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Evaluation of Radiation Hazard Indices for Selected Dumpsites in Port Harcourt, Rivers State, Nigeria

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ABSTRACT

Activity concentration of soil samples from selected dumpsites within Port Harcourt, Rivers State, Nigeria was determined. These dumpsites are recipients of municipal waste from different sources. Two soil samples each from ten selected dumpsites were collected. Gamma Spectrometry analysis was carried out to determine specific activity using NaI(Tl) scintillation detector. The activity concentrations of the soil samples obtained with gamma spectroscopy ranged from 32.21 Bq/Kg to 100.10 Bq/kg for ^{232}Th, 29.16 Bq/Kg to 61.18 Bq/Kg for ^{238}U and 222.15 Bq/Kg to 1166.99 Bq/Kg for ^{40}K. The equivalent radiation exposure for the locations ranged from 0.50 mSv/yr to 1.08 mSv/yr with nine of the locations having values below the permissible threshold of 1.0 mSv/yr for soil. Furthermore, Annual Gonadal Equivalent Dose (AGED) values are above the permissible threshold of 300 mSv/yr for the locations. Four of the hazard indices; Excess Lifetime Cancer Risk (ELCR), Annual Effective Dose Equivalent, AEDE (outdoor and indoor) and Activity Concentration Index (ACI) are below the world permissible limits for most locations while that of few locations are higher due to high specific activity of the radionuclides. The remaining indices, external hazard index (H_{ex}), internal hazard index (H_{in}) and radium equivalent activity (Ra_{eq}) are below permissible limits of 1.0, 1.0 and 370 Bq/Kg respectively. The results were compared with previous works as well as world standards and correlate with those reported for similar environment in Nigeria. Generally, radiation burden and associated risk posed by municipal waste to the studied environment and scavengers is minimal.

Keywords: *Radioactivity, Dumpsites, Gamma Spectrometry, Specific Activity, Absorbed Dose, Effective Dose, Radiation Hazard Indices*

1. INTRODUCTION

Human activities generate different forms of wastes and when improperly managed emanate mal-odour (due to degradation of the waste), pose health burden, aesthetic nuisance and decrease the economic and social values of an area. In addition, radiation emanates from the wastes (most especially when contaminated) coupled with the natural background radiation from the environment. The environment is thus continuously exposed to these radiations due to poor management of the wastes. Exposure to radiation which is present everywhere on the earth surface, underneath the earth and in the atmosphere (Murugesan *et al.*, 2011) causes detrimental effects to flora and fauna. Out of the total radiation dose received by human, approximately 87% is due to natural radiation sources while the remaining is due to anthropogenic sources (UNSCEAR, 1993). The populace is exposed to natural background radiation from three different sources: cosmic rays, internal radioactivity and terrestrial radioactivity. The terrestrial radioactivity which varies with geological condition of the location and altitude (Ajayi, 2002 and UNSCEAR, 1993) is the major external source of radiation to human body (Alaamer, 2008). It has its contribution from ^{238}U, ^{232}Th and their progeny as well as ^{40}K associated with rocks, soils, food, air, buildings and groundwater amongst others in the environment (Murugesan *et al.*, 2011). It is thus of great importance to observe and monitor radiation due to these radionuclides in soils.

Municipal solid waste (MSW), a combination of all of a city's solid and semi-solid waste, includes mainly domestic waste that comes from homes, schools, hospitals, commercial areas (USEPA, 2012) and industries but exclude industrial hazardous waste. MSW mainly contains everyday items used and disposed such as appliances, clothing materials, paint, batteries, products packaging, furniture and paper. MSW in most cases is not radioactive but become radioactive when contaminated by radionuclides from other sources thereby posing radiation hazards to the populace. Of all the categories of MSW, household hazardous waste is the most detrimental and usually contaminates other MSW waste categories. This household hazardous waste includes paint, batteries, pesticides containers and electronic waste which includes cellular phones, computers and printers (EEA, 2013).

The work evaluated the Radiation Hazard Indices (RHI) of municipal waste from different sources in Port Harcourt, South-South Nigeria.

Evaluation of hazard indices is of immense importance as it will be very useful in evaluating the radiological impact (by estimating the likelihood of developing various effects (risks) associated with prolonged radiation exposure) of the waste and provide baseline data for further studies on the study locations. The results will help the populace and government to be conscious of the hazardous effects of improper waste management and take necessary preventive measures. These will minimize exposure of the populace to high level radiation and associated detrimental effects.

This research is thus of immense importance due to the need to ascertain the radiological burden posed by these wastes on the environment.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out in **ten** locations within Port Harcourt city. Port Harcourt is the second largest city in Southern Nigeria and it is the capital of the oil rich Rivers State.

The economic activities of Port Harcourt include manufacturing and extraction processes such as food and beverages processing, car assemblying, paper products manufacturing, paints making, petroleum products refining, mining, metal works and soap making amongst others. Commercial services include legal services, hospitality, medical, educational and engineering services. Wastes of different forms and sources generated due to these enormous economic activities dominate the area which gives rise to several waste dumps and dumpsites which are not properly managed.

The ten selected dumpsites are highlighted with the soil sample description (code) in Table 1.

2.2 Sampling and Analysis

Twenty (20) soil samples were collected from the ten (10) selected dumpsites (two samples from two different points in each dumpsite). The samples were prepared using standard methods (IAEA, 1989) and kept in the laboratory for twenty-eight (28) days to allow for secular equilibrium and to enhance Radon-226 production (Cember and Johnson, 2009).

The soil samples were analysed using the Gamma Spectrometer (a 3” X 3” NaI(Tl) scintillation detector) at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. The detector is enclosed in a 100 mm thick lead shield. IAEA – 375 reference soil standard was used for energy and efficiency calibration. The counting time for each of the samples was 25, 200 seconds (7 hours). The photopeaks observed with regularity belong to those headed by ^{238}U – and ^{232}Th- series in addition to the non-series ^{40}K. The details of the analysis are in accordance with standard methods as given by Downey et al., (2008) and Reguigui (2006).

2.3 Radiation Hazard Indices

Radiation Hazard Indices are standard parameters used to estimate the effects of radiation exposure on the health of people and the environment. These indices are useful in estimating the radiological effects of samples that contains radionuclides (^{238}U, ^{232}Th and ^{40}K) by a single parameter, which takes into consideration the radiation hazard associated with them. The indices and the corresponding equations are presented below.

2.3.1 Annual Gonadal Equivalent Dose (AGED)

The gonads, the bone marrow and the bone surface cells are considered as organs of interest by UNSCEAR (1988) because they are the most sensitive parts of human body to radiation. An increase in AGED has been known to affect the bone marrow and destroys the red blood cells which are then replaced by white blood cells. This situation results in a blood cancer (leukemia).

AGED is calculated with given activity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) using the relation (Mamont-Ciesla et al., 1982),

$$\mathrm{AGED\ (mSv/yr)} = 3.09\mathrm{C_{Ra}} + 4.18\mathrm{C_{Th}} + 0.314\mathrm{C_K} \qquad (1)$$

Where, $\mathrm{C_{Ra}}$, $\mathrm{C_{Th}}$, and $\mathrm{C_K}$ are the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) in soil samples respectively.

2.3.2 Activity Concentration Index (Representative Gamma Index)

Activity Concentration Index (**$\mathbf{I_{\gamma r}}$**) is used to estimate the gamma radiation hazard associated with the natural radionuclides in specific investigated samples. The activity concentration index is given by Alam et al., (1999) as:

$$\mathrm{I_{\gamma r}} = \mathrm{C_U}/150 + \mathrm{C_{Th}}/100 + \mathrm{C_K}/1500 \qquad (2)$$

An increase in the representative gamma index greater than the universal standard of unity may result in radiation risk leading to the deformation of human cells thereby causing cancer.

Values of $\mathrm{I_{\gamma r}} \leq 1$ corresponds to an annual effective dose of less than or equal to 1 mSv, while $\mathrm{I_{\gamma r}} \leq 0.5$ corresponds to annual effective dose less or equal to $0.3\ \mathrm{mSv}$ (Turham et al., 2008).

2.3.3 Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent received outdoor by a person is calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy. Taking into consideration that people on average, spent 20% of their time outdoors, occupancy factor for outdoor and indoor is 0.2 (5/24) and 0.8 (19/24) respectively (UNSCEAR 2000 and Veiga et al., 2006). AEDE is determined by the equations below.

$$\mathrm{AEDE\ (Outdoor)\ (\mu\,Sv/y) = Absorbed\ dose\ D\ (nGy/h)} \times 8760\mathrm{h} \times 0.7\,\mathrm{Sv/Gy} \times 0.2 \times 10^{-3} \qquad (3)$$

and also,

$$\text{AEDE (Indoor)}\ (\mu\,\text{Sv/y}) = \text{Absorbed dose D (nGy/h)} \times 8760\text{h} \times 0.7\,\text{Sv/Gy} \times 0.8 \times 10^{-3}. \;\ldots\ldots \quad (4)$$

The AEDE (indoor) occurs within a house whereby the radiation risks due to building materials only are taken into consideration while AEDE (outdoor) involves a consideration of the absorbed dose emitted from radionuclides in the environment such as ^{226}Ra(^{238}U), ^{232}Th and ^{40}K.

The standard AEDE (Outdoor) value is 70 µSvyr^{-1} and that for AEDE (Indoor) is 450 µSvyr^{-1}. These indices measure the risk of stochastic and deterministic effects in the irradiated individuals (Alias et al., 2008).

2.3.4 Excess Lifetime Cancer Risk (ELCR)

This is associated with the probability of developing cancer over a lifetime at a given exposure level. It is a value depicting the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose.

An increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancer of the breast, prostate or even blood.

Excess lifetime cancer risk (ELCR) is given according to Taskin et al., (2009) as

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where,

AEDE is the Annual Effective Dose Equivalent, DL is the average duration of life / life expectancy (estimated as 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert.

For stochastic effects, International Commission on Radiological Protection (ICRP) uses RF as 0.05 Sv^{-1} for public (Taskin et al., 2009) with the ELCR UNSCEAR standard being 0.29 X 10^{-3}.

2.3.5 External Hazard Index (H_{ex})

Beretka and Matthew (1985) defined external hazard index (H_{ex}) by the equation below,

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \;\ldots\ldots\ldots (6)$$

Where, C_{Ra}, C_{Th} and C_K are the radioactivity concentration in Bq/kg of ^{232}Th, ^{238}U and ^{40}K. The value of this index must be less than unity for the radiation hazard to be insignificant. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 Bq/Kg), Beretka and Matthew (1985).

2.3.6 Internal Hazard Index (H_{in})

The internal hazard index is given as (Beretka and Matthew, 1985):

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_K/4810 \;\ldots\ldots\ldots\ldots (7)$$

H_{in} should be less than unity for the radiation hazard to be insignificant. Internal exposure to radon and its daughter products are very hazardous and can lead to respiratory diseases like asthma and cancer.

2.3.7 Radium Equivalent Activity (Ra_{eq})

According to UNSCEAR (2000), Radium Equivalent Activity (in Bq/Kg) is estimated using the equation given below:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_k \;\ldots\ldots\ldots\ldots\ldots(8)$$

Ra_{eq} is a single parameter used to represent the radionuclide concentrations of Ra-226, Th-232 and K-40 taking into account their respective radiation hazards.

3. RESULTS AND DISCUSSION

The specific activity of ^{40}K ranged from 222.15 Bq/Kg to1166.99 Bq/Kg and are the values for SLB and OK respectively with an average of 643.10±5.94 Bq/Kg for all the sites. ^{238}U radionuclide concentration ranged from 29.16 Bq/Kg to 61.18 Bq/Kg for ELE and UPTH respectively with the average being 41.96±5.53 Bq/Kg. The specific activity of ^{232}Th is between 32.21 Bq/Kg and 100.10 Bq/Kg with ELE and EGR having the least and the highest respectively with a mean of 62.61±18.97 Bq/Kg for all the locations. These values are above the world average values of 420 Bq/Kg, 33 Bq/Kg and 45 Bq/Kg for ^{40}K, ^{238}U and ^{232}Th respectively (Murugesan *et al.*, 2011).

These results are similar to that obtained by Jibiri and Temaugee (2013) in which activity concentrations of radionuclides in the soil samples around the mining sites in Benue State, North Central Nigeria ranged from 425±216.06, 40.34±12.58 and 33.69±4.73 Bq/Kg for ^{40}K, ^{238}U and ^{232}Th respectively. Obed *et al.*, (2005) obtained similar results when natural radioactivity concentration in soil samples in eighteen (18) cities across Nigeria was determined with the activity concentrations of ^{40}K, ^{238}U and ^{232}Th ranging from below detection limits (BDL) to 1459.4 Bq/Kg, 9.2 Bq/Kg to 113.7 Bq/Kg and BDL to 175.7 Bq/Kg respectively.

The gamma absorbed dose rates calculated using the gamma spectrometry results ranged from 57.05 nGy/hr to 123.10 nGy/hr for SLB and OK respectively as shown in Table 4 with an average of 86.71±12.86 nGy/hr. This average value is above the world average of 55 nGy/hr for soil but comparable with gamma absorbed dose rate across Nigerian cities reported to be between 19±5 nGy/hr and 88±44 nGy/hr by Farai and Jibiri (2000). Comparing the average gamma absorbed dose rate of 38.17±12.45 nGy/hr reported by Avwiri *et al.*, (2011) for Eliozu dumpsite to 85.09 nGy/hr obtained in this work, is relatively high and may be attributed to high average activity concentrations of ^{40}K, ^{238}U and ^{232}Th compared to that obtained by Avwiri *et al.*, (2011). This may be due to the fact that more decomposition of the mixed wastes (dumped at the site) has occurred with time thereby increasing the assay of the radionuclides in the soil. In addition, the results obtained agreed with that of Oladapo *et al.,* (2012) for soils around Olusosun dumpsite in Lagos State.

The equivalent dose rate calculated using the same result ranged from 0.5 mSv/yr for SLB to 1.08 mSv/yr for OK with an average of 0.76±0.11 mSv/yr as presented in Table 4. Equivalent dose rates for the locations fall below UNSCEAR 1.0 mSv/yr threshold except for OK (with 1.08mSv/yr) which is slightly higher than the standard limit set by UNSCEAR (2002).This high value observed for OK may be attributed to the presence of different sources of naturally occurring radionuclides like waste from food stuffs, ash, charcoal and animal wastes from an abattoir in the location.

Annual Gonadal Equivalent Dose (AGED) obtained ranged from 383.55 mSv/yr to 848.08 mSv/yr with SLB having the least while OK has the highest as shown in Table 5. The average value of AGED for the locations is 593.29±81.16 Sv/yr which is above the threshold value of 300 mSv/yr. The AGED values for all the locations are above the threshold limit. Figure 1 compares the AGED values for the locations with the standard. The high values of AGED for all the locations indicate that the possibilities of developing bone marrow problems, sterility or even leukemia in the long run are high most especially for locations like OK with extremely high AGED values.

Activity Concentration Index (ACI) calculated for the locations is between 0.87 and 1.90 for SLB and OK respectively with the mean value being 1.33±0.19 which is above the standard. Only SLB- and ELE activity concentration index values are below the UNSCEAR threshold of unity as observed in Figure 2 implying negligible effects.

The Annual Effective Dose Equivalent (for both outdoor and indoor conditions) was also calculated for the locations and shown in Table 6. The AEDE (outdoor) value ranges between 69.97 μSv/yr and 150 μSv/yr for SLB and OK respectively with a mean of 106.34±15.77 μSv/yr which is far above the 70 μSv/yr standard permissible limit. These AEDE (outdoor) values are higher than that reported by Jibiri and Temaugee (2013) in which the average AEDE (Outdoor) value of 71±6 μSv/yr was obtained for soils around the mining site in Benue State. On the other hand, the AEDE (indoor) value ranges between 279.89 μSv/yr and 603.89 μSv/yr which are also for SLB and OK respectively. The AEDE (indoor) average value is 425.35±63.09 μSv/yr which on the contrast to AEDE (outdoor) average is below the 450 μSv/yr threshold. All the locations are above the AEDE (Outdoor) threshold with SLB being an exception while only OK and EGR are far above threshold for AEDE (Indoor) as can be observed in Figures 3 and 4 respectively. The reason can be attributed to high absorbed dose rate values due to high radionuclides concentration in both OK and EGR.

Excess Lifetime Cancer Risk Index (ELCR) obtained ranged from 0.24 X 10^{-3} to 0.53 X 10^{-3} which are for SLB and OK, with the values for other locations shown in Table 7. An average value of (0.37±0.06) X10^{-3} which exceeds the 0.29 X 10^{-3} UNSCEAR threshold was obtained. All the locations have ELCR values above the permissible threshold except SLB and ELE (as seen in Figure 5). These values are higher when compared with that obtained by Avwiri *et al.*, (2012) in which the ELCR of the soil profile for Udi and Ezeagu Local Government Area of Enugu State, Nigeria were obtained to be 0.065 X 10^{-3} and 0.057 X 10^{-3} respectively. The high values of the ELCR index in this work are due to high AEDE caused by high specific activity of radionuclides in the locations. These high values imply that the probability of developing cancer over a lifetime considering seventy years as the average life span of humans is to some extent high.

External and Internal Hazard indices are below the unity threshold for all the locations (as shown in Table 7 and Figures 6 and 7), with the ranges from 0.33 to 0.68 and 0.41 to 0.79 as well as averages of 0.49±0.07 and 0.60±0.08 respectively. OK has the highest value in the two cases while both ELE and SLB have the least H_{ex} and only ELE the least H_{in}. These values are very close to the world average of 0.5 for both indices (Murugesan *et al.*, 2011) suggesting that external and internal exposure to radiation (exposure to radon and its daughters) is negligible. These two hazard indices are comparable to that reported by El-Taher *et al.,* (2012) in which the indices are below unity for sediments from Nile River in upper Egypt. Alaamer (2008) also reported a very low H_{ex} value of 0.13 when soil in Riyadh, Saudi Arabia was assessed for radioactivity using high-resolution gamma ray spectrometry. These indices with values below unity indicate that soils from these study areas can be safely used as building materials.

Finally, all the locations have their Radium Equivalent Activity values below the 370 Bq/Kg world standard limit as shown in Figure 8 with a mean value of 181.01±27.70 Bq/Kg. The mean value obtained is higher than the world average of 129.7 Bq/Kg but very comparable with that obtained by authors like Murugesan *et al.*, (2011) and Farai *et al.*, (2008). The values imply that effects of exposure to radiation are negligible as the permissible limit of 370Bq/Kg of Ra_{eq} is equivalent to unity value of H_{ex}.

The results showed trends that are generally low for most radiation hazard indices calculated except for few indices whose values are above the UNSCEAR recommended thresholds. Therefore, there may be no serious immediate radiological effects to the populace and the environment in these areas except for few locations where the risk due to radiation is significant and may need to be further investigated and monitored.

4. CONCLUSIONS AND RECOMMENDATION

Soil samples from ten dumpsites in Port Harcourt have been analysed using the Thalium Drifted Sodium Iodide Gamma Spectroscopy. The activity concentrations of Th-232, U-238 and K-40 obtained were used to determine the radiometric parameters and radiation hazards indices. The equivalent dose rate calculated using the gamma spectrometry results were all below the 1.0 mSv/yr threshold except for OK dumpsite which is slightly above the limit.

The hazard indices calculated revealed that AGED values are above the permissible threshold for all the locations. Four of the radiation hazard indices; ELCR, AEDE (outdoor and indoor) and ACI are below the world standard for some of the locations. The ELCR values for only ELE and SLB are below 0.29X10^{-3} UNSCEAR (2000) standard. ELE, SL, SLB, PGH, OFR and ELS values for the AEDE (Indoor) are below the permissible threshold of 450 µSv/yr while for the AEDE (Outdoor) only SLB has its value below the 70 µSv/yr permissible limit. The ACI values for only ELE and SLB are below the permissible unity value. Every other location has its value of the four above-mentioned indices higher than the world permissible limits due to relatively high specific activity of the naturally occurring radionuclides especially K-40 in the samples. The high concentration of ^{40}K in those locations may be likely due to the presence of biological materials which account for high composition of the wastes. The remaining three hazard indices; H_{ex}, H_{in} and Ra_{eq}, are below the permissible standards of 1.0, 1.0 and 370 Bq/Kg respectively for all the locations. The results correlate with that obtained in previous works in some of the dumpsites. The low level activity observed in the dumpsites suggests that the immediate environment have been impacted with radionuclides from different wastes dumped on the sites. Based on these findings, the potential risk posed by wastes in most of the studied dumpsites to the environment (human, plants and animals) is minimal except for few locations (OK, ENK and EGR) where the risk due to radiation is significant and need to be monitored with time.

Further investigation is recommended using the High Purity Germanium (HPGe) detector for the locations.

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Table 1. Description of the Dumpsites and the Nature of Waste

S/N	Location	Code	Associated Wastes
1	University of Port Harcourt Teaching Hospital Dumpsite	UPTH	Medical and office wastes including used syringes, plasters, bandages, pharmaceuticals, plastics, paper etc. are being dumped at the site.
2	Eneka Dumpsite	ENK	Domestic non-hazardous waste mainly from offices, operational and residential locations and wastes arising from estate management activities, including but not limited to garbage (cardboard/paper), garden waste, food, plastics, metals (tins/ cans) and trash (Uwakwe (2012)).
3	Eneka – Igwuruta Road waste dumps	EGR	Market, residential and commercial wastes which include food, glass, plastics, ashes, paper, nylon, tin cans etc.
4	Elele waste dump	ELE	Market waste and residential waste such as sugarcane molasses, scraps of metals (from used items like vehicles, household electronics (television sets etc)), ashes, cattle dung and other animal wastes (bones) from a small abattoir in the area.
5	Trans Amadi Industrial Layout (Slaughter Area)	SL	Wastes from the market, abattoir (animal wastes- bones, fur, hooves etc), plastics, human wastes and other waste sediments deposited by Woji river along its banks.

6	Woji Side of Woji River	SLB	Wastes from industrial activities like building construction, welding (metal scraps), small market wastes and other commercial wastes around the vicinity.
7	University of Port Harcourt Post Graduate Hostel waste dump	PGH	Household waste generated in the hostel which include packaging materials, paper, kitchen waste, plastics, wood, spoilt electronic gadgets etc.
8	University of Port Harcourt OFRIMA Block waste dump	OFR	Science laboratories and office wastes such as waste papers, used chemicals (solvents), wood, broken glasses and apparatus, wastes from guinea pigs and rabbits, sawdust and wood shavings.
9	Rumuodomaya Market waste dump	OK	Different wastes including market, household and agricultural wastes dumped there are vegetables, rotten tubers and fruits, potatoes, nylons, packaging materials and ashes. In addition, there is an abattoir near the market which generates wastes from cattles and other animals killed in the market.
10	Eliozu Reclaimed Dumpsite	ELS	Mixture of medical, industrial, commercial, market, household and agricultural wastes which include tin cans, textiles, leather, damaged electronics, glass, wood, food.

Table 2: Specific Activity of the Soil Samples Obtained from Gamma Spectrometry Analysis

S/N	Sample Name	K-40 ($BqKg^{-1}$)	U-238 ($BqKg^{-1}$)	Th-232 ($BqKg^{-1}$)
1	UPTH 1	721.90± 5.63	61.76±4.84	66.09±16.08
2	UPTH 2	893.33± 6.41	60.59±15.47	33.02±3.14
3	ENK 1	169.86± 2.94	43.98±3.81	94.61±22.33
4	ENK 2	713.25± 5.45	37.00±3.35	79.89±19.36
5	EGR 1	645.61± 4.97	47.26±3.97	60.84±15.46
6	EGR 2	535.52± 4.79	51.55±4.09	139.35±30.53
7	ELE 1	547.32± 4.59	26.35±2.79	39.52±11.38
8	ELE 2	640.90± 5.21	31.97±3.13	24.89±8.53
9	SL 1	849.29±6.21	60.98±4.71	90.50±21.05
10	SL 2	245.35±3.33	33.12±3.08	8.79±5.33
11	SLB 1	165.14± 2.87	34.07±3.25	38.79±11.61
12	SLB 2	279.16±3.41	37.70±3.35	58.28±15.00
13	PGH 1	782.45±5.75	35.69±3.23	12.47±6.14
14	PGH 2	767.51±5.57	40.00±3.56	111.12±25.31
15	OFR 1	439.59±4.02	44.72±3.87	44.98±12.47
16	OFR 2	474.97±4.30	28.35±2.87	81.12±19.11
17	OK 1	1394.25±8.48	46.98±4.00	88.63±20.72
18	OK 2	939.72±6.48	36.79±3.25	79.89±19.27
19	ELS 1	666.85±5.27	47.16±3.91	77.78±18.78
20	ELS 2	990.05±6.74	33.13±3.08	21.51±7.87

Table 3: Average Radionuclides Concentration (Bq/Kg) of Soil Samples

S/N	Sample	Specific Activity (Bq/Kg)		
		K-40	U-238	Th-232
1	UPTH	807.62 ± 4.27	61.18 ± 8.10	49.56± 8.19
2	ENK	441.56 ± 3.10	40.49 ± 2.54	87.25±14.78
3	EGR	590.57 ± 3.51	49.41 ± 2.85	100.10±17.11
4	ELE	594.11 ± 3.47	29.16 ± 2.10	32.21± 7.11
5	SL	547.32 ± 3.52	47.05 ± 2.81	49.65±10.86
6	SLB	222.15 ± 2.23	35.89 ± 2.33	48.54± 9.48
7	PGH	774.98 ± 4.00	37.85 ± 2.40	61.80±13.02
8	OFR	457.28 ± 2.94	36.54 ± 2.41	63.05±11.41
9	OK	1166.99 ± 5.34	41.89 ± 2.58	84.26±14.15

10	ELS	828.45 ± 4.28	40.15 ± 2.49	49.65±10.18

Table 4: The Absorbed Dose and Equivalent Dose Rates

S/N	Sample	D (nGy/hr)	E (mSv/yr)
1	UPTH	93.17	0.82
2	ENK	94.02	0.82
3	EGR	112.67	0.99
4	ELE	58.91	0.52
5	SL	76.24	0.67
6	SLB	57.05	0.50
7	PGH	89.95	0.79
8	OFR	76.87	0.67
9	OK	123.10	1.08
10	ELS	85.09	0.75

Table 5: The Annual Gonadal Equivalent Dose (Sv/yr) and Activity Concentration Index (Representative Gamma Index) for the Locations

S/N	SAMPLE	AGED (Sv/yr)	ACI
1	UPTH	649.80	1.44
2	ENK	628.47	1.44
3	EGR	756.53	1.72
4	ELE	411.29	0.91
5	SL	524.78	1.18
6	SLB	383.55	0.87
7	PGH	618.62	1.39
8	OFR	520.04	1.18
9	OK	848.08	1.90
10	ELS	591.73	1.32

Table 6: The Annual Effective Dose Equivalent, AEDE (Outdoor and Indoor), µSv/yr for the Locations

S/N	SAMPLE	AEDE, (OUT) (µSv/yr)	AEDE, (IN) (µSv/yr)
1	UPTH	114.27	457.07
2	ENK	115.31	461.25
3	EGR	138.18	552.70
4	ELE	72.25	289.01
5	SL	93.50	374.00
6	SLB	69.97	279.89
7	PGH	110.31	441.24
8	OFR	94.28	377.11
9	OK	150.97	603.89
10	ELS	104.35	417.40

Table 7: The Excess Lifetime Cancer Risk (ELCR), External and Internal Hazard Indices and Radium Equivalent Activity

S/N	SAMPLE	ELCR (X 10^{-3})	H_{ex}	H_{in}	REA (Bq/Kg)
1	UPTH	0.40	0.52	0.69	194.24
2	ENK	0.40	0.54	0.65	199.26
3	EGR	0.48	0.64	0.78	238.03
4	ELE	0.25	0.33	0.41	120.97
5	SL	0.33	0.43	0.56	160.19

6	SLB	0.24	0.33	0.43	122.41
7	PGH	0.39	0.50	0.60	185.90
8	OFR	0.33	0.44	0.54	161.91
9	OK	0.53	0.68	0.79	252.24
10	ELS	0.37	0.47	0.58	174.94

GRAPHICAL COMPARISON OF THE HAZARD INDICES AND UNSCEAR (2000) STANDARDS

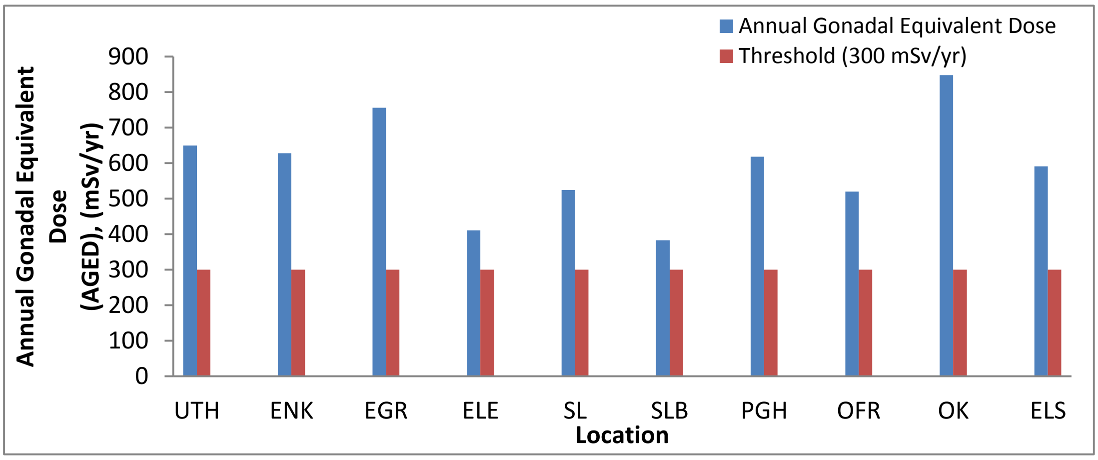

Figure 1: Annual Gonadal Equivalent Dose (AGED) Compared with the UNSCEAR (2000) Threshold for the Locations

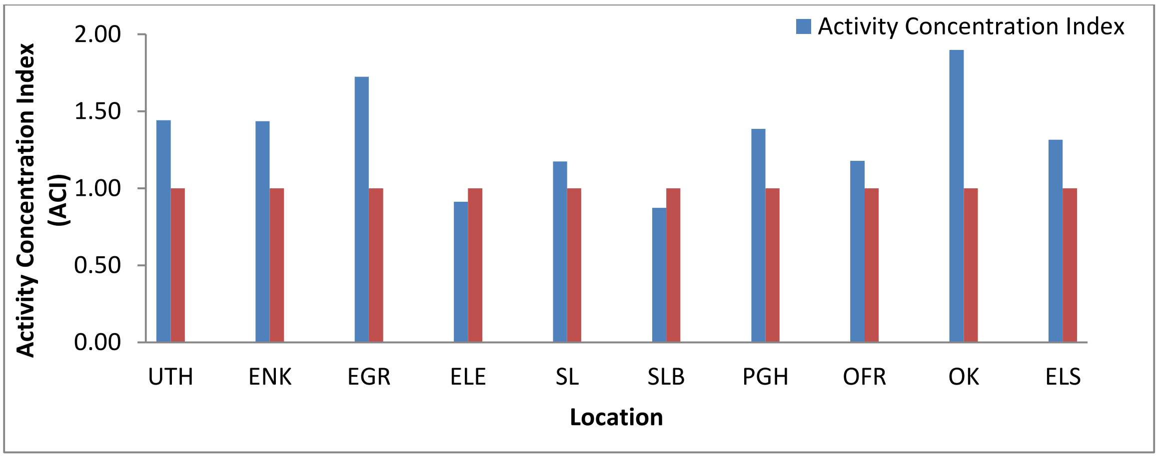

Figure 2: Activity Concentration Index (ACI) Compared with the UNSCEAR (2000) Threshold for the Locations

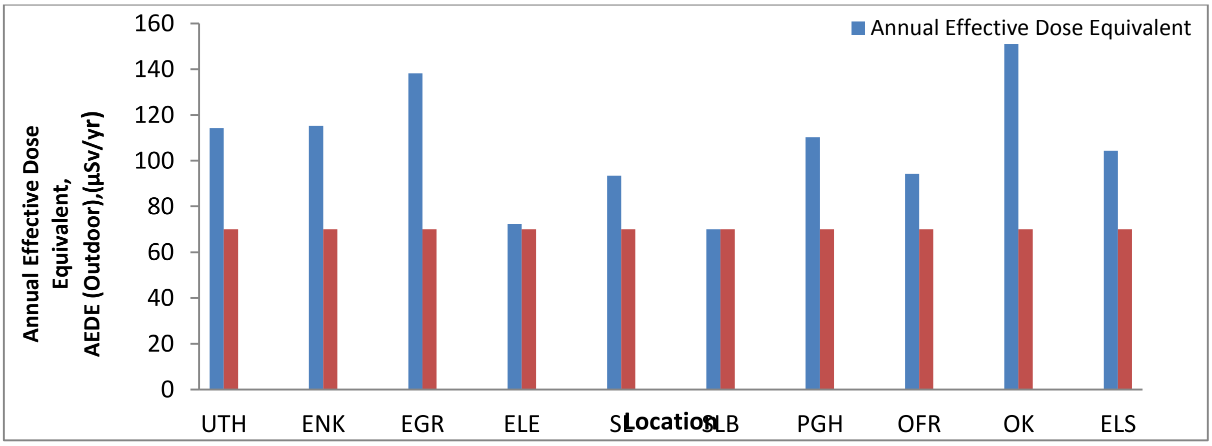

Figure 3: Annual Effective Dose Equivalent, AEDE (Outdoor) Compared with the UNSCEAR (2000) Threshold for the Locations

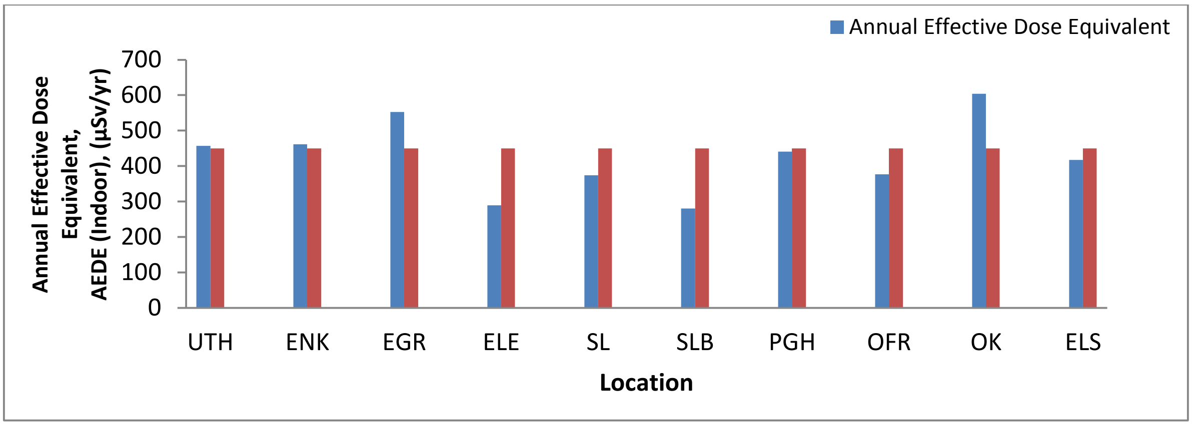

Figure 4: Annual Effective Dose Equivalent, AEDE (Indoor) Compared with the UNSCEAR (2000) Threshold for the Locations

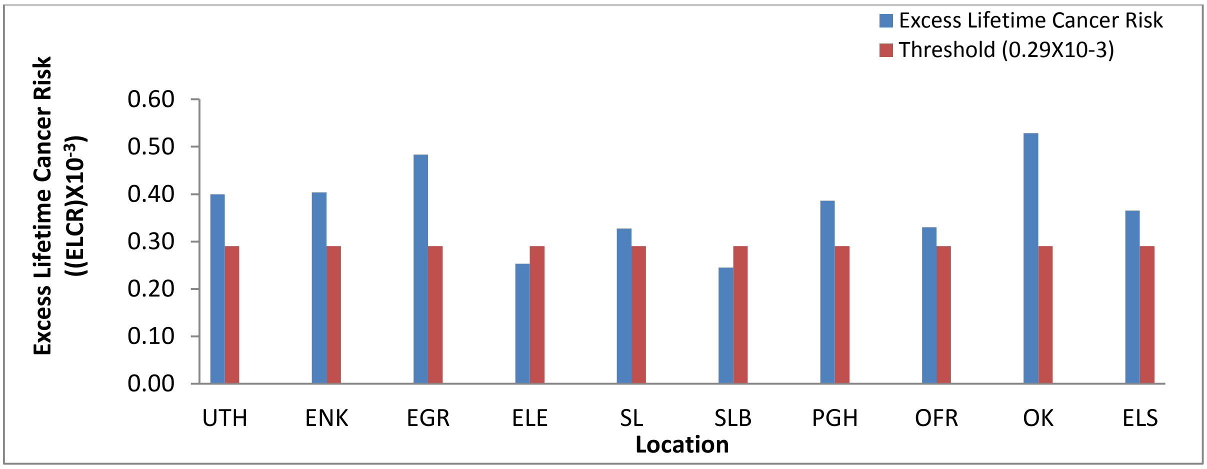

Figure 5: Excess Lifetime Cancer Risk (ELCR) Compared with the UNSCEAR (2000) Threshold for the Locations

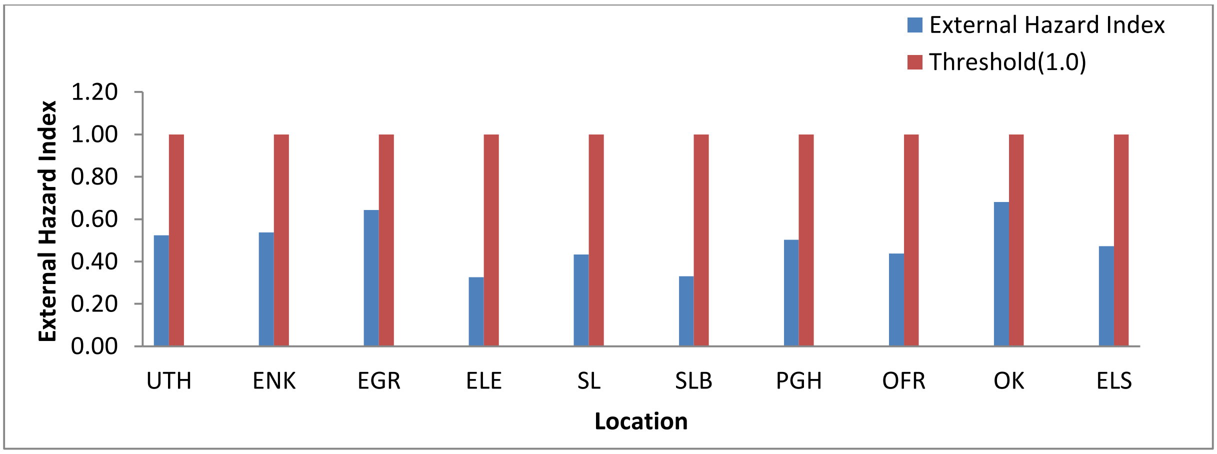

Figure 6: External Hazard Index (H_{ex}) Compared with the UNSCEAR (2000) Threshold for the Locations

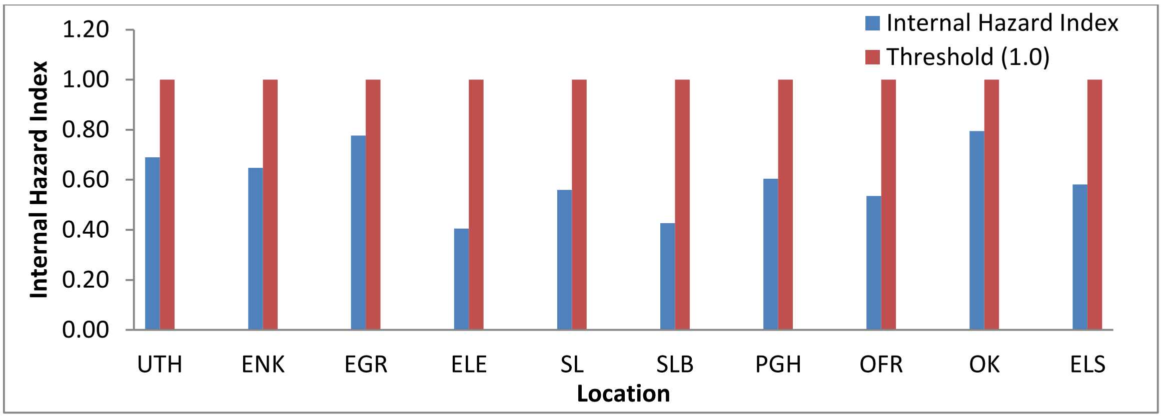

Figure 7: Internal Hazard Index (H_{in}) Compared with the UNSCEAR (2000) Threshold for the Locations

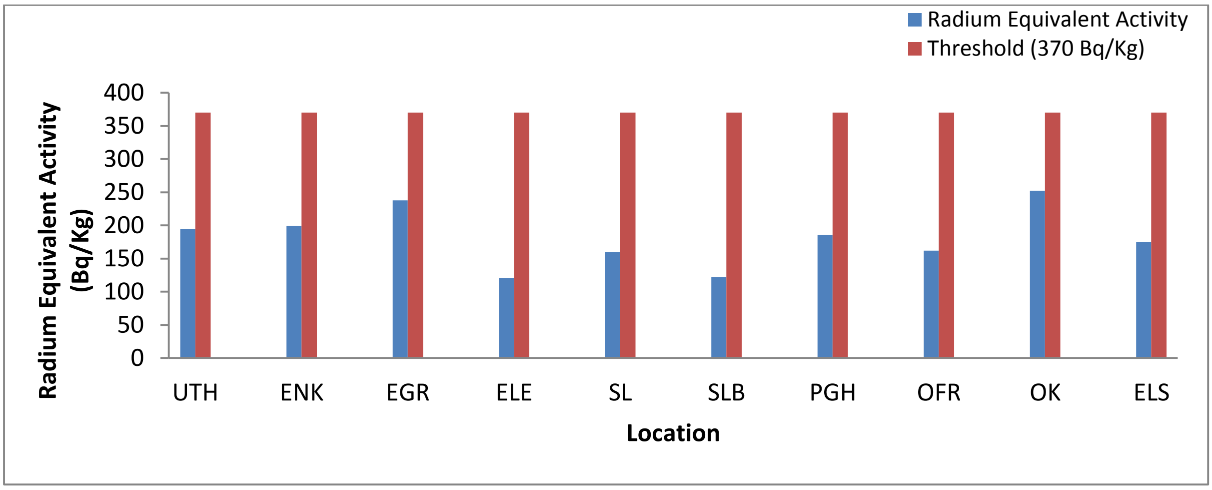

Figure 8: Radium Equivalent Activity (Ra_{eq}) Compared with the UNSCEAR (2000) Threshold for the Locations