Volume 19, No 3 | International Journal of Radiation Research, July 2021

Background radiation level measurement using hand held dosimeter and gamma spectrometry in Ijebu-Ife, Ogun State Nigeria

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► ***Original article***

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Revised: April 2020
Accepted: June 2020

Int. J. Radiat. Res., July 2021; 19(3): 591-598

DOI: 10.29252/ijrr.19.2.591

ABSTRACT

Background: The knowledge of distribution of radionuclides and background radiation levels in the environment is important for assessing the effects of radiation exposure due to both terrestrial and extra-terrestrial sources. ***Materials and Method:*** In-situ gamma dose survey and gamma spectrometry was employed to investigate background radiation levels in Ijebu-Ife. ***Results:*** In-situ gamma dose rates vary from 0.02 to 0.10 µSv/hr with mean value of 0.05 µSv/hr which is less than 0.133 µSv/hr, recommended by the ICRP. The resulting annual effective dose was below 1 mSv/yr maximum permissible limit for the general public set by the UNSCEAR, 2000. The activity concentrations of the three naturally occurring radionuclides in soils ranged from Below Detection Level (BDL) to 320.11 ± 28.53, 9.11 ± 1.65 and 8.55 ± 0.95 Bq/kg with mean values of 119.05 ± 11.24 Bq/kg, 4.44 ± 1.01 Bq/kg and 4.55 ± 0.62 Bq/kg respectively which are lower than the average values of 400, 35, and 30 Bq/kg recommended by the UNSCEAR, 2000 for ^{40}K, ^{226}Ra, and ^{232}Th respectively. The mean computed values for absorbed dose rate, annual effective dose and radium equivalent are 10.03 nGy/hr, 0.03 mSv/yr, 20.11 Bq/kg respectively, which fall within UNSCEAR, 2000 threshold. ***Conclusion:*** A significant positive relationship exists between the in-situ and evaluated effective dose equivalents ($r = 0.89$, $p < 0.05$). Radiation dose results indicate insignificant radiological risk, making the study area safe for living and agriculture purposes.

Keywords: *Radionuclides, in-situ dose rate, gamma spectrometry.*

INTRODUCTION

Natural radioactivity is known to be naturally present in our environment [1], existing in various geological formations such as soils, rocks, plants, water and air [2], since the formation of the earth [3]. Naturally occurring radionuclides are common occurrences in the environment [4] and their accumulation in air, soil, water and plant parts represents the exposure pathway to humans [1].

Human exposure from primordial sources constitutes about 85% of natural background radiation [2], making human exposure to ionizing radiation from natural sources continuous and inevitable. Background radiation serves as baseline value in assessing possible environmental radiation pollution and can also be employed in mineral characterization of an area, since environmental natural radioactivity is due to the decay of radionuclides derived from minerals presents in the earth crust [5].

Natural background radiations are mainly from rock disintegration through a natural process. They are carried to the soil by rain and flows [6], making soil radioactivity one of the main determinants of natural background radiation. Soil also plays a significant role in human exposure to Ionizing radiation [7, 8]. Possible associations of natural background

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[DOI: 10.52547/ijrr.19.3.591]

radiation with reported incidences of reproductive abnormalities in Abeokuta, a neighbouring town to our study area though with different geology, was observed by [9]. Therefore, assessment of environmental radionuclides is of great interest to many researchers throughout the world because of the hazard it poses to the ever-growing world population [8].

Knowledge of background radiation levels in the environment is also important for assessing the effects of radiation exposure to humans, predicting the level of natural radioactivity without laboratory measurement [10], and also forms the baseline for assessment of future radioactive contamination or pollution in the environment. The aim of this study was to measure the background radiation level in Ijebu Ife, Ogun State, Nigeria, and study the relationship between in-situ measurements of gamma dose rates using portable dosimeter and laboratory measurement of soil samples.

MATERIALS AND METHODS

Study area

Ijebu-Ife in Ogun State lies within the Dahomey basin, an inland, offshore, coastal sedimentary basin in the Gulf of Guinea (11). It lies at latitude 604610011 North, 400310011 East with 67 meters' elevation above the sea level, in the tropical region of South-Western Nigeria linking the region to the eastern part of the country.

Sample collection and preparation

Samples were collected randomly from different locations in Ijebu-Ife, ranging from farm lands, river banks, around dwellings and yet to be settled areas (developing sites) as suggested by [12, 13] due to the lithological homogeneity of the area.

At each sampling point, a hand held survey meter and global positioning system was used to measure the absorbed dose and coordinates of the location before collecting soil samples at a depth of about 20cm, in order to also avoid the effect of plant cycling of the radionuclides according to [14]. The collected samples were then transferred to the laboratory in a well labelled polythene bag where they were air-dried, crushed to a fine powder, sieved with a 2mm mesh screen to obtain a fine-grained homogenous soil sample [15], and packed in to well labelled airtight containers in order to prevent the escape of ^{220}Rn and ^{222}Rn to bring the daughter radionuclide into secular radioactive equilibrium with their respective long-lived parents [16-18].

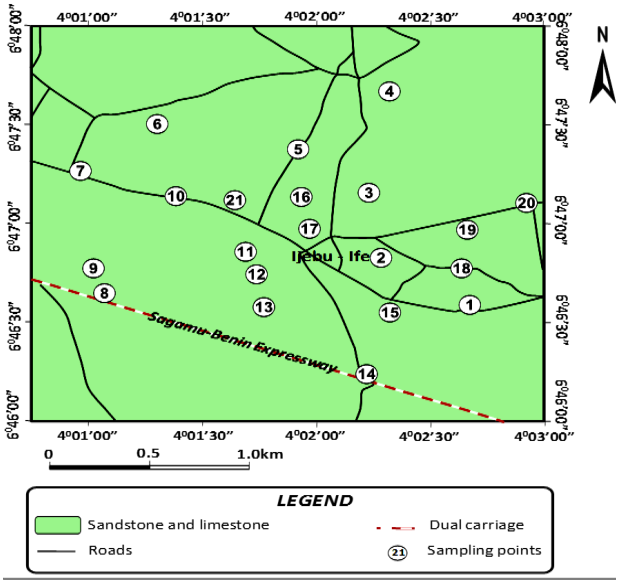


Figure 1. Geological map of the study area. Numbers in the map refers to the sampling sites in the area.

Experimental Method

In-situ absorbed dose-rate measurements using a survey meter and Gamma ray spectrometric analysis of soil samples using NaI (Tl) detector were employed in this study.

In-situ absorbed dose rate measurements

The survey meter is a Cesium Iodide (CsI) scintillation based Gamma RAE II R which provides an estimate for gamma dose rate only [10]. Provided by RAE Systems P/N 047-4505-000, USA), Gamma RAE II R is a rapid γ-ray (gamma) source detector and dosimeter in a single unit with high sensitivity to low radiation energy/level making contribution of gamma-rays from cosmic sources negligible [19]. During measurements, the survey meter was held at gonad height on a tripod stand such that

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it is one-meter above ground level [3]. At each location, absorbed dose rates (μSv/hr) were measured for 5 min and repeated six times. The mean of the six readings over the total sampling time of 30 min was recorded according to [3] to provide desirable accuracy (<10% SD) at a 95% confidence level. The mean of all the locations was computed and considered as the representative absorbed dose value for that location.

To assess the radiological implication, the annual effective doses $H_m\left(\frac{mSv}{yr}\right)$ corresponding to the measured gamma absorbed doses $D_m\left(\frac{\mu Sv}{hr}\right)$, was calculated using equation 1:

$$H_m\left(\frac{mSv}{yr}\right) = D_m\left(\frac{\mu Sv}{hr}\right) \times \left(24 \times 365 \frac{hr}{yr}\right) \times 0.4 \times 10^{-3} \quad (1)$$

where 0.4 is the outdoor occupancy factor, considering that people in this area spend an average of 40% (about 10 hours) of their time outdoors.

Gamma ray spectrometry

Gamma spectrometry was done using a well shielded NaI(TI) detector from CANBERRA France of 3" x 3" crystal dimension with resolution 7.5% for 137Cs (662 keV) coupled to a computer-based multichannel analyzer (MCA) card system GENIE 2000 programmed used for data acquisition and spectra analysis, available at National Institute of Radiation Protection and Research (NIRPR) University of Ibadan, Nigeria with necessary energy and efficiency calibrations using IAEA standard source. Each sample was counted for 10,800 seconds and activity concentrations of $^{238}U/^{226}Ra$ and ^{232}Th were determined using the γ-lines of their decay products: ^{214}Bi (1764.5 keV) and ^{208}Ti (2614.5 keV), respectively while the activity concentration of ^{40}K was determined using its 1460 keV γ-line.

Activity concentration and radiological parameters

The activity concentrations C(BqKg^{-1}) of the radionuclides were calculated using equation 2, as given by Jibiri and Okeyode [8].

$$C(BqKg^{-1}) = KC_n \quad (2)$$

Where; C_n is the count rate under the corresponding peak, $K = \frac{i}{\varepsilon \rho_\gamma M_s}$ is the efficiency of the detector at specific gamma-ray energy, ρ_γ is the absolute transition probability of the specific gamma-ray, M_s is the sample mass.

Radium equivalent

The radium equivalent activity Ra_{eq} which represents the weighted sum of activities of the measured natural radionuclides and is based on the estimation that 1Bq/kg of ^{226}Ra, 0.7Bq/kg of ^{232}Th, and 13Bq/kg of ^{40}K produce the same radiation dose rates, is given in equation 3 by [8, 20] as:

$$Ra_{eq} = C_{Ra} + 1.43\, C_{Th} + 0.077 C_K \quad (3)$$

Where; C_{Ra}, C_{Th} and C_K are the activity concentration in Bq/kg of ^{226}Ra, ^{232}Th, and ^{40}K.

Absorbed dose rate

The absorbed dose rate in air from terrestrial sources of gamma radiation was estimated from the result of the activity concentration of the radionuclides, using the relation given in equation 4 by Otwoma, Patel [12].

$$D\left(\frac{nGy}{hr}\right) = 0.427 C_{Ra} + 0.662 C_{Th} + 0.043 C_K \quad (4)$$

Where; $D\left(\frac{nGy}{hr}\right)$ the dose rate, at 1m above ground level due to ^{226}Ra, ^{232}Th and ^{40}K in the soil samples.

Annual effective dose

The annual effective dose, $H_E\left(\frac{mSv}{yr}\right)$ to the population due to activity concentration of the radionuclides in soil samples was estimated using the dose conversion coefficient that converts the absorbed dose rate in air to the effective dose $\left(0.7 \frac{Sv}{Gy}\right)$ using equation 5 according to Sadiq and Agba [21].

$$H_E\left(\frac{mSv}{yr}\right) = D\left(\frac{nGy}{hr}\right) \times \left(24 \times 365 \frac{hr}{yr}\right) \times 0.4 \times 0.7 \frac{Sv}{Gy} \times 10^{-6} \quad (5)$$

Where; 0.4 is the outdoor occupancy factor considering that the residents spend 40% (about 10 hours) of their time outdoor on average.

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External and internal hazard index

External and internal hazard indices are used to quantify the effect of radon, a progeny of radium and its short-lived products to the respiratory organs. The External Hazard Index (H_{ex}) is given by the equation 6:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \quad (6)$$

The internal hazard index (H_{in}) is also given by equation 7 as:

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (7)$$

The value of both indices must be less than unity for the radiation hazard to be negligible [2].

Statistical analysis

Statistical package for social science (SPSS) was employed for statistical analysis of data, correlation analysis was used to measure the relationship between in-situ effective dose and laboratory measured effective and represented on a scatter plot.

RESULTS

In-situ absorbed dose

One hundred and twenty-six data were obtained using a portable dose survey meter in Ijebu Ife area of Ogun state for in-situ background radiation. The average absorbed dose rate for each sampling point obtained from in-situ measurement using Gamma RAE IIR dosimeter is presented in table 1 with its corresponding effective dose estimated using equation 1. From table 1 the result of the absorbed dose rate which represents the background radiation level was found to vary from 0.02 μSv/hr to 0.10μSv/hr with a mean value of 0.05 μSv/hr and values of the corresponding annual effective dose ranges from 0.07 mSv/yr to 0.350 mSv/yr with a mean value of 0.182 ± 0.02 mSv/yr. The absorbed dose rate and annual effective dose result is summarized in figure 2.

Table 1. Absorbed dose rate and annual effective dose of Ijebu-Ife, Ogun State. Nigeria.

Location Code	D_m (μSv/hr)	H_m (mSv/yr)
S01	0.10	0.350
S02	0.04	0.140
S03	0.06	0.210
S04	0.04	0.140
S05	0.06	0.210
S06	0.07	0.245
S07	0.04	0.140
S08	0.04	0.140
S09	0.02	0.070
S10	0.09	0.315
S11	0.05	0.175
S12	0.06	0.210
S13	0.04	0.140
S14	0.06	0.210
S15	0.03	0.105
S16	0.06	0.210
S17	0.05	0.175
S18	0.03	0.105
S19	0.04	0.140
S20	0.06	0.210
S21	0.05	0.175
Minimum	0.02	0.070
Maximum	0.10	0.350
Mean ± SD	0.052	0.182 ± 0.02

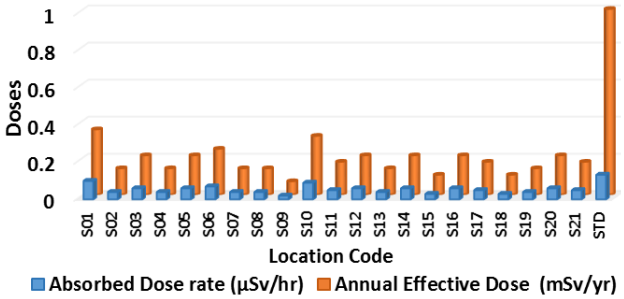


Figure 2. In-situ absorbed dose rate and annual effective dose of Ijebu-Ife, Ogun State. Nigeria and standard.

Table 2 presents the results of activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K as well as radium equivalent value in soils of Ijebu-Ife Ogun State using gamma-ray spectroscopy, while table 3 shows the values of absorbed dose rate and annual effective dose as result of human exposure because of the long-lived gamma rays in soil. From table 2, it is observed that the activity concentrations of ^{40}K in soil varies from

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Below Detection Limits (BDL) to 320.11±28.53 Bq/kg with mean value of 119.052±11.24 Bq/Kg, the values of the activity concentration for ^{226}Ra range from BDL to 9.11 ± 1.65 Bq/Kg with mean value of 4.444±1.01 Bq/Kg and the values obtained for the activity concentration of ^{232}Th in soil range from BDL to 8.55±0.95 Bq/kg with mean values of 4.545±0.62 Bq/Kg as shown in table 2. Table 2 also presents radium equivalent value calculated according to equation 3, which was found to lie in the range of 6.481 Bq/Kg to 38.186 Bq/kg with a mean value of 20.301±1.80.

In table 3 the absorbed dose rate of the samples was calculated using equation 4 and it was found to lie within 2.814 nGy/hr to 19.753 nGy/hr with a mean values of 10.025 nGy/hr, and annual effective dose obtained using equation 5 was found to vary from 0.007 mSv/yr to 0.049 mSv/yr with a mean value of 0.025 mSv/yr. From table 3 also, external and internal radiation hazard index calculated using equation 6 and 7 was found to vary from 0.0185 to 0.1031 and 0.0297 to 0.1241, with mean values of 0.054±0.01 and 0.066±0.01 respectively.

Table 2. Activity concentration of naturally occurring radionuclides and its radium.

SAMPLE CODE	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	^{232}Th. (Bq/kg)	RaEq (Bq/kg)
S01	320 ± 28.53	7.76 ± 1.71`	4.04 ± 0.48	38.186
S02	30.06 ± 2.94	5.38 ± 1.30	5.61 ± 0.61	15.717
S03	148.91 ± 14.50	3.41 ± 0.85	8.55 ± 0.95	27.103
S04	120.73 ± 11.37	2.60 ± 0.63	1.14 ± 0.14	13.526
S05	253.51 ± 21.28	4.60 ± 0.98	1.26 ± 0.16	29.922
S06	249.87 ± 22.48	2.12 ± 0.52	3.42 ± 0.42	26.251
S07	125.86 ± 11.47	1.83 ± 0.45	5.95 ± 2.72	20.029
S08	68.34 ± 7.33	5.03 ± 1.28	0.59 ± 0.08	11.136
S09	BDL	5.18 ± 1.29	0.91 ± 0.11	6.481
S10	150.95 ± 14.82	8.91 ± 1.84	6.43 ± 0.73	29.728
S11	100.01 ± 9.38	3.79 ± 0.85	5.14 ± 0.58	18.841
S12	18.03 ± 2.21	4.46 ± 1.14	5.48 ± 0.64	13.685
S13	81.54 ± 10.31	9.11 ± 1.65	4.46 ± 0.53	21.766
S14	106.87 ± 10.39	8.49 ± 1.91	7.37 ± 0.83	27.258
S15	36.69 ± 3.69	3.67 ± 0.88	3.48 ± 0.41	11.472
S16	160.99 ± 15.14	4.63 ± 0.99	6.21 ± 0.68	25.907
S17	144.72 ± 13.01	1.58 ± 0.39	7.17 ± 0.80	22.977
S18	87.34 ± 8.86	2.14 ± 0.45	BDL	8.865
S19	43.15 ± 4.43	BDL	5.67 ± 0.67	11.431
S20	191.40 ± 17.19	2.64 ± 0.68	4.65 ± 0.52	24.027
S21	61.01 ± 6.74	5.99 ± 1.44	7.92 ± 0.90	22.013
Minimum	BDL	BDL	BDL	6.481
Maximum	320 ± 28.53	9.11 ± 1.65	8.55 ± 0.95	38.186
Mean ±SD	119.05 ± 18.19	4.44± 0.55	4.55± 0.55	20.301 ± 1.80

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Table 3. Absorbed dose rates and annual effective dose effective dose for soils of Ijebu-Ife, Ogun State.

SAMPLE CODE	D (nGy/hr)	H_E (mSv/yr)	H_{ex}	Hi_n
S01	19.753	0.048	0.1031	0.1241
S02	7.304	0.018	0.0434	0.0570
S03	13.519	0.033	0.0731	0.0824
S04	7.056	0.017	0.0365	0.0436
S05	13.699	0.034	0.0700	0.0824
S06	13.914	0.034	0.0719	0.0766
S07	10.132	0.025	0.0541	0.0590
S08	5.477	0.013	0.0301	0.0437
S09	2.814	0.007	0.0185	0.0315
S10	14.552	0.036	0.0803	0.1044
S11	9.321	0.023	0.0519	0.0611
S12	6.307	0.016	0.0370	0.0490
S13	10.349	0.025	0.0598	0.0834
S14	13.010	0.032	0.0746	0.0966
S15	5.449	0.013	0.0310	0.0409
S16	13.011	0.032	0.0710	0.0825
S17	11.644	0.029	0.0620	0.0663
S18	4.669	0.011	0.0249	0.0297
S19	5.609	0.014	0.0319	0.0309
S20	12.436	0.031	0.0659	0.0720
S21	10.424	0.026	0.0595	0.0756
Minimum	2.814	0.007	0.0249	0.0297
Maximum	19.753	0.048	0.1031	0.1241
Mean ±SD	10.021 ± 0.92	0.025 ± 0.00	0.054 ± 0.01	0.066± 0.01

In-situ and laboratory measured effective dose

Table 4 presents the results of in-situ and laboratory measured effective doses with in-situ effective dose ranging from 0.070 mSv/yr to 0.350 mSv/yr, with a mean value 0.182 ± 0.02 mSv/yr while effective dose result obtained from laboratory measurement of activity concentration of soil samples ranged from 0.007 mSv/yr to 0.048 mSv/yr with mean values of 0.025 mSv/yr. The relationship between in-situ and laboratory measurement of effective dose is presented in figure 3, which shows a linear relationship between in-situ and laboratory measured effective dose. The correlation coefficient ($r = 0.89$, $p < 0.05$), also shows a significant positive relationship between in-situ and laboratory measured effective dose in figure 3.

Table 4. In-situ and Laboratory measured effective dose of Ijebu-Ife, Ogun State.

Location Code	H_E (mSv/yr)	H_m (mSv/yr)
S01	0.048	0.350
S02	0.018	0.140
S03	0.033	0.210
S04	0.017	0.140
S05	0.034	0.210
S06	0.034	0.245
S07	0.025	0.140
S08	0.013	0.140
S09	0.007	0.070
S10	0.036	0.315
S11	0.023	0.175
S12	0.016	0.210
S13	0.025	0.140
S14	0.032	0.210
S15	0.013	0.105
S16	0.032	0.210
S17	0.029	0.175
S18	0.011	0.105
S19	0.014	0.140
S20	0.031	0.210
S21	0.026	0.175
Minimum	0.007	0.070
Maximum	0.048	0.350
Mean±SD	0.025±0.00	0.182±0.02

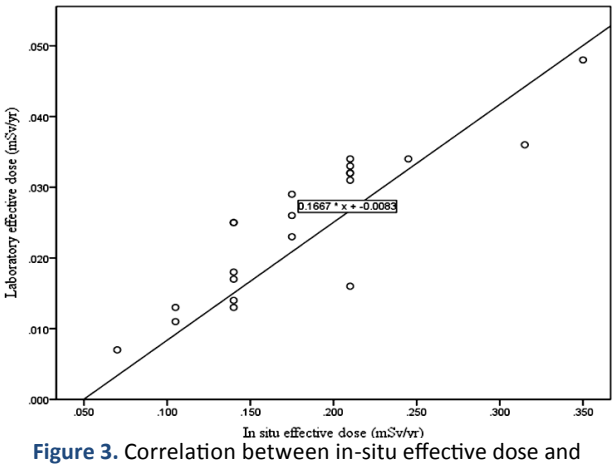


Figure 3. Correlation between in-situ effective dose and laboratory effective dose.

DISCUSSION

Generally, the gamma absorbed dose rate recorded in all locations using a hand held survey meter are within the same range, which

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can be attributed to geological homogeneity of the study area [11]. Absorbed dose rates for all measured locations fall below the standard background radiation level of 0.133 μSv/hr, recommended by the International Commission on Radiological Protection [22] and the corresponding effective dose was below the 1 mSv/yr maximum permissible limit for the general public set by the United Nations for Scientific Committee on the Effects of Atomic Radiation [3], and 2.3 mSv/yr in India [10, 23], 0.19-1.64 mSv/yr in Abeokuta Nigeria [24]. The low radiation levels in the area can be attributed to natural sources as there is no contribution from artificial sources or cosmic radiation [19].

The high-level activity concentration of potassium-40 compared to thorium- 232 and radium-226 could be due to the presence of sandstone, known to host the mineral feldspar (potassium) as the second most abundant mineral in the study area and as a result of the abundance of ^{40}K in nature. The low levels of thorium and radium are also associated with the absence of black sands, which are enriched in the mineral monazite [25]. The values obtained for the activity concentration of ^{40}K, ^{226}Ra, and ^{232}Th are lower than the world's average value of 400, 30, and 35 $BqKg^{-1}$ for ^{40}K, ^{226}Ra, and ^{232}Th, respectively reported by [2] and values obtained in other part of the country [8, 16]. Radiological parameters such as radium equivalent activity, absorbed dose rate, effective dose, external and internal hazard index, have their mean values 20.11 Bq/Kg, 10.025 nGy/hr and 0.025 mSv/yr, below the recommended limit of 370 Bq/Kg , 60 nGy/hr and 1 mSv/yr and unity respectively [2]. The low radiological hazard indices imply there is no radiation exposure threat in the study area and the soil is safe for building and agricultural purposes, which is the principal occupation of its residents. The low radioactivity level is attributed to the presence of sandstone and limestone, which form the underlying soil, and the absence of clay minerals [25] in the study area, and the low variation in the soil radioactivity is attributed to the lithological homogeneity of the study area as observed from the geological map in figure 1.

The in-situ effective dose measured using a survey meter was found to be higher than the calculated effective dose rate from the measured activity concentrations of naturally occurring radionuclides in the laboratory, because of on field contributions and the difference in sampling techniques and sampling [26]. Correlation analysis shows a linear relationship between effective dose rate values measured using the survey meter, and activity concentration of soil indicates a significant positive correlation (R^2=0.89) between the results of the two different methods, which is in accordance with the observations of [27], for low dose values. Thus, high effective dose rates from measured activity concentration of naturally occurring radionuclides are associated with a higher in-situ dose rate measured using a survey meter.

CONCLUSION

In-situ measurements of the gamma absorbed dose rates using a survey meter and analysis of the soil samples from Ijebu-Ife, Ogun State, revealed background radiation levels to be as low as reasonably achievable for members of the general public, and the estimated radiological parameters were found to be below the threshold values recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation [2]. The low background radiation level compared to the world average values of 1mSv/yr [2] and those obtained from other places is attributed to the type of geology and underlying rock/soils present in the study area [25]. Hence, the results obtained will form the baseline data for assessing the contribution to radiation in the environment from future industrial activities in Ijebu-Ife.

***Conflicts of interest*:** *Declared none.*

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[DOI: 10.52547/ijrr.19.3.591]