stern from natural radiation sources(17). Naturally occurring radioactive materials are mainly from cosmic and terrestrial sources of which the radioactive isotopes of Potassium-40 and the commonUranium-238 and Thorium-232radionuclides are of terrestrial origin(15, 14). The radiological health impact of radioactive materials in the environment is a subject of growing interest to researchers across the globe, as human beings are inevitably exposed to ionizing radiation. The earth crust, being a natural source of radiation constitutes a low-level gamma radiation that the soil or rock continually delivers to the environment. However, the soil emits varying radioactivity concentrations from one geological formation to the other with high concentrations commonly found in granitic bedrocks(9, 16). Activity concentrations of natural radio nuclides interacting with biological tissues are the major factor in determining the risk of human exposure. Radionuclides in soil get to human body in either or all of absorption, ingestion or inhalation routes of intake as the soil is applicable for agricultural, building construction, ornamental and domestic purposes(12). Previous studies (3, 4, 7, 15, 16,and 10) on soil have revealed radiation hazard indices lower than the maximum permissible limit set by regulatory bodies like International Commission on Radiation Protection (ICRP) and World Health Organization (WHO). However, in a groundwater radioactivity survey in Tanke-Ilorin, Nwankwo, (2013)reported annual effective dose value of 1.30 mSv/y greater than 1 mSv/y tolerable level to the general public set by ICRP(13). Other authors (13, 7, 11) also reported high risk of radiological impact due to soil radionuclide. Geology of Kwara state, notable for minerals such as quartz, kaolin, limestone, marble, feldspar, petroleum, Gold and granite rocks which are natural sources of radiation can have a radiological health risk to the dwellers in regions where concentration is significantly elevated. Therefore, this study aims to evaluate radiological hazard indices due to soil radionuclides.

2. Materials and Method

2.1 Study area

Kwara state is located within the North central region of Nigeria with population density of about 2,365,353 (National Bureau of Statistics, 2016) and has geographical coordinates 8°30'N and 5°00'E. Kwara state is rich in all kinds of mineral resources including, limestone, quartz, and granite. Soil samples were collected in areas with granite rock basement within Ilorin, Omuaran, and Oloru regions. Figure 1 presents the map of Kwara state showing the study areas.

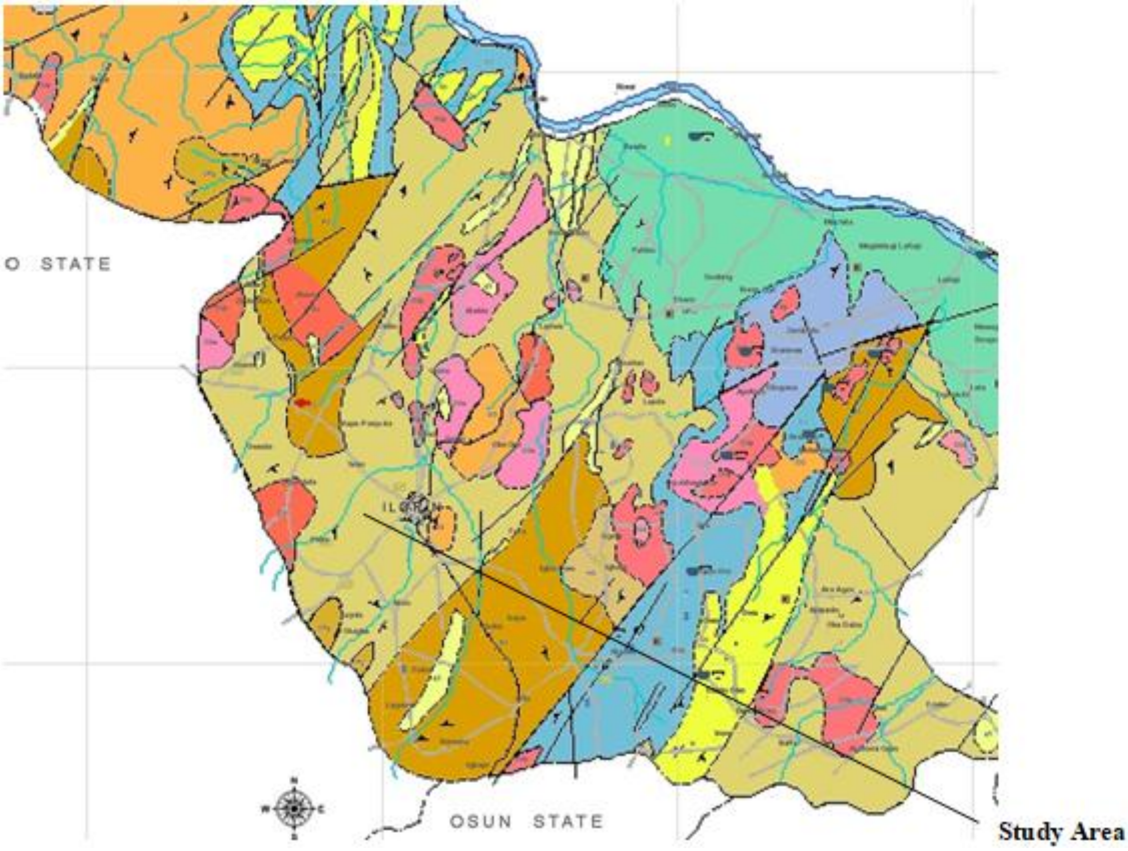

Figure 1: Geological map of Kwara state showing the study area

2.2 Sample Collection ad Preparation

Following a square-grid based (100m ×100m) sampling design, soil were collected in polythene bags at the four corners of each square-grid and sum up to a total of 64 soil samples in 16 residential, industrial and commercial locations within the study area. Care was taken to ensure that only homogenous samples, free from debris and vegetation at 20cm depth were collected. Global Positioning System was used to take coordinates of each location at the centre of the grid. All samples were labeled accordingly for easy identification. In other to attain a completely dried state, samples were oven-dried at 80 degree Celsius for 4 hours and crushed before passing through a 2mm mesh sieve. The powder soil sample (200 grams) were stored in a plastic container and tightly sealed for four weeks to attain a state of secular equilibrium prior to gamma spectrometry[2].

2.3 Activity Concentration Measurement

Radioactivity counting of soil samples were performed for a period of 36000s using a lead-shielded, NaI(TI) detector (Model No. 802 series, Canberra Inc.) connected to a Canberra Series 10 plus Multichannel Analyzer with Model No. 1104 through a preamplifier, with 0.662 MeV energy resolution at 8% efficiency capable of distinguishing gamma ray energies. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K were determined from correspondent γ-peaks of 1.76 MeV (^{214}Bi), 2.615 MeV (^{208}Ti) and 1.460 MeV (^{40}K) respectively. The activity concentrations (C) of soil radionuclides in Bq/kg were estimated after subtracting decay correction using equation (1)[5]

$$C\ (Bq/kg) = \frac{Cn}{\varepsilon P_{\gamma} M_s} \qquad (1)$$

Where C_n is the count rate under the correspondent peak, ε is the detector efficiency at each energy of γ-ray, P_{γ} is the absolute transition probability of γ-ray and M_s is the mass of the sample.

2.4 Evaluation of Radiological Hazard Indices

Radiological indices are very useful in determining human exposure risk as elevated ^{238}U, ^{232}Th and ^{40}K concentrations could pose a biological effect to irradiated individual. Therefore, soil radionuclide concentrations were evaluated in terms of Radium Equivalent (Ra_{eq}), Absorbed Dose Rate (D), External Hazard Index ($H_{ext.}$), Internal Hazard Index (H_{in}),Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR).

2.4.1 Radium Equivalent Activity Index

Equation (2) represents radium equivalent index which was used to obtain the weighted sum of ^{238}U, ^{232}Th and ^{40}K activity concentrations in soil samples. It is based on the assumption that 370 Bq/kg of^{238}U, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma radiation dose rates[2, 13].

$$Raeq = C_U + 1.43C_{Th} + 0.077C_K \qquad (2)$$

Where C_U, C_{Th}, C_K are the specific activity concentrations in Bq/kg of ^{238}U, ^{232}Th and ^{40}K respectively. The maximum value of Ra_{eq} in soil samples is required to be less than 370 Bq/kg in order to keep the external dose below 1mSv/y limit set by International Commission on Radiological Protection (ICRP) [2, 13].

2.4.2 Absorbed Dose Rate

The gamma absorbed dose rate (D) in the outdoor air from distribution of soil radionuclides (^{238}U, $^{232}Th$and ^{40}K) at 1 meter above sea level was estimated using the expression in equation (3)[2, 15].

$$D\ (nGy/h) = 0.462C_U + 0.604\ C_{Th} + 0.042\ C_K \quad (3)$$

Where 0.462, 0.604 and 0.042 represent the dose factors for C_U, C_{Th} and C_K which are concentrations in Bq/kg for uranium, thorium and potassium respectively.

2.4.3 External Hazard Index and Internal Hazard Index

External radiation field are generated from natural radionuclides to which humans are exposed. Therefore, external hazard index (H_{ext}) was evaluated in order to assess radiological risk of soil samples while internal hazard index (H_{in}) was useful to quantify internal hazard due to soil radon. Expressions in (4) and (5) were utilized to calculate H_{ext} and H_{in} respectively which are expected to be less than unity to give a safe level of radiation[12, 13 and15].

$$H_{ext} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (4)$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (5)$$

2.4.4 Annual Effective Dose

The Annual Effective Dose (AED) in mSv/y received by individual member of the public was estimated using 0.7×10^{-6}Sv/Gy as conversion factor (CF) to convert the absorbed dose rate (D) in nGy/h to human effective dose equivalent with outdoor and indoor occupancy factors (OF) of 0.2 and 0.8 respectively according to [18]using equations (6) and (7)[8].

$$AED_{outdoor} = D \times CF \times OF_{out} \quad (6)$$

$$AED_{indoor} = D \times CF \times OF_{in} \quad (7)$$

Since humans are assumed to spend 20% of their time outside and 80% indoors, OF_{out} equals (0.2 × 24 hrs × 365 days) and OF_{in} equals (0.8 × 24 hrs × 365 days). Meanwhile, a dose limit of 1mSv/y has been set by ICRP for individual member of the public [18].

2.4.5 Excess Lifetime Cancer Risk

The Excess Lifetime Cancer Risk (ELCR) was estimated according to[5] using equation (8). Where, $AED_{outdoor}$ represents outdoor annual equivalent dose, DL is the average duration of life (70 years) and RF is the Risk Factor (Sv^{-1}). For stochastic effects, ICRP uses RF value of 0.05 for public [17]. Average value of ELCR is given as 0.29×10^{-3}[18].

$$ELCR = AED_{outdoor} \times DL \times RF \quad (8)$$

3. Results and Discussion

The mean concentrations of ^{238}U, ^{232}Th and^{40}K in soil samples with Ra_{eq} from each location are presented in table 1. Activity concentrations in Bq/kg of ^{238}U and ^{232}Th in all locations range from 1.76±1.5to 16.25±2.1 at ASD and 2.98±4.8 to 33.9±3.8 at TK respectively with average values6.87±2.3 for $^{238}U$and 11.84±6.1 for ^{232}Th. As expected, activity concentration of^{40}K in all locations is much higher than ^{238}U and ^{232}Th concentrations and range from 332.24±2.7 Bq/kg at ASD to 1580.68±6.5 Bq/kg at TK with average value 902.17±7.1 Bq/kg. It was observed that^{238}U and ^{232}Thhave average values less than the world average values of 35Bq/kg and 30Bq/kg respectively[18] and that reported by[1] for southwestern Nigeria while ^{40}K shows average value significantly higher than the world limit of 400 Bq/kg in 14 sampling regions. Even though both TK and ASD locations have granite rock basement, increased activity concentration was observed in TK as against ASD. The high radionuclide concentrations in location TK could be associated to anthropogenic activities as the area is densely populated and notable for commercial and industrial activities. On the other hand, ASD location is a residential area and sparsely populated where little or no anthropogenic activities could enhance radionuclide concentrations [13]. Also, mean values of Ra_{eq}(31.6000 to 186.4300) Bq/kg in all locations are lower than the maximum tolerable level of 370 Bq/kg set by the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). Average values of absorbed dose rate (48.2150) nGy/hr, external hazard index (0.2766), internal hazard index (0.2694), annual effective dose (0.2368 indoor and 0.3074 outdoor) mSv/y and excess lifetime cancer risk in all locations other than TK (0.4050×10^{-3}) were found lower than the limits set by radiation protection agencies as presented in table 2. However, locations QP (0.2636×10^{-3}), WS (0.2562×10^{-3}), and OK (0.2149×10^{-3}) showed values very close to world limit. Overall average value (0.2564×10^{-3}) of ELCR falls below the world average (0.29×10^{-3}) recommended by [18].The present results were compared with previous studies in table 3and these results agree with the findings of [2, 6, 7, 8 and 14] indicating a safe level of exposure due to soil radionuclides but contrary to [19] which record higher values above ICRP limits. Figures 2 and 3 are the histogram representations of the results.

Table 1: Mean Concentration of Soil Radionuclides with Radium Equivalence

Name of Location (Code)	Geographical Coordinates Lat. / Lon.	Soil Radionuclide Concentration in $BqKg^{-1}$			
		^{238}U	^{232}Th	^{40}K	Ra_{eq}
Queens Park (QP)	N8°47'76'' / E4°53'55''	7.93± 7.6	9.3 ± 4.3	1241.45 ± 66.3	116.73
Sango (WS)	N8°31'37''/ E4°35'68''	5.18 ± 3.9	10.48 ± 3.0	1212.92± 4.1	113.56
Okelele (OK)	N8°43'65''/ E4°24'15''	9.68 ± 7.8	11.97 ± 3.6	912.75 ± 3.2	97.18
Tanke (TK)	N8°28'11'' / E4°39'82''	16.25± 2.1	33.9 ± 3.8	1580.68± 6.5	186.43
AsaDam (ASD)	N8°26'97''/ E4°32'45''	1.76 ±1.5	2.98 ± 4.8	332.24 ± 2.7	31.60
Wara (WR)	N8°27.68''/ E4°29'26''	2.73 ± 5.1	10.3 ± 1.4	387.38 ± 1.4	47.29
Eiyenkorin (EYK)	N8°23'68''/ E4°27'87''	3.38 ± 5.7	11.45 ± 6.8	1011.48± 2.9	97.64
Malete (MLT)	N8°70'81''/ E4°47'40''	3.45 ± 6.6	11.2 ± 2.3	1166.95± 2.7	109.45
Ote (OT)	N8°19'35''/ E4°23'32''	12.52± 2.1	12.73±0.32	659.92±34.5	81.53

Yakuba (YK)	N8°33’45’’/ E4°37’44’’	5.78 ± 4.5	8.58 ± 3.56	1301.75± 4.3	118.28
Omuaran (OMRA1)	N8°83’67’’/ E5°10’174’’	13.58± 4.3	19.13 ± 5.6	1077.50± 31.3	123.90
Omuaran (OMRA2)	N8°81’47’’/ E5°10’53’’	5.95 ± 4.5	12.15 ± 3.6	1057.00 ± 41.3	104.71
Omuaran (OMRA3)	N8°81’47’’/ E5°10’53’’	6.45 ± 7.1	14.38 ± 5.3	530.50 ± 46.7	67.86
Oloru (OLRA1)	N8°40’54’’/ E4°49’11’’	7.25 ± 4.2	9.53 ± 2.3	529.25± 35.8	61.63
Oloru (OLRA2)	N8°40’52’’/ E4°38’10’’	4.68 ± 9.3	4.98 ± 3.8	799.22 ± 41.9	73.34
Oloru (OLRA3)	N8°40’52’’/ E4°38’23’’	3.45 ± 7.6	6.38 ± 6.8	633.75± 22.3	61.37
Max.		16.25	33.9	1580.68	186.43
Min.	Study Area	1.76	2.98	332.24	31.60
Ave.		6.87	11.84	902.17	98.09

Table 2: Calculated Radiological Hazard Indices

Name of Location (Code)	Ra_{eq}(Bq/kg)	D (nGy/hr)	AED_{in}(mSv/y)	AED_{out}(mSv/y)	$H_{ext.}$	H_{in}	ELCR (× 10^{-3})
Queens Park (QP)	116.73	61.4218	0.3013	0.0753	0.3153	0.3368	0.2636
Sango (WS)	113.56	59.6657	0.2927	0.0732	0.3064	0.3206	0.2562
Okelele (OK)	97.18	50.0375	0.2455	0.0614	0.2621	0.2883	0.2149
Tanke (TK)	186.43	94.3717	0.4629	0.1157	0.4642	0.5473	0.4050
AsaDam (ASD)	31.60	16.5671	0.08125	0.0203	0.0853	0.0900	0.0711
Wara (WR)	47.29	23.7524	0.1165	0.02913	0.1276	0.1351	0.1019
Eiyenkorin (EYK)	97.64	50.9293	0.2498	0.0625	0.2636	0.2727	0.2188
Malete (MLT)	109.45	57.3706	0.2814	0.0704	0.2951	0.3045	0.2464
Ote (OT)	81.53	41.1898	0.2020	0.0505	0.2201	0.2540	0.1768
Yakuba (YK)	118.28	62.5262	0.3067	0.0767	0.3193	0.3350	0.2685
Omuaran (OMRA1)	123.90	63.0834	0.3094	0.0774	0.3345	0.3712	0.2709
Omuaran (OMRA2)	104.71	54.4815	0.2673	0.0668	0.2827	0.2988	0.2338
Omuaran (OMRA3)	67.86	33.9464	0.1665	0.0416	0.1832	0.2006	0.1456
Oloru (OLRA1)	61.63	31.3341	0.1537	0.0384	0.1664	0.1860	0.1344
Oloru (OLRA2)	73.34	38.7373	0.1900	0.0475	0.1980	0.2107	0.1663
Oloru (OLRA3)	61.37	32.0649	0.1573	0.0393	0.1657	0.1751	0.1376
Max.	186.43	94.3717	0.4629	0.1157	0.4642	0.5473	0.4050
Min.	31.60	16.5671	0.08125	0.0203	0.0853	0.0900	0.0711
Ave.	98.09	48.2150	0.2368	0.3074	0.2766	0.2694	0.2564
WHO	-	56	0.1	0.1	1	1	0.29×10^{-4}
ICRP	-	60	1	1	1	1	-
(UNSCEAR, 2008)	370	-	-	-	-	-	0.29

Table 3: Comparison of average values of radiological indices for soil radionuclide obtained in the present study with other location in Nigeria

Reference	Location	Ra_{eq} (Bq/kg)	D (nGy/hr)	AED_{out} (mSv/y)	H_{ext}	H_{in}	ELCR (× 10^{-3}
Present study	Kwara	98.09	48.2150	0.3074	0.2766	0.2694	0.2564
Ibikunle et al., 2019	Southwest	210.57	95.40	0.117	0.57	0.71	4.1000
Fredrick et al., 2017	Ebonyi	-	-	0.24	-	-	0.8470
Ajiboye et al.,2016	Ekiti	95.99	45.18	-	0.26	0.32	-
Orosun et al., 2016	Kwara	114.50	59.45	72.91	0.31	0.35	0.2552
WHO / UNSCEAR		- / -	54 / -	0.1 / 1	0.1 / 1	0.1 / 1	0.29×10^{-4}/ 0.29×10^{-3}

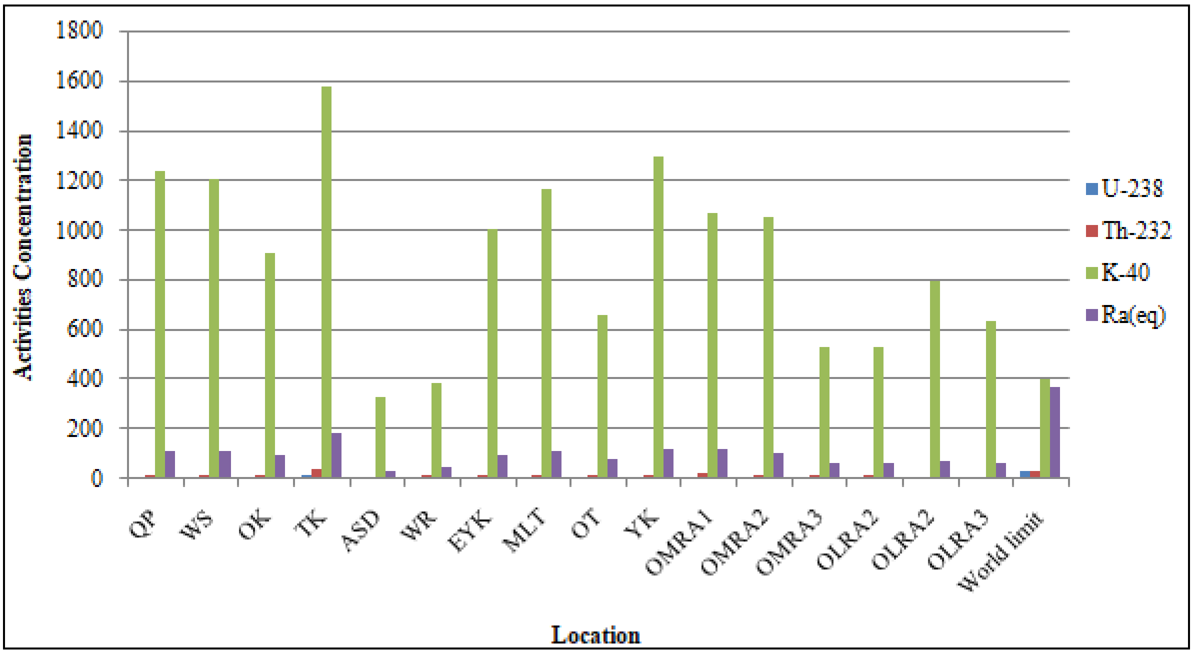

Figure 2: Distribution of soil radionuclide in Kwara state, Nigeria.

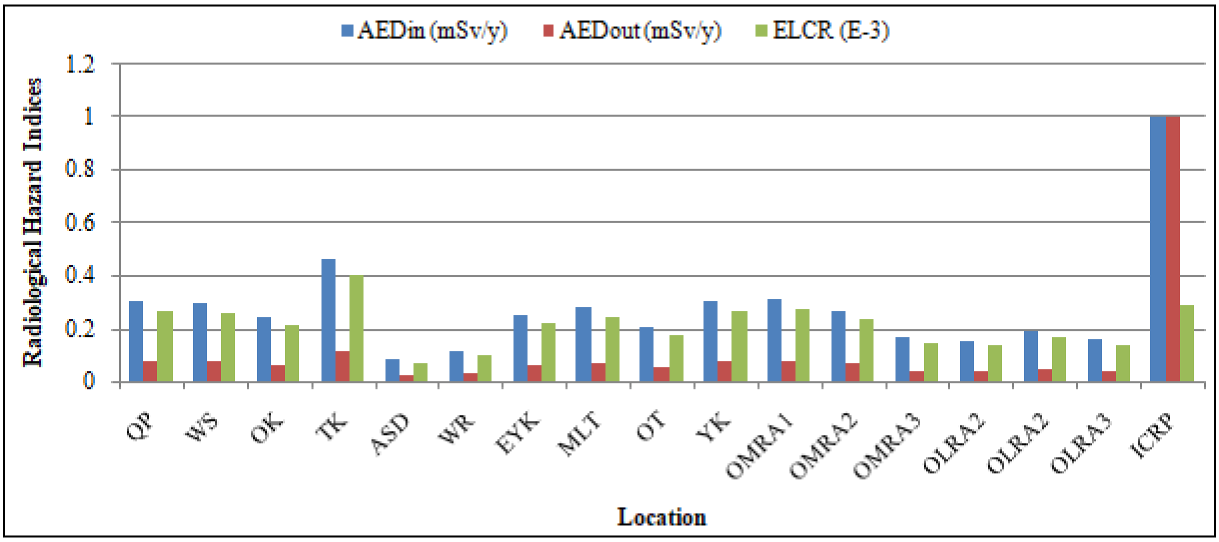

Figure 3: Annual effective dose and excess lifetime cancer risk due to soil activities in Kwara state, Nigeria.

4. Conclusion

Natural radionuclides, ^{238}U, ^{232}Th and ^{40}K concentrations directly determine the degree of radiation exposure of the general public. From measured activity concentrations, only ^{40}K with 902.17 Bq/kg showed a significant value higher than 400 Bq/kg world limit. The values of estimated radiological hazard indices fall below the ICRP limits in all locations except for ELCR inTK (0.4050 × 10^{-3}) which showed a higher value than 0.29 × 10^{-3} world average limit. Overall, the average ELCR (0.2564 × 10^{-3}) value in the study area is below the world average limit. It can be concluded that there is low probability of an individual who will spend at least 70 years within the study area to develop cancer. Therefore, from radiological point of view, soil in the study area is deemed acceptable for diverse purposes. However, further study especially in QP, WS, OK and TK area is recommended to keep exposure as low as achievable. This study will provide baseline data for future investigations.

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