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RESEARCH ARTICLE

Geogenic Radiological Impact Assessment of Soil Samples Collected from Parts of Sagamu Southwestern Nigeria

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ABSTRACT

This study is an assessment of the radionuclide concentration level and radiological hazards in soils from Sagamu, Ogun state Nigeria. Soil samples collected from 15 locations were analysedusing a 76 x 76mm Sodium Iodide [NaI (TI)] detector crystal. The estimated average absorbed dose rates, annual effective dose, gamma radiation index and excess lifetime cancer riskof the soil samples were 42.07 nGy/h, 51.59 μSvy^{-1}0.66and 0.181μSvy^{-1}respectively. Mean radium equivalent activity of 95.4 Bq/Kgwasalso obtained for the soil samples. The average soil radionuclides activity concentrations in the area of study were within the worldwide range; although at some locations higher values of^{226}Ra and ^{232}Th activity concentration were observed. The results of the estimated radiological parametersin this study are lower than the International Commission on Radiological Protection (ICRP) maximum permitted limit.Hence, they have nosignificant radiological health impacts on the environment and the populace.

Keywords: Geology, Radionuclide, Spectroscopy, Activity concentration, Radiological parameters

INTRODUCTION

Radioactivity is a natural phenomenon, and the leading part of the external irradiation for humans comes from terrestrial radionuclides that are found within the earth crust. Benefits of radiation and radioactive substances span through their applications in power generation to medicine, industry and agriculture. The concentration activity of naturally occurring radionuclides (NOR) in soil can be influenced by human-made activities that are enhanced by industrial processes, such as oil and gas extraction, production of phosphate fertilizers, coal mining and combustion, and cement production. However, the risks of the exposure of these radiations and radioactive substances to health (and factory) workers, general public and the environment in its entirety may have to be assessed, monitored and ultimately controlled.

Human exposure to outdoor radiations from naturally occurring radioactive materials (NORM)usually emanate from the topmost few centimetre of the soil[1]. The concentration of these NORM depends mainly on geological and geographical conditions and may perhaps appear at different levels in soils of different geological regions [2]. Nonetheless, the humans' exposure dose rate depends on type, density and mineral constituents of the soil [3][4][5]. It is therefore of paramount importance to estimate radiation dose from the natural radionuclides in order to determine the health risks and radiological hazards they posed to the general populace. This study is an evaluation of the concentration activity of NORM contents which include 226Ra, 232Th and 40K in soil samples obtained from Sagamu Southwestern Nigeria.Estimates of the corresponding radiological health risk associated with the soil in this area are presented.

Location, Physiography and Geology of Study Area

The study area ischaracterized by gently undulating topography with average elevation of 260 m above sea level (Fig. 1) within the tropical humid region.The climatic condition common to the sub-equatorial belt of Southwestern Nigeriais sub-divided into wet and dry seasons with mean annual temperature of 28°C. The rainy season starts from April to October with heavy downpours in June/July, while the remaining months are always dry with little or no rain [6]. Mean annual rainfall, which forms the major source of groundwater recharge within this area is about 1,270 mm. The vegetation within the study area is greatly influenced by climate and relief. Present day vegetation cover is sparse owing to commercial and residential activities within the town. The population of Sagamu is ~253, 412 (Wikipedia, 2013) and its proximity to Lagos has made it an industrial hub of Ogun state, Nigeria.

The geological setting of Sagamu, an area in the southwestern part of Nigeria is that of a sedimentary terrain located within the eastern Dahomey basin (Fig. 2)[7]. This basin extends into western Nigeria as far as the Okitipupa Ridge or Ilesha Spur and as far west as the Volta Delta complex in Ghana. The rocks within the Dahomey are extensive wedge of Cretaceous, Paleocene and Neocene sediments which thicken markedly from the onshore margin of the basin [8].The Cretaceous sedimentsrest unconformably on the basement complex and west of the Okitipupa high consisting mainly coarse grained clastic sediments known as Abeokuta Formation in western Nigeria and "Maestrichtian Sableux"[9]in Benin (Dahomey).

Six lithostratigraphic formations were identified within the stratigraphy ofeastern Dahomey basin, from oldest to youngest, Abeokuta, Ewekoro, Akinbo, Oshosun, Ilaro, and Benin Formations. Some workers have described the Cretaceous Abeokuta Formation as a group consisting of Ise, Afowo, and Araromi Formations[10][11].The local geology of the study area is a sedimentary environment consisting predominantly sequence of shale and clayey lithology belonging to Akinbo Formation.

MATERIALS AND METHODS

Sample collection and preparation A total of 75 samples were collected from the study area, 5 soil samples from each sampling location. Table1 shows the sampling points, area code and the number of samples collected. Soil samples weighing about 2 Kg each were collected in black nylon bags. The samples were then spread in trays and dried until there was no detectable change in the mass of the sample at 110°C in a temperature controlled oven. The dried samples were then crushed using mortar and pestle; the crushed samples were sieved using the 2 mm mesh size. The samples were later sealed in a radon tight container for about four weeks so as to reach secular equilibrium between radon ^{226}Ra and its daughternuclides before radiometric counting.

Radioactivity Measurement

The radioactivity measurement of the soil samples were carried out using a Gamma-ray spectroscopy. The spectrometer used was a 76 x 76mm NaI (TI) detector (Bircon model, serial number ff-669) enclosed in a graded 10cm thick Canberra Lead shield. The detector was coupled to a Canberra series 10 plus multichannel Analyser (MCA) (Model No. 1104) through a pre-amplifier using 5m connection co-axial cable. NaI (TI) detector was employed owing to its modest energy resolution which was measured by Full Width Half Maximum Height (FWHN) of approximately 8% at energy of 0.662 Mev (^{137}Cs peak). The standard International Atomic Energy Agency (IAEA) sources were used for calibration [12].The soil samples were placed on top of the detector and the counting period was 10 hours and the net area under the corresponding γ-ray peaks in the energy spectrum was used to compute the activity concentrations in the soil samples using equation (1). The detection limit below which the measured values are regarded as below the detection limit (BDL) of the measuring system in this study are 4.2 BqKg^{-1} for ^{226}Ra, 5.1 BqKg^{-1} for ^{232}Th,and 17.3 BqKg^{-1} for ^{40}K.

$$C_s = \frac{C_a}{P_\gamma (M_s/V_s)\varepsilon_\gamma t_c}(BqKg^{-1}) \qquad (1)$$

where C_s is the sample concentration, C_a is the net peak area of a peak energy, ε_γ is the efficiency of the detector for a γ - energy of interest, M_s/V_s is the sample mass/volume of soil, t_c is total counting time, while P_γ is abundance of the γ - line in a radionuclide.

RESULTS AND DISCUSSION

Activity concentrations

The radionuclides contents obtained within the study area is displayed in Table 2. The activity for ^{226}Ra, ^{232}Th and ^{40}K is found to vary from 17.35 ± 0.6 Bq/Kg to 46.16 ± 0.5 Bq/Kg, 20.72 ± 0.7 Bq/Kg to 58.31 ± 0.4 Bq/Kg and 37.18 ± 0.3 Bq/Kg to 82.20 ± 0.3 Bq/Kg respectively in the soil samples studied. These values, when compared to the worldwide average activity concentrations of 32, 45 and 420 Bq/Kg for ^{226}Ra, ^{232}Th and ^{40}K [2]showed that the measured activity concentration of ^{226}Ra is higher in some locations such as Isale-oko, Ita-Oba, Falowo, Awolowo and Sabo markets, Isokun and NNPC. Simialrly, the activity of ^{232}Th is above the average worldwide values at Isale-oko, Falowo, Ijuku, Isokun, and Surulere areas. ^{40}K activity concentrations within the area of study however are below the worldwide average values. This low activity concentration of^{40}Kradionuclide within the top soil may be responsible for the low crop yield and higher demand for fertilizer by farmers in this part of the country.

Figure 3 shows the correlation of various radiological parameters using regression analysis technique. The correlation coefficients of both Radium equivalent activity and excess lifetime cancer risk with ^{232}Thradionuclide activity concentration of the soil samples within the study area (Fig.3 a and b) are quite high indicating strong connections between these radiological parameters and the natural radionuclide.The radiological maps of the radionuclides measurements in the area localising each sampling point using their geographical coordinates are presented in Fig. 4(a, b and c). Highest concentrations of the measured radionuclides (^{226}Ra, ^{232}Th and ^{40}K) are found to be localized towards the north-eastern part of the study area. The observed variations in the radionuclides concentration activitiesof the topsoil across all the sampling locations in Sagamu showthe inhomogeneity in the near surface lithologies, which may not be unconnected to their clay contents and shaliness. This, as stated before, is based on the local geology of the study area with sediments from Akinbo formations forming the topsoil.

Radiological assessment

Radium Equivalent Activity (Ra_{eq})

The radium equivalent activity (Ra_{eq}) is the most widely used radiation hazard index which is estimated to compare the activity concentration of samples containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K natural radionuclides. It represents the weighted sum of the activities of the NORM based on the assumption that 370 Bq/Kg of ^{226}Ra, 259 Bq/Kg of ^{232}Th and 4810 Bq/Kg of ^{40}K produce the same gamma radiation dose rate. This parameter was calculated using the relation:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \qquad (2)$$

where C_{Ra}, C_{Th} and C_K are the soil samples activity concentrations (in Bq/Kg dry weight) of ^{226}Ra, ^{232}Th and ^{40}K respectively. Table 3 presents the range of radium equivalent in the soil samples from minimum to maximum as 48 Bq/Kg to 123 Bq/Kg at Ajegunle and Falawo respectively.

Radiation dose estimation

The external exposure to radiation arriving from the natural occurring radionuclides materials(NORM) can be determined considering the absorbed gamma dose rate in air at 1 m above the ground level. The mean activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K (in Bq/Kg dry weight) radionuclides in soil samples from the 15 locations were used to estimate the absorbed dose rate in the air by applying the dose coefficientsand the relationproposed [2]

$$D(nGyh^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \qquad (3)$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations (in Bq/Kg dry weight) of ^{226}Ra, ^{232}Th and ^{40}K respectively in the soil samples. The absorbed dose rates were found to vary from 21.13 $nGy\ h^{-1}$ to 54.21 $nGy\ h^{-1}$ at Ajegunle and Falawo respectively. The annual effective dose $H_E(\mu Svy^{-1})$ received by member of the public was calculated using equation 4[2].

$$H_E(\mu Svy^{-1}) = D(nGyh^{-1}) \times O_c \times F_c \times 8760 \times 10^{-3} \qquad (4)$$

where O_c is the outdoor occupancy factor taken as 0.2 [13] and F_c is the coefficient of conversion used in translating the absorbed dose rate to effective dose incurred by adult taken as 0.7[2]. The mean value for the annual effective dose from Table 3 is 51.9 μSvy^{-1}which is less than 1 mSvy^{-1} the recommended safety limit for the general public according to ICRP[14]. Hence, in terms of radiation dose estimation, the soil in the area studied does not pose any health hazard for the inhabitants. High correlation coefficient is however observed between the estimated radiation absorbed dose rates and excess lifetime cancer risk in the study area as shown in Fig. 3.

Gamma Index estimation

The gamma index (I_γ) is defined in order to examine the applicability of using materials in construction purposes. It is employed to estimate the radiation hazard associated with the naturally occurring radionuclides (NOR) in specific investigated samples. For a typical material, it is given by the following expression of ECRP[15]

$$I_\gamma = \sum_X \frac{C_X}{K_X} \le 1 \qquad (5)$$

where C_X (Bq/Kg) is the measured activity of each nuclide in the building material, K_X (Bq/Kg)is the activity concentration of each NOR in the material and it is assumed to produce the same gamma radiation dose rate, that is, 150, 100 and 1500 Bq/Kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively [15][16]. Based on the dose criterion of 1 mSvy^{-1}[14]Table 3 shows that I_γ is less than unity in the soil samples investigated in this research.

Excess Lifetime Cancer Risk

The Excess Lifetime cancer risk (E_L) was estimated using the following equation by Taskin, et al. [17]

$$E_L = H_E(\mu Svy^{-1}) \times D_L \times R_F(Sy^{-1}) \qquad (6)$$

where D_L is the average duration of life (estimated to be 70 years) and R_F is the Risk Factor taken as 0.05 for the general public. The computed values for this radiological parameters range from 0.091 to 0.233 at Ajegunle and Falowo respectively in the study area.

CONCLUSION

Assessment of the radiological parameters in order to evaluate the corresponding health hazards is important. In this investigation a total of 75 soil samples collected from 15 locations within the studyarea were studied for assessment of radionuclides activity concentrations and selected radiological parameters. The average soil activity concentration of ^{40}K radionuclide in Sagamu were below theworldwide average values, whereas, higher concentration activity levels of ^{226}Ra and ^{232}Th were measured in some locations within the study area. The estimated Radium equivalent activity, annual effective dose, and the lifetime risk of cancer were lower than the world's average and are within the safe limits according to International Commission on Radiological Protection (ICRP). Therefore the use of the geomaterialsin the study area for construction purposes poses no immediate health hazard to the populace. High correlation coefficients observed between both estimated radium activity equivalent and absorbed dose rates with excess lifetime cancer risk (≈ 1) show their strong interrelationships.

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Table 1: Sample collection plan

Area code	Sampling Area	Soil
L1	Isale Oko	5
L2	Ita Oba	5
L3	Falawo	5
L4	Makun	5
L5	Awolowo Market	5
L6	OOU Teaching Hospital	5
L7	Agura	5
L8	Sonariwo market	5
L9	Sabo Market	5
L10	Ajegunle	5
L11	Ijuku	5
L12	Isokun	5
L13	NNPC	5
L14	Temidire	5
L15	Surulere	5
Total		75

Table 2: Specific activity of ^{226}Ra, ^{232}Th and ^{40}K in soil samples

Location	No.	^{226} Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
L1	5	37.54 ± 0.6	54.36 ± 1.1	82.20 ± 0.3
L2	5	43.31 ± 0.9	38.76 ± 0.8	67.64 ± 0.2
L3	5	41.64 ± 1.2	52.90 ± 1.3	72.41 ± 1.3
L4	5	22.81 ± 0.7	41.82 ± 1.2	68.33 ± 1.0
L5	5	39.06 ± 1.1	26.14 ± 0.6	54.32 ± 0.9
L6	5	27.42 ± 0.3	38.04 ± 0.9	46.64 ± 0.4
L7	5	17.35 ± 0.6	40.99 ± 1.2	43.06 ± 0.4

L8	5	25.07 ± 1.0	38.96 ± 0.5	55.46 ± 0.2
L9	5	46.16 ± 0.5	32.31 ± 1.3	81.48 ± 1.3
L10	5	15.29 ± 0.7	20.72 ± 0.7	37.18 ± 0.3
L11	5	32.13 ± 0.8	54.14 ± 0.7	42.44 ± 1.6
L12	5	40.33 ± 1.2	48.23 ± 1.1	63.89 ± 0.8
L13	5	35.51 ± 0.9	38.11 ± 0.7	55.72 ± 1.4
L14	5	29.36 ± 0.6	32.23 ± 1.6	43.26 ± 0.6
L15	5	28.03 ± 1.3	58.31 ± 0.4	66.36 ± 0.6
Minimum		17.35 ± 0.6	20.72 ± 0.7	37.18 ± 0.3
Maximum		46.16 ± 0.5	58.31 ± 0.4	82.20 ± 0.3
Mean		32.07 ± 0.8	41.07 ± 0.94	58.69 ± 0.8
UNSCEAR (2000)		35	30	400

Table 3: Estimated Radiological parameters in the study area

Location	Ra_{eq}(Bq/Kg)	D (*nGy h*$^{-1}$)	H_E (μ*Svy*$^{-1}$)	I_γ	E_L (*μSv y*$^{-1}$)
L1	122	53.61	65.75	0.85	0.23
L2	104	46.24	56.71	0.72	0.198
L3	123	54.21	66.48	0.85	0.233
L4	88	38.65	47.4	0.61	0.166
L5	81	36.1	44.27	0.56	0.155
L6	86	37.59	46.1	0.59	0.161
L7	79	34.57	42.4	0.55	0.148
L8	85	37.43	45.9	0.59	0.161
L9	99	44.24	54.26	0.69	0.19
L10	48	21.13	25.91	0.33	0.091
L11	112	49.31	60.47	0.78	0.212
L12	114	50.43	61.85	0.79	0.216
L13	94	41.75	51.2	0.65	0.179
L14	79	34.84	42.73	0.55	0.15
L15	117	50.94	62.47	0.81	0.219
MEAN	95.4	42.07	51.59	0.66	0.181
UNSCEAR (2000)		54	66		0.29

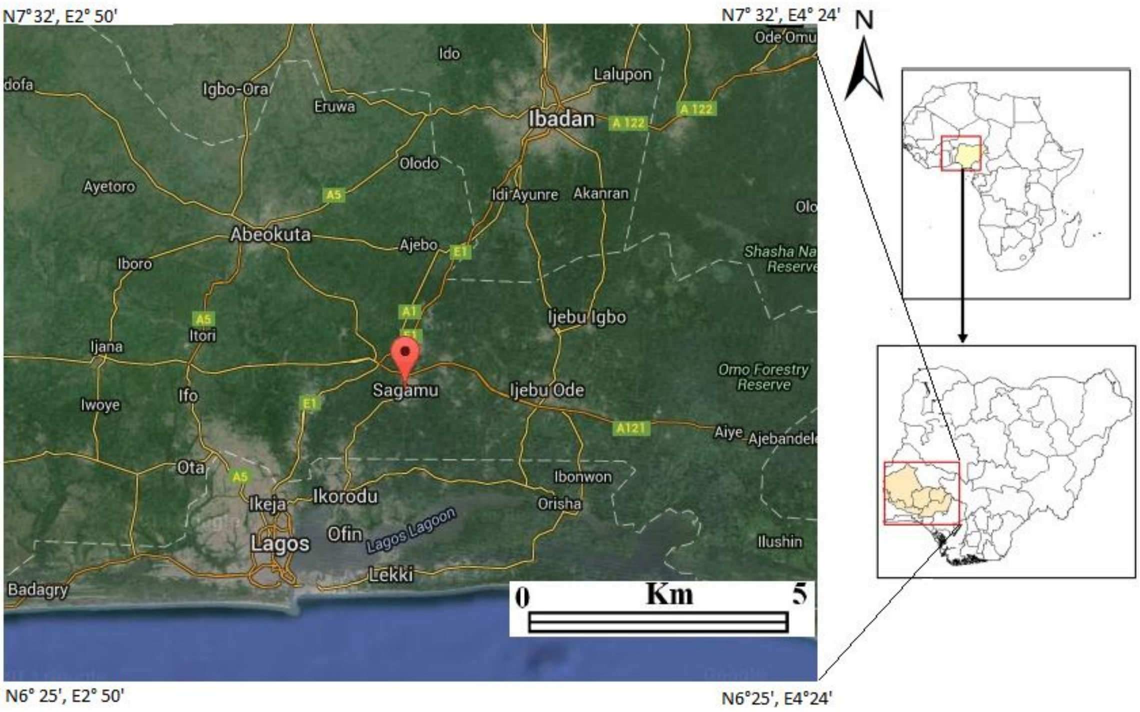

Fig. 1: Topographical map of the study area showing relief and accessibility. Inset: the position of the study area on the map of Nigeria and Africa. ©Google earth image downloaded 17.30 GMT 02.10.2015.

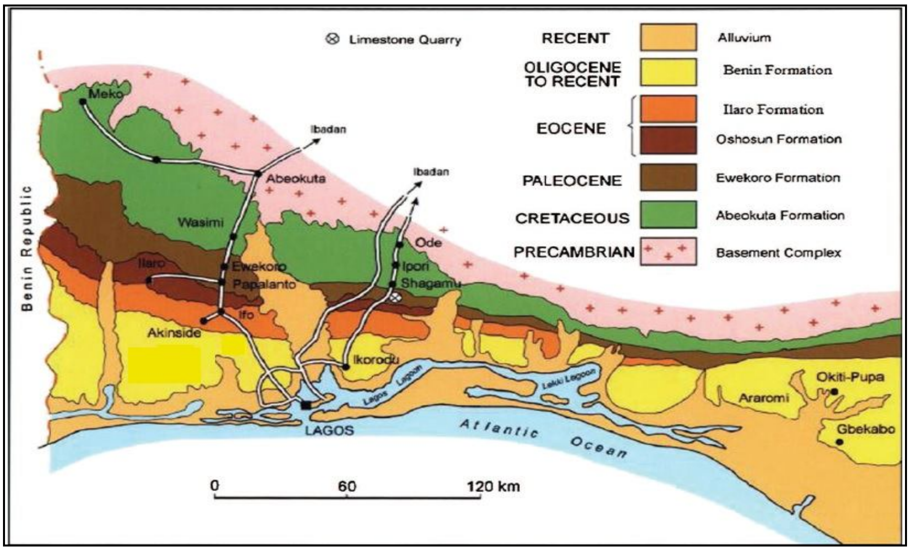

Fig. 2: Generalized geological map of Eastern Dahomey Basin (modified after[7]).

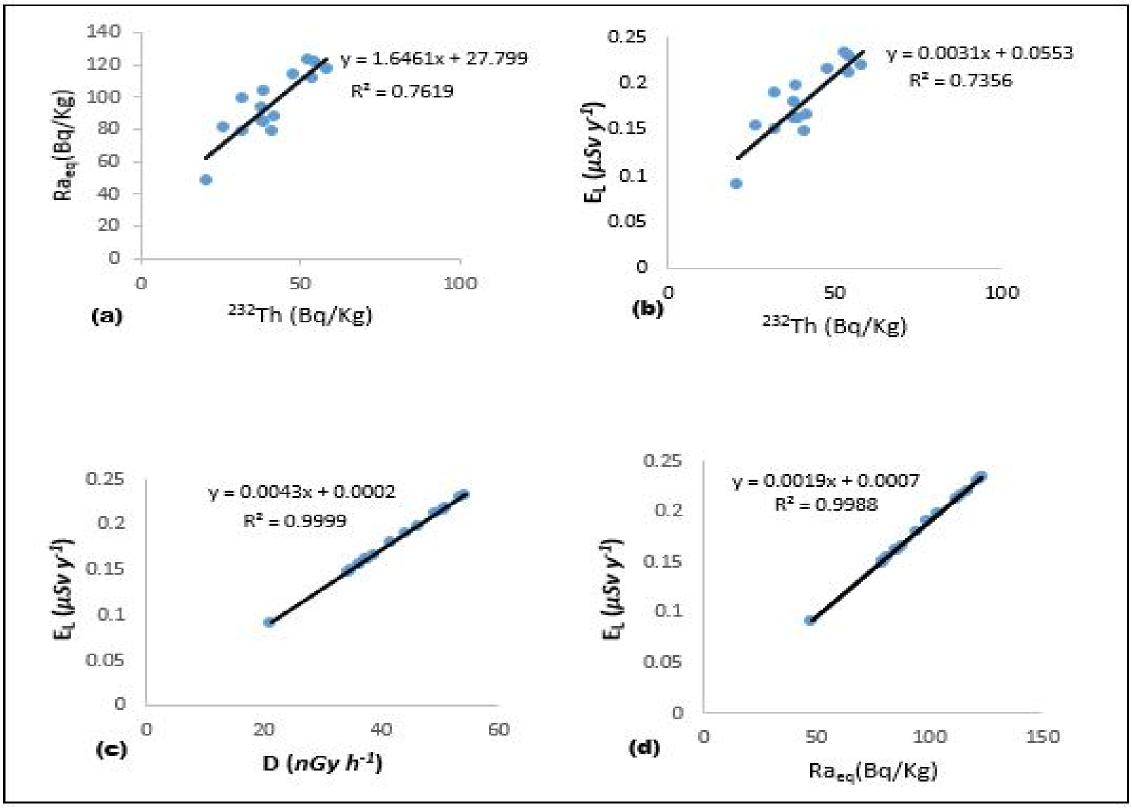

Fig.3.Correlation of various estimated radiological parameters (a) Ra_{eq} activity with ^{232}Th Concentration (b) Excess lifetime cancer risk with ^{232}Th Concentration (c) Excess Lifetime cancer risk with the absorbed dose rate (d) Excess lifetime cancer risk with Ra_{eq} activity

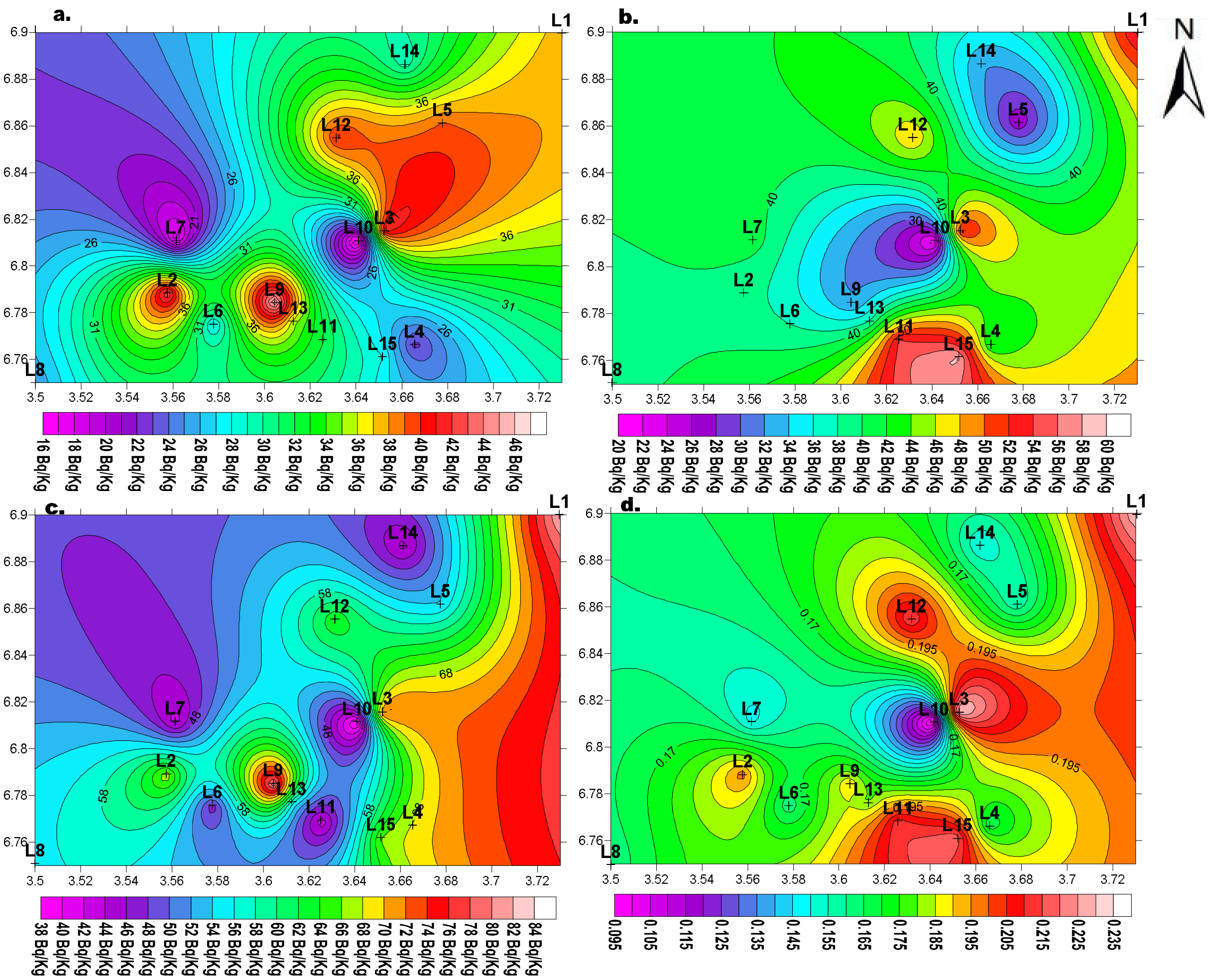

Fig. 4 Radiological maps of the study area showing (a) ^{226}Ra Concentration activity (Bq/Kg) (b) ^{232}Th Concentration activity (Bq/Kg) (c) ^{40}K concentration activity (Bq/Kg) and (d) Excess lifetime cancer risk