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Measurements of radioactivity levels in part of Ota Southwestern Nigeria: Implications for radiological hazards indices and excess lifetime cancer-risks

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Abstract. Super SPEC RS-125 radiation detector with large 2.0 x 2.0 NaI crystal and linear energy ranging from 0.80 MeV to 1.2 MeV was used to measure the activities of primordial nuclides and the radiation dose exposures rate in Iyana-Iyesi, Ota, southwestern Nigeria. The measured activities vary from $17 \pm 0.02 \text{ Bqkg}^{-1}$ to $30.49 \pm 0.01 \text{ Bqkg}^{-1}$, $50.01 \pm 0.16 \text{ Bqkg}^{-1}$ to $158.49 \pm 0.17 \text{ Bqkg}^{-1}$, and $406.9 \pm 0.42 \text{ Bqkg}^{-1}$ to $1275.48 \pm 0.82 \text{ Bqkg}^{-1}$ for ^{238}U , ^{232}Th and ^{40}K respectively. The acquired gamma radiation dose rate range from $138.696 \pm 2.06 \text{ (nGyh}^{-1}\text{)}$ to $350.103 \pm 7.21 \text{ (nGyh}^{-1}\text{)}$ with mean value of $148.22 \text{ (nGyh}^{-1}\text{)}$, almost three times higher than the recommended safe limit of $55 \text{ (nGyh}^{-1}\text{)}$. The measured activities and radiation dose rate were engaged to estimate the annual outdoor effective dose, gamma index, excess lifetime cancer risks and annual gonadal dose equivalent. It was observed from all the estimated parameters, those values in the study area are well above the recommended safe limit for normal background radiation. This suggest that the dwellers and those using the excavated geomaterials from this area for construction purposes are exposed to very high radiation from natural radionuclides. Further research to evaluate the mineralogy and geochemistry of the clay deposits in the area is highly recommended.

1. Introduction

Sources of radiation exposure for humans are the natural radionuclides within the environment constituting the background radiation level. Terrestrial components of this background radiation level consist of those radionuclides localizing within the soil, water, air and materials for building constructions whose quantitative abundance in an area depends significantly on the physiography, localized rock types and the regional geological setting. Man-made sources such as nuclear activities and accidents have also been reported to contribute immensely to the background radiation levels [1] [2] [3] [4]. Measurements of radionuclides distribution is a critical prerequisite for estimation of radiological health hazards and risks caused by radiation exposure. Lung cancer, hepatic skin, leukaemia and atrophy of the kidney are among the health hazards usually attributed to the long-term exposure either by inhalation or otherwise. Prolong exposure to non- ionizing radiation can also result to acute leucopenia, sterility, anaemia and ultimately death; children whose mothers were exposed to radiations during pregnancy suffer the risk of mental retardation [5]. It is of prime importance to evaluate the natural environmental radiation level and compare the measurements with the standard dose limits of public exposures. Estimation of the distribution pattern of the natural occurring



radionuclides together with their consequent radiological hazard risks is equally essential in providing some sense of control on prevailing radiation levels. Such study would also establish a baseline for future research work within a particular region. The objective of this work therefore, was to measure the activity concentration level in selected locations within Ota, southwestern Nigeria with the aim of assessing the potential outdoor radiation dose and consequent health risks their exposure pose to people within Ota and its environs.

2. Methodology

2.1. Study Area

The study site is located within the Iyana-Iyesi, Ota, southwestern Nigeria. The physiographic setting is characterized by gentle sloping low area with mean altitude of about 65 m with respect to the sea level. Ota is situated in a humid region characterized by both dry and raining seasons ranging from November to March and April to October respectively. Though intermittent rainfalls are often experienced and reported during dry season due to its closeness to the Atlantic Ocean. The regional geology as presented in Figure 1 is that of Dahomey basin [6], breaking apart from the eastern part of the Niger Delta basin by the continental extension of chain fracture zone [7]. The stratigraphy comprises of Ise, Afowo, Araromi, Ewekoro, Akinbo, Oshosun, Ilaro, and Benin Formations with the first three formations belonging to the Abeokuta Group. However, the local geological setting within Ota consists of the clayey sand, sandy clay, lateritic clay, kaolinitic clay lens, and unconsolidated sand units with the last rock type serving as the main groundwater yield aquifer in Ota and in the area.

2.2. Field Survey

Super SPEC RS-125 spectrometer with large 2.0 x 2.0 NaI crystal was used to measure both the activities of natural occurring radionuclides and the radiation dose exposures in ten location points within Ota, southwestern Nigeria. The data acquisition was maintained about 1 metre above the topsoil. The equipment was calibrated using 5 minutes spectral accumulation on Thorium, Uranium and Potassium pads with 10 minutes accumulation on the background (BG) pad according to Canadian Geophysical Institute. RS-125 portable handheld radiation detector was choosing for this research due to its high accuracy with probable error of about five percent. It also offers good integrated design with large detector, large data storage, high sensitivity and ease of use. Five readings at the interval of 80 seconds were acquired with average result recorded at each station point. The linear energy of the detector ranges approximately between 0.80 MeV and 1.2 MeV which cover majority of the radiation emissions from the terrestrial sources. The mode of data presentation by the equipment was parts per million for both ^{238}U and ^{232}Th , while ^{40}K was in percentage; the data were later converted to Bqkg^{-1} using [8] conversion factor.

2.3. Estimation of radiation hazards parameters

The outdoor absorbed dose rate of 1 metre height can be estimated using UNSCEAR [1] guidelines which is based on the assumption that the naturally occurring radionuclides will have a uniform distribution at that height. The outdoor annual effective dose in units of mSvy^{-1} was computed using the equation (1) based on [9] with conversion coefficient of 0.7 SvGy^{-1} and outdoor occupancy of 0.2 denoting that people around the world spend 20% of their time outdoors on the average. The gamma Index (I_γ) was estimated using the equation (2) according to [10] for the radiation risks resulting from the exposure to the naturally occurring radionuclides. It determines the level of radiation associated with the activity concentrations K_U , K_{Th} and K_K of Uranium, Thorium and Potassium.

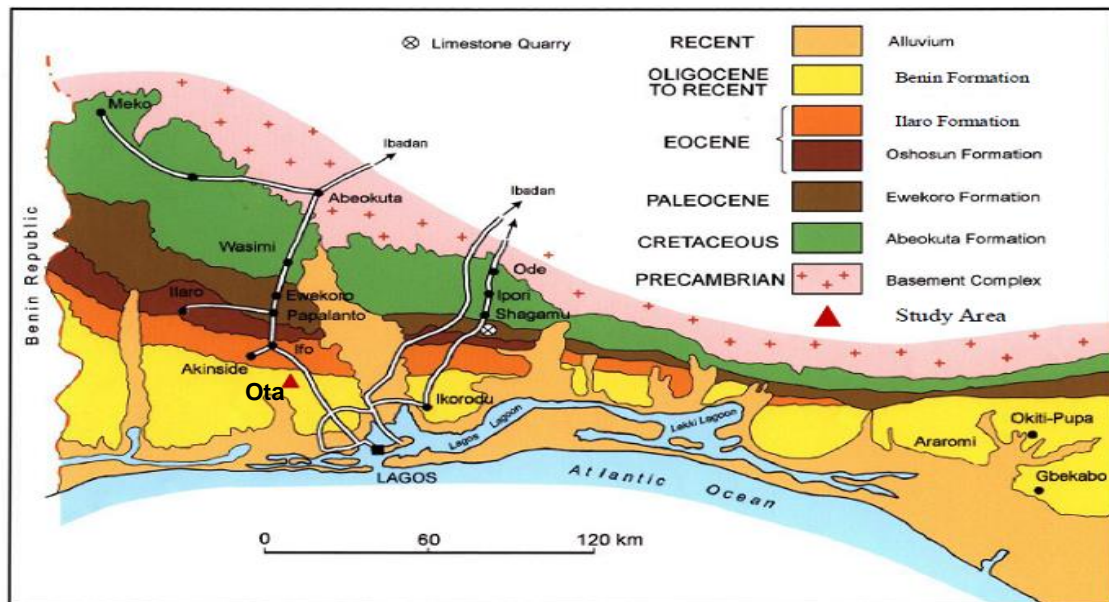


Figure 1. Geological map of the Nigerian section of Dahomey basin (modified after [6])

Excess lifetime cancer risk was calculated according to equation (3) [11]. This determines the possible chance a person exposed to radiation (from birth till death) has over the lifetime risk of cancer development or being diagnosed with cancer. E is the outdoors annual effective dose, LE is the lifetime expectancy of people in Nigeria (average of 54.5 years) according to the latest data published by world health statistics [12]; life expectancy for male is 53.5 years, while that of the female is 55.6 years. Cancer risk factor per Sievert (RF) was stochastically calculated as 0.05 for the general public [13]. Howlader [14] employed this same radiological tool (ECLR) to evaluate the widespread of cancer in the United States. He reported the possibility that a man living in US will develop cancer in his lifetime is 43.3% whereas that of a woman is 37.8%. In this study, the calculated annual gonadal dose equivalent (AGDE), which evaluate the possible effects of the specific activities of ^{238}U , ^{232}Th and ^{40}K on the bone marrow activities and bone surface cells was determined using the equation (4) after [15] with all symbols having their usual meanings.

$$H_E (\text{mSvy}^{-1}) = 1.23 \times 10^{-3} \times \text{Dose rate} \quad (1)$$

$$I_\gamma = \frac{K_U}{150} + \frac{K_{Th}}{100} + \frac{K_K}{1500} \quad (2)$$

$$\text{ECLR} = E \times LE \times \text{RF} \quad (3)$$

$$\text{AGDE} (\mu\text{Svy}^{-1}) = 3.09K_K + 4.18K_U + 3.09K_{Th} + 4.18K_{Th} + 0.314K_K \quad (4)$$

3. Results and Discussion

The measured activities and the radiation dose across the entire ten location points are displayed in Table 1. The activity concentration for ^{238}U , ^{232}Th and ^{40}K radionuclides are within the ranges $17 \pm 0.02 \text{ Bqkg}^{-1}$ to $30.49 \pm 0.01 \text{ Bqkg}^{-1}$, $50.01 \pm 0.16 \text{ Bqkg}^{-1}$ to $158.49 \pm 0.17 \text{ Bqkg}^{-1}$, and $406.9 \pm 0.42 \text{ Bqkg}^{-1}$ to $1275.48 \pm 0.82 \text{ Bqkg}^{-1}$ respectively in the entire area of study. The corresponding mean values of measured activity concentrations are 25.498 Bqkg^{-1} , 77.772 Bqkg^{-1} , and $710.704 \text{ Bqkg}^{-1}$ for ^{238}U , ^{232}Th and ^{40}K respectively. These values were compared to the worldwide standard mean activity concentrations of 32, 45 and 420 Bqkg^{-1} for ^{238}U , ^{232}Th and ^{40}K respectively according to [1]. It was observed that the measured activity concentrations of ^{238}U are lower and acceptable in all the locations. However, the mean activity concentrations for ^{232}Th and ^{40}K across all the location points in the area are higher than the worldwide average standard. There are also strong positive correlations of

0.999 and 0.747 between the later estimated excess lifetime cancer risk and the activities of both ^{232}Th and ^{40}K respectively as shown in Figure 2 (a and b). These high activity concentrations of Thorium and Potassium may be connected to the local geology with clay as the dominant lithology in the area. The stratigraphy of the area comprises of the clayey sand, lateritic clay and kaolinite clay and unconsolidated sand units. The mineralogy composition of the clay lithology within the area appears to be rich in K-feldspar which must have contributed directly and indirectly to the activity concentrations of the measured naturally occurring radionuclides. These observations suggest that the clay rich geomaterials from this area pose a great danger of very high radiation exposure to the dwellers, and construction of buildings and roads with such materials should be discouraged.

Evaluation of the eternal primordial gamma radiation on the entire study site required the measurement of the total absorbed dose rate D ($n\text{Gyh}^{-1}$); the acquired values for this radiological parameter across all the station points range from 138.696 ± 2.06 ($n\text{Gyh}^{-1}$) to 350.103 ± 7.21 ($n\text{Gyh}^{-1}$) with mean value of 148.22 ($n\text{Gyh}^{-1}$). The measured dose rates are found to be higher than the world average dose rate of 55 ($n\text{Gyh}^{-1}$). The increase in the level of the acquired total γ - radiation dose rates can be linked directly to the high levels of activity concentrations of ^{232}Th and ^{40}K . The measured absorbed dose rate and the radionuclides activity of both ^{232}Th and ^{40}K are observed to be elevated for locations L8 and L9. These observations are not unconnected to the outcrops (surface expressions) of a thick lateritic clay unit close to these locations points. These clay materials are equally being used for levelling and filling during both road and building construction in Ota and its environs, thereby contributing significantly to the high level of radionuclides activity concentration and other estimated radiological hazards in the entire area.

Table 1. Measured Activity concentrations of naturally occurring radionuclides and absorbed dose rate

Location	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	Dose rate ($n\text{Gyh}^{-1}$)
L1	29.79±0.02	56.84±0.12	432.33±0.53	152.006±12.2
L2	27.37±0.03	59.48±0.12	425.16±0.61	152.442±5.57
L3	26.14±0.02	60.9±1.04	485.15±1.54	158.783±4.13
L4	30.41±0.02	58.51±0.12	446.02±0.72	155.471±1.74
L5	30.03±0.04	53.62±0.15	406.9±0.42	139.984±6.52
L6	20.84±0.02	50.01±0.16	627.95±0.33	138.696±2.06
L7	20.45±0.02	87.97±0.12	852.92±0.63	208.863±3.87
L8	30.49±0.01	158.49±0.17	1242.22±0.47	350.103±7.27
L9	22.46±0.02	135.94±0.13	1275.48±0.82	300.286±3.38
L10	17±0.02	55.96±0.12	912.91±0.45	144.837±4.21
Mean	25.498	77.772	710.704	148.422

Table 2 shows the results of all estimated radiological parameters in this study. The annual effective dose in air received by an adult outdoors calculated across all the station points spanned from 0.17 mSvy^{-1} to 0.429 mSvy^{-1} with mean value of 0.233 mSvy^{-1} . These values are obviously higher than the worldwide outdoors annual effective dose average of 0.007 mSvy^{-1} [1], but below the set-limit of 1.0 mSvy^{-1} maximum dose recommended for public exposure by the International Commission on Radiologic Protection [16]. Location L8 recorded the highest calculated annual effective dose across the entire study site as shown in the contour image map (Figure 3 (a)). The results of the estimated γ - radiation hazards index also called representative index or gamma index is displayed in Table 2. This radiological parameter determines the level of γ -radiation associated with the measured activity concentrations of the primordial nuclides. The value of the gamma index I_γ must be less than unity (1) in order to keep the radiation level insignificant, however the range of the estimated gamma index (Table 2) is from 1.008 Bqkg^{-1} to 2.616 Bqkg^{-1} with mean value of 1.422 Bqkg^{-1} . The calculated values

in all the location points are greater than the recommended permissible limit of unity according to the recommendation of [1]. Figure 3(b) shows the spread of gamma index in the study area with location L8 having the highest and also a strong relationship in terms high positive correlation of 0.976 was observed between the levels of estimated γ -radiation index and ELCR (Figure. 4(a)). This further confirms that prolong exposure to the high level of γ -radiation in this area will pose lifetime cancer risks to the dwellers.

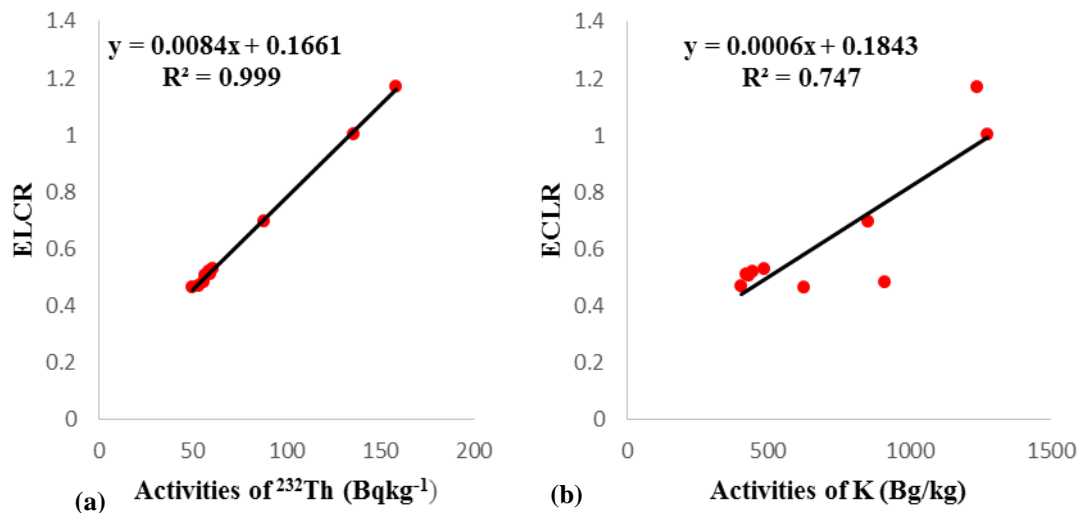


Figure 2. Correlation of ELCR and activities of (a) ^{232}Th and (b) ^{40}K

Table 2. Estimated radiological parameters

Location	H_E ($mSvy^{-1}$)	I_γ	ELCR ($mSvy^{-1}$)	AGDE (μSvy^{-1})
L1	0.186	1.055	0.508	465.39
L2	0.187	1.061	0.509	466.7
L3	0.195	1.107	0.531	487.67
L4	0.191	1.085	0.52	478.59
L5	0.172	1.008	0.468	444.69
L6	0.17	1.058	0.464	470.61
L7	0.256	1.585	0.698	698.72
L8	0.429	2.616	1.17	1146.76
L9	0.368	2.359	1.004	1038.13
L10	0.178	1.282	0.484	573.1
Mean	0.233	1.422	0.635	627.04

Excess lifetime cancer risks factor was directly determined using the annual effective dose radiation which is solely dependent on the measured radiation dose rate in the area of study. ELCR is usually used to quantitatively evaluate the effects of prolong exposure to the γ – radiation associated with the measured natural occurring radionuclides. The estimated ELCR values as shown in Table 2 and Figure 5(a) ranging from $0.464 mSvy^{-1}$ to $1.17 mSvy^{-1}$ with mean value of $0.635 mSvy^{-1}$ are higher than the world permissible standard of $0.29 mSvy^{-1}$ [10].

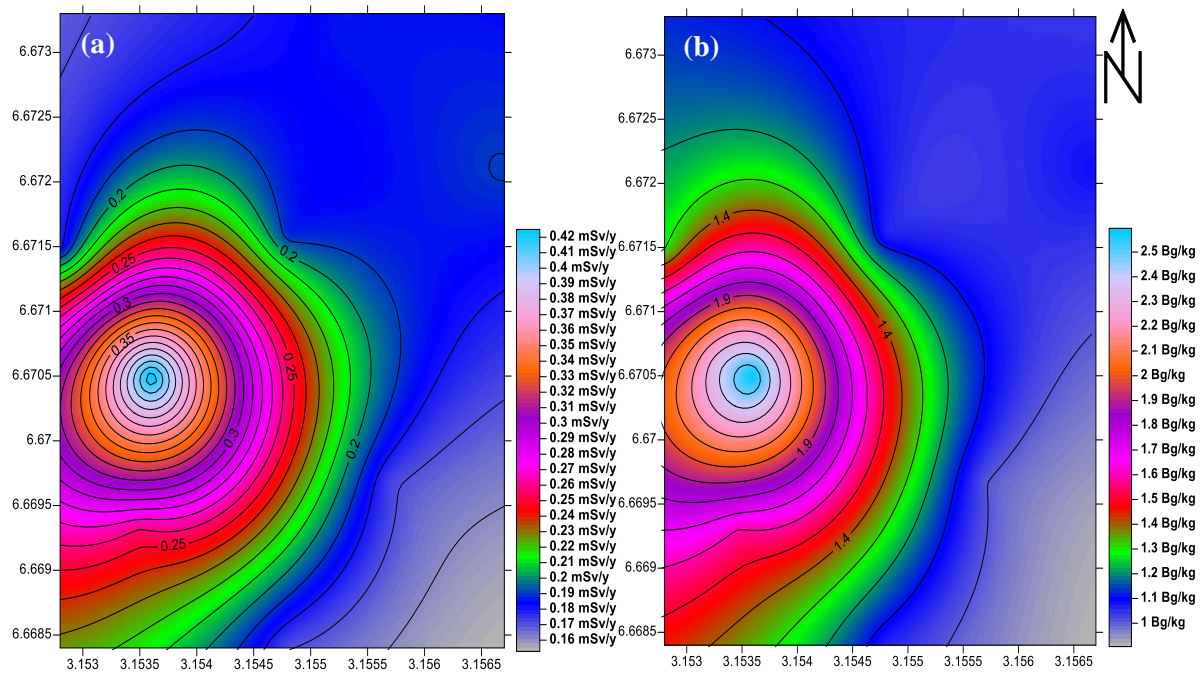


Figure 3. Location contour maps for estimated (a) Outdoor annual effective dose and (b) Gamma Index

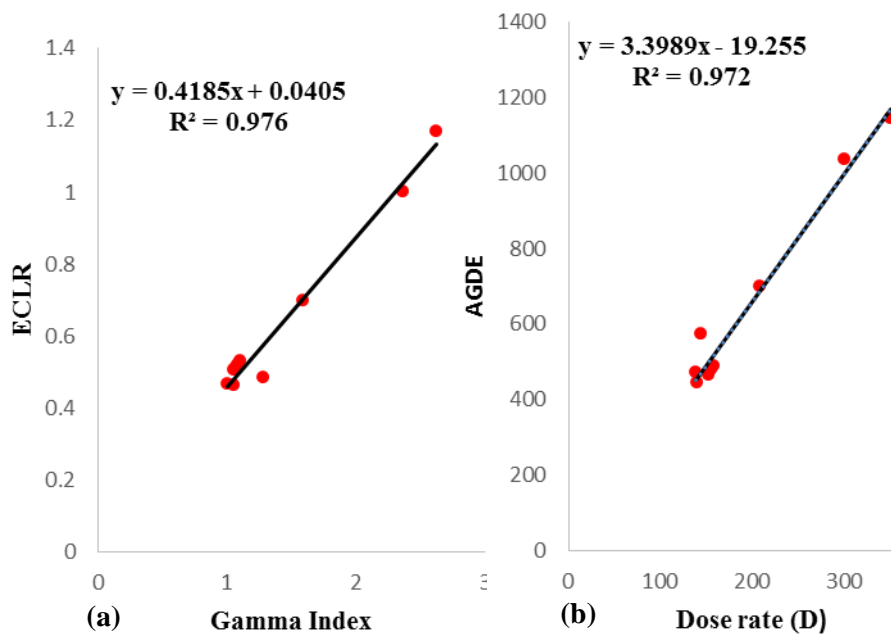


Figure 4. Correlation of (a) ECLR and Gamma Index I_γ (b) AGDE and γ – radiation dose rate

The United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) have so much interests on the activity of the bone marrow, this is because gonads are essential organs that can be affected by radiation exposure [17]. Exposure to radiation with high annual gonadal dose equivalent can result to leukaemia in the bone marrow. The calculated AGDE ($\mu\text{Sv/y}^{-1}$) in this research spanned from 444.69 ($\mu\text{Sv/y}^{-1}$) to 1146.76 ($\mu\text{Sv/y}^{-1}$) with mean value of 627.04 ($\mu\text{Sv/y}^{-1}$). These values

are two times above the average $300(\mu\text{Sv}\text{y}^{-1})$ annual gonadal dose equivalent values around the world. The elevation in the estimated values for AGDE can be linked to the high levels of activity concentrations of ^{232}Th and ^{40}K nuclides which may not be unconnected to the local geology. Several geologic materials such as granites, silt, and clay have been reported to be rich in naturally occurring radionuclides of ^{232}Th and ^{40}K [18]. Figure 5 (b) shows the contour image map of the estimated AGDE in the study area and the strong connection between the AGDE and the measured γ – radiation dose rate with positive correlation of 0.972 (Figure 4 (b)). This reveals that both measured radionuclides activity concentrations and dose rate within the study area are pointer to the possibility of severe AGDE risks associated with prolong exposure to γ – radiation exposure.

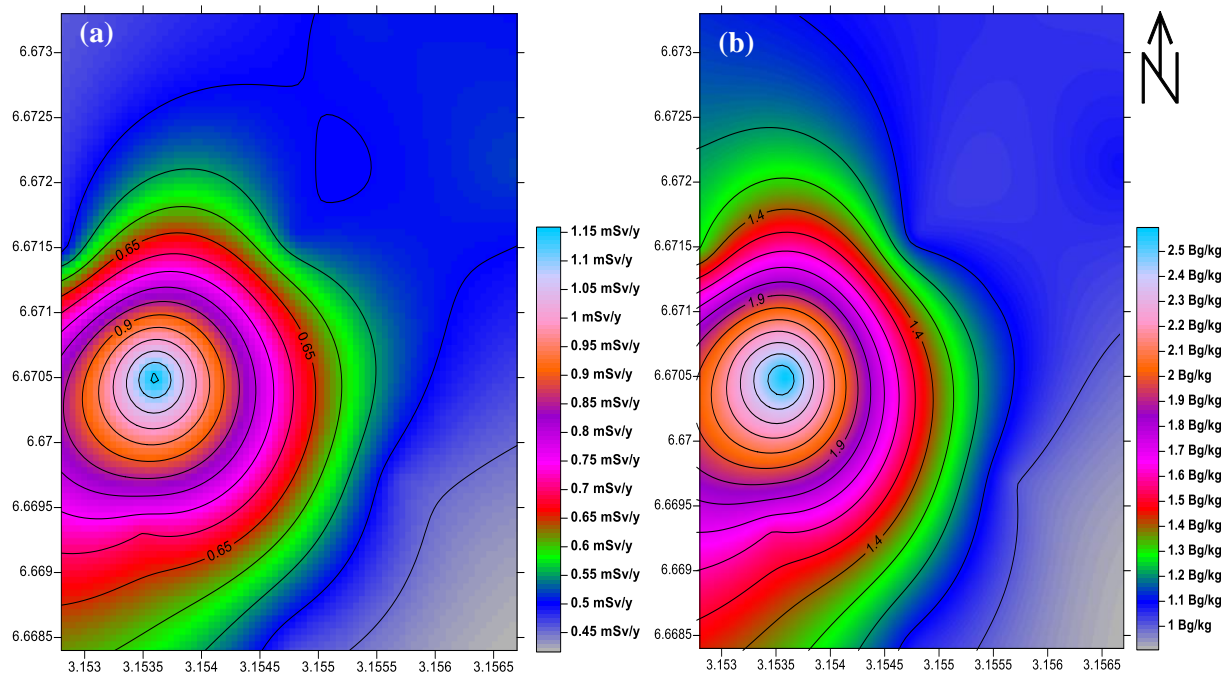


Figure 5. Location contour maps for estimated (a) ECLR and (b) AGDE

4. Conclusion

The activity concentrations of radionuclides and γ – radiation dose rate were measured in ten locations within Iyana-Iyesi Ota, southwestern Nigeria using Super SPEC RS-125 spectrometer. The measured activity concentration of ^{238}U were observed to be below the worldwide average of 32 Bqkg^{-1} . However, the rest of the measured radionuclides including ^{232}Th and ^{40}K were observed to be higher than the worldwide average of 45 and 420 Bqkg^{-1} which may be interpreted to be from the lateritic clay deposits close to the site and the geological setting of Ota which is predominantly silt, clay, clayey sand and unconsolidated sand. The average measured radiation dose rate in the area is $148.422 \text{ (nGyh}^{-1}\text{)}$ which is equally higher than permissible limit of $55 \text{ (nGyh}^{-1}\text{)}$. Consequently, all the estimated radiological parameters in the area such as outdoor annual effective dose, gamma index, excess lifetime cancer risks and annual gonadal dose equivalent are above the permissible limits of $0.007 \text{ mSv}\text{y}^{-1}$, Unity (1), $0.29 \text{ mSv}\text{y}^{-1}$ and $300(\mu\text{Sv}\text{y}^{-1})$ respectively. This suggests that people living in this community and those using the excavated geomaterials from this environment for buildings and roads construction are exposed to radiation above the worldwide recommended safe limits. Further research involving the mineralogy and geochemistry of clay with other geomaterials within this area is highly recommended so as to further understand the sources of radiation.

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