Measurement of Radionuclides and their Impact on the Environment Around Asphalt Plants in Delta State

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ABSTRACT

Measurement of radionuclides and their impact on the environment around asphalt plants in some selected Asphalt mixing plant within Delta State, Nigeria was carried out. The Background Ionizing Radiation and the GPS of the location was measured using a well calibrated Gamma scout; Geiger counter multi-radiation meter and a GARMIN GPS meter and the result obtained at Raycon, DLA and Neodede Hot Asphalt Mixing Plants for outdoor exposure, shows a total mean value of (0.01492±0.038) (mRh^{-1}), (0.01497±0.037) (mRh^{-1}) and (0.01413±0.014) (mRh^{-1}) respectively. The total mean values obtained in the selected radiological centers were all above the world average BIR level of 0.013 (mRh^{-1}) as recommended by UNSCEAR (2000). These results were used to calculate some hazard indices such as the Equivalent dose (ED) in $mSvy^{-1}$, the absorbed dose rate (ADR) in $nGyh^{-1}$, Annual Effective Dose Equivalent (AEDE) and Excess Life Cancer Risk (ELCR). All the values obtained for each Parameter were above the world permissible limits as given by UNSCEAR (2000). The average activity concentration of ^{40}K, ^{238}U and ^{232}Th in the soil of the three study areas were (603.21±30.94) Bq/Kg, (5.70 ±0.678) Bq/Kg and (6.91 ± 0.405) Bq/Kg. For ^{40}K the average activity concentration was high and above the world recommended limit of 420 Bq/Kg (UNSCEAR 2000). ^{238}U and ^{232}Th were below the world recommended limits which are 33 Bq/Kg and 45 Bq/Kg. respectively. The Activity Concentration results were used to calculate the following radiological parameters: Absorbed gamma dose rate (DR) in (nGy/h), Annual Effective Dose Equivalent AEDE in (μSvy^{-1}), the Radium Equivalent (Ra_{eq}), Excess Life Cancer Risk (ELCR) and External Hazard Index. All the calculated radiological Values were above the recommended limit given by (UNSCEAR 2000). Water samples in the study areas was also collected and the average activity concentration of ^{40}K, ^{238}U and ^{232}Th were obtained and the Radiological Parameter were also calculated.

INTRODUCTION

Naturally occurring radioactive materials (NORM) are radioactive substances that are present in the environment without human intervention. Uranium and Thorium, which both produce radium and random gas when they decay, make up the majority of NORM. These substances spontaneously degrade and make up a sizable portion of a person's yearly background radiation exposure. In the right geological setting, one can locate naturally occurring radioactive mineral resources (Bhaumik et al., 2004). The background radiation in the vicinity is increased by their presence in the outcrop. The residents of the area may suffer negative effects from high exposure levels. The United Nations Scientific Committee on the Effects of Atomic Radiation Report (UNSCEAR, 2000) states that natural background radiation, with an average yearly effective dose of 2.4 msv worldwide, is the major source of human exposure.

The most important form of transportation is roads. As a result, most municipalities have a pressing need for a reliable road system. In actuality, developing countries spend a sizable portion of their annual budgets on road expansion, whereas rich nations place more emphasis on road upkeep. Road transportation has become the primary means of moving people and commodities in Nigeria due to the expansion of the country's road networks and vehicle fleets. For instance, the highway mode carries over 96% of all domestic passenger traffic in Nigeria, compared to approximately 4% for the remaining modes (water, air, and rail) (Arosanyin, 2000). 88% of the 190,000 km of Federal Highways are asphalt concrete wearing course carriage, with the remaining 7% being asphalt surface coating, according to a 2018 report from the Federal Ministry of Works and Housing's Highways Management Services Division (FMWH 1994). Earth roads that have not yet been constructed make up the remaining 5%.

Avwiri et al. (2021) examined the ionizing radiation exposure rate and related health concerns at several chosen solid mineral mining locations in Edo-North Nigeria using Digilert 200 and Rados Radiation Monitoring Meters combined with the Geographical Positioning System (Garmin GPSMAP 76S). Across the entire study, the mean exposure rates ranged from 0.0100.005mRh^{-1} 1 to 0.027mRh^{-1}. Except for the liberated limestone mining hole, where we observed 0.010mRh^{-1}, the obtained mean exposure rates were all higher than the ICRP standard limit of 0.013mRh^{-1}. It was also discovered that limestone mining sites had low exposure rates, but granite mining sites had high exposure rates. The calculated equivalent dose rate ranges from 1.049mSvy^{-1} to 2.287mSvy^{-1}, which is far beyond the general public's recommended allowable limit of 1.0mSvy^{-1}. Although 91.7% of the mining sites had greater absorbed dose rates, the mean AEDE measured across the entire study area was lower than the ICRP standard. The average extra lifetime cancer risk ranges between 0.472 x 10-3 and 1.27 x 10-3. According to the findings of the study, the risk of contracting cancer from radiation exposure is higher in areas such as the Cinoma pit, Cetraco pit, Niger-Cat pit, Jigom pit, Oaries pit, and Petra-Quarries pit. An Assessment of the Environmental Impact of Asphalt Production in Nigeria is carried out by Rilwani et al. (2020). The research was able to examine the environmental impact of asphalt manufacturing in Nigeria, utilizing the Delta State Direct Labour Agency's HMA facility at Agbarha-Otor in Ughelli North

Local Government Area, Delta State as a case study. He gathered soil, water, and vegetation samples during a field survey, and he also conducted interviews and focus group talks with stakeholders. The laboratory results from field samples gathered show that the HMA facility has a minor impact on the soil, plants, and water around it. The production of hot asphalt concrete takes place at an asphalt plant, sometimes referred to as a Hot Mix Asphalt (HMA) facility. A Hot Mix Asphalt plant is a group of mechanical devices that combine, heat, dry, and mix bitumen (asphalt cement) with aggregates (inert mineral components like sand, gravel, crushed stone, slag, rock dust, or powder). The impact of development activities (like building and maintaining roads) on the physical environment and the welfare of people is a major concern for the international community (UNCED 1992). Hot Mix Asphalt plants have affected host communities in Nigeria physically and socially, although this issue has not yet been resolved. Hot mix asphalt factories release pollutants into the atmosphere that are chronic toxicants, carcinogens, and acute system toxicants. These pollutants can irritate the upper respiratory tract and induce headaches, fatigue, wheezing and shortness of breath, dizziness, and nausea. Like other environmental pollution health impacts, the possible health effects of asphalt plant pollution depend on the length of exposure and the number of pollutants present in the environment. The Nigerian Nuclear Regulatory Authority (NNRA) is vested with the legislative power to regulate nuclear and radiation-generating sources in Nigeria and to oversee compliance with radiation safety and protection regulations. The levels of natural radioactivity in the area near asphalt factories have been the subject of numerous research around the globe. Terrestrial radiation level in a few Port Harcourt, Nigeria, asphalt factories (Avwiri et al., 2023) in one of the most recent works completed. This study aims to estimate and quantify the level of natural radionuclide contamination in air, soil, and water because of the operations of construction firms building asphalt-mixing facilities.

MATERIALS AND METHOD

Study Area

The soil surrounding asphalt plants in Delta State, Nigeria, is the subject of the investigation. The region now known as Delta State was formerly a cohesive unit of Nigeria's former Western Region. After being a part of the defunct Bendel State (1976-1991) and the Mid-Western State (1963-1976), it attained independence on August 27, 1991. The capital of Delta State is Asaba. The following specific Delta State locales were used for the work. The Delta State map is depicted in Figure 1. The state's following asphalt plants were examined.

1. **Raycon Construction Company Asphalt Plants:** This plant is situated in the Ughelli North local government region, along the Ughelli Patani express road, in one of the city's busiest neighborhoods. The location of Ughelli North is 5.500187 latitude and 5.993834 longitude. More than six (6) years have passed since the asphalt plant first began operating. The asphalt plant is next to a defunct asphalt plant owned by the same building business. The location was changed to allow the business room to grow. A micro block industry and residential buildings surround the asphalt company. The congested Ughelli Patany express road is close by. The site of the Raycon Asphalt facility is depicted on Plate

2. **Delta State Direct Labor Agency (DLA) Asphalt plant:** The asphalt plant is situated on the outskirts of Agbara-otor town, at a latitude of 5°32'04.8"N and a longitude of 6°04'29.2"E. The asphalt facility is operated by the Delta State Direct Labour Agency. Ughelli, the administrative center of Ughelli North Local Government Area in Delta State, Nigeria, located 6 kilometers away from Agarha-otor. The study area is covered in recent Niger Delta sediments. The plant is situated in a remote location of a non-residential area, near to a river where there are several sand-drenching activities taking place. There are numerous open ponds close to the Hot Mix Asphalt Plant, which is bordered by a Kaolin deposit along the riverbank. As a result, fishing is one of the main pastimes of the locals in the studied regions. More than ten (10) years have passed since the asphalt plant first began operations. On Plate 2, the location of the plant is depicted on a google map.
3. **Neodede Enterprise Asphalt Plants Okpanam:** The town of Okpanam is bordered to the east by Asaba, to the southeast by Igbuzo (Ibusa), to the south by Ogwashi-Uku, to the west by Issele Azagba, to the north by Akwukwu Igbo, to the north by Atuma, and to the north by the River Niger. The power plant is situated in the Oshimili North Local Government Area of Delta State, Nigeria, in a place known as Isela-Asaba of Okpanam. In a dispersed residential neighborhood, the plant is situated. Four (4) years have passed since the factory first began operating. In addition to measuring the background radiation levels in the area around the plants, soil and water samples were also gathered for later study in the lab.

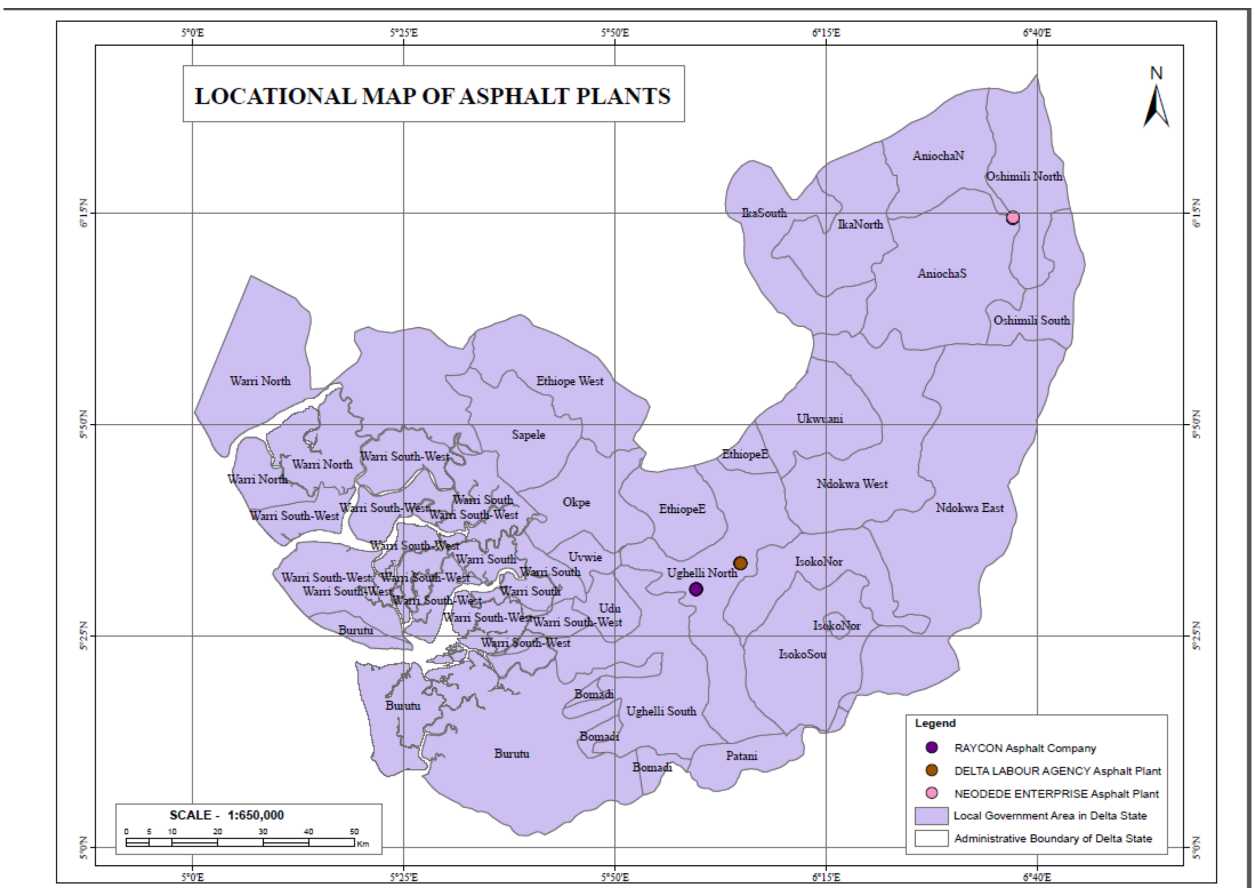

Figure 1: ARCGIS MAP SHOWING THE STUDY AREAS

Measurement of Background Ionizing Radiation (BIR):

After mapping the research regions with the GAMMA- SCOUT radiation meter, the background ionizing radiation of the area was measured. Ten (10) measurements were made at intervals of 15–30 meters between randomly selected sample points that encompassed the study areas' cardinal directions (East, West, North, and South). In the study, a Geographical Positioning System (GPS) was also used to measure the elevation and GPS of the study regions. An ARCGIS map of the research areas was created using this data.

Activity Concentration Measurements**:** The levels of radioactive activity in the samples were measured using a 7.62 cm by 7.62 cm NaI (Tl) detector. The entire electronic instrumentation for the detector was housed inside a cylindrical lead shield with a thickness of around 100 mm and connected to a PC-based multichannel analyzer for data collection and gamma spectra processing. Standard sources of known gamma-ray energies and activity were generated by the **Nigerian Nuclear Regulatory Authority (NNRA)** research lab University of Ibadan and used for the energy calibration. The sample container was counted using the same shape as its empty counterpart. This count was deducted from the gross count to determine the background count. The activity concentrations of ^{40}K, ^{238}U, and ^{232}Th were calculated using the ^{214}Bi line at 1120.3 keV and the ^{228}Ac line at 911.1 keV, respectively. The activity concentrations of 40K, 238U, and ^{232}Th, as well as the NaI(Tl) detector system's detection limits, were directly estimated using gamma-ray transition data at 1460.8 keV. To obtain meaningful counts below the picture peaks, the prepared samples were put into the detector and counted for 25,200 seconds.

Radiological Risk Parameters:

Some radiological parameters will be determined in order to calculate the radiation risk to the populace exposed to these radionuclides in the soil as a result of the post-product facilities of the asphalt production company:

Radium Equivalent Activity (Ra_{eq}): The radium equivalent (Raeq) activity is the weighted average of the 238U, 232Th, and 40K activities. It is based on the assumption that the radiation dosage rates produced by 1 Bq kg-1 of 238U, 0.7 Bq kg-1 of 232Th, and 13 Bq kg-1 of 40K are equivalent. The relation will be used to determine the radium equivalent activity index (Avwiri et al., 2013).

$$Ra_{eq} = C_u + 1.43C_{Th} + 0.077C_K \quad (1)$$

Where Cu, C_{Th} and C_k are the activity concentration in $Bqkg^{-1}$ of ^{238}U, ^{232}Th and ^{40}K.

Absorbed Dose rate (ADR): The absorbed dose rate (D) will be computed using the following expression.

$$D = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (2)$$

Where, D is the absorbed dose rate in $nGyhr^{-1}$, C_U, C_{Th}, and C_K are the concentrations of uranium, thorium and potassium respectively.

Annual Gonadal Equivalent Dose (AGED): It has been seen that an increase in AGED can impact the bone marrow, destroying red blood cells and replacing them with white blood cells. Due to this circumstance, a lethal blood malignancy called leukemia develops. Using the calculation, the AGED for those living close to the steel company will be assessed (UNSCEAR, 2000);

$$\mathbf{AGED\ (Sv/yr) = 3.09C_{Ra} + 4.18C_{Th} + 0.314C_K} \quad (3)$$

Where C_{Ra} ,C_{Th} and C_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples.

Representative Gamma Index (Iγ): This is used to calculate the potential risk from gamma radiation posed by the natural radionuclides found in the samples under study. The estimation of the representative gamma index will be as follows:

$$\mathbf{I\gamma = C_{Ra}/150 + C_{Th}/100 + C_K/1500 \quad \leq 1} \quad (4)$$

Annual Effective Dose Equivalent (AEDE): By applying a dose conversion factor of 0.7 Sv/Gy to the absorbed dose rate and using occupancy factors for indoor and outdoor spaces of 0.2 and 0.8, respectively, it is possible to compute the annual effective dose equivalent that a member of the public receives. The following equations are used to calculate AEDE (Veiga et al., 2006);

$$\mathbf{AEDE_{(outdoor)}(\mu Sv/y) = Absorbed\ dose\ D\ (nGy/h) \times 8760h \times 0.7Sv/Gy \times 0.2 \times 10^{-3}} \quad (5)$$

Excess Lifetime Cancer Risk (ELCR): The Excess Lifetime cancer risk (ELCR) will be calculated using the following equation (Jankowski et al., 2011);

$$\mathbf{ELCR = AEDE \times DL \times RF} \quad (6)$$

Where AEDE is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to be 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public.

Hazard Indices (H_{ex}): The external hazard (Hex) indices will be evaluated using the relations (Ramasamy et al., 2009);

$$\mathbf{H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \quad \leq 1} \quad (7)$$

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

RESULTS AND DISCUSSION

Results

Table 1 presents the Average values of BIR and the radiological indices of the Locations. Figures 1 to 3 display the comparison of the BIR results with the internationally accepted benchmark (UNSCEAR, 2000), as well as the estimated hazard indices. Table 2 shows the average Activity Concentrations of Naturally Occurring Radionuclides (^{40}K, ^{238}U and ^{232}Th) in Soil, Table 3 represents the Radiometric parameters such as Absorbed Dose Rate (ADR), AEDE, ELCR, $I_{\gamma r}$, H_{ex} and Ra_{eq} for soil Samples. Figure 4-12 shows the activity concentration of radionuclide and their radiological parameters versus the world standard. Table 4 shows the average activity concentration of radionuclides in soil samples, Table 5 Some the Radiometric parameters such as Absorbed Dose Rate (ADR), AEDE, ELCR, $I_{\gamma r}$, H_{ex} and Ra_{eq} for water Samples. Table 6 represents the Comparison of the Radiometric Parameters of the work with other work within and outside Delta State

Table 1: Average values of BIR and the radiological indices of the Locations

LOCATION	BIR (mRh^{-1})	EDR (mSvy^{-1})	ADR (nGyh^{-1})	AEDE (µSvy^{-1})	ELCR (x10^{-3})
RAYCON	0.01492±0.038	2.2546±0.0025	129.804±3.288	159.191±22.08	0.56±0.27
DLA	0.01497±0.037	1.2588±0.004	129.978±0.338	159.406±35.47	0.56±0.43
NEODEDE	0.01413±0.014	1.1807±0.0015	122.931±0.133	150.765±13.47	0.53±0.16
WORLD STANDARD (UNSCEAR, 200)	0.013		84.00	70.00	0.29x10^{-3}

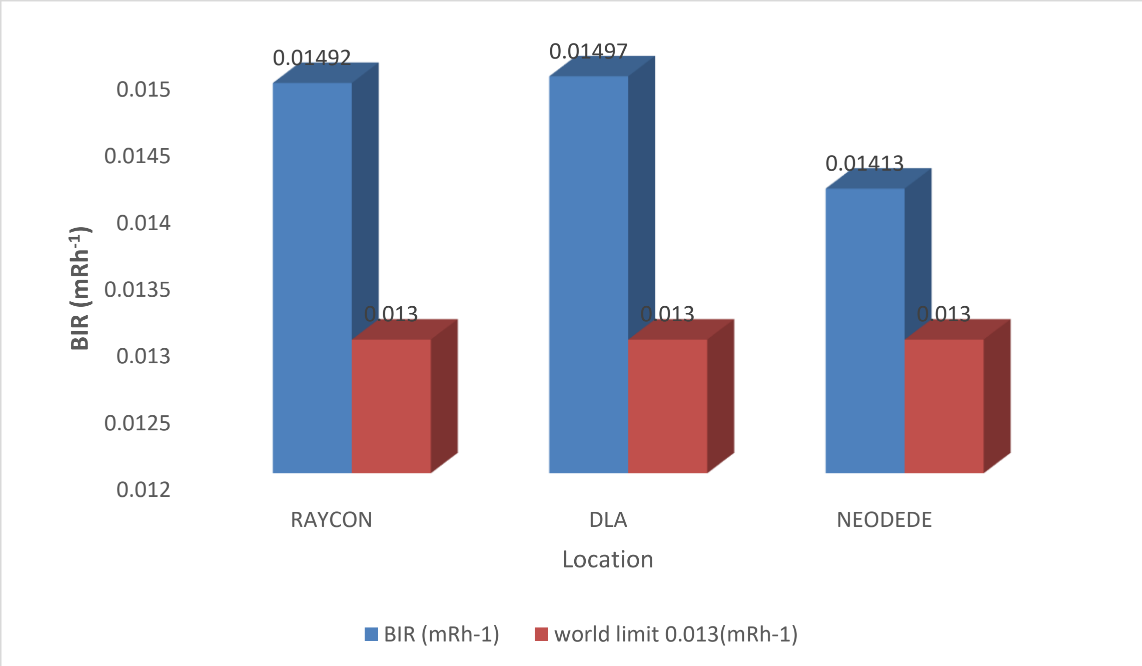

Figure 1: Comparing BIR (mRh^{-1}) with UNSCEAR world standard limit

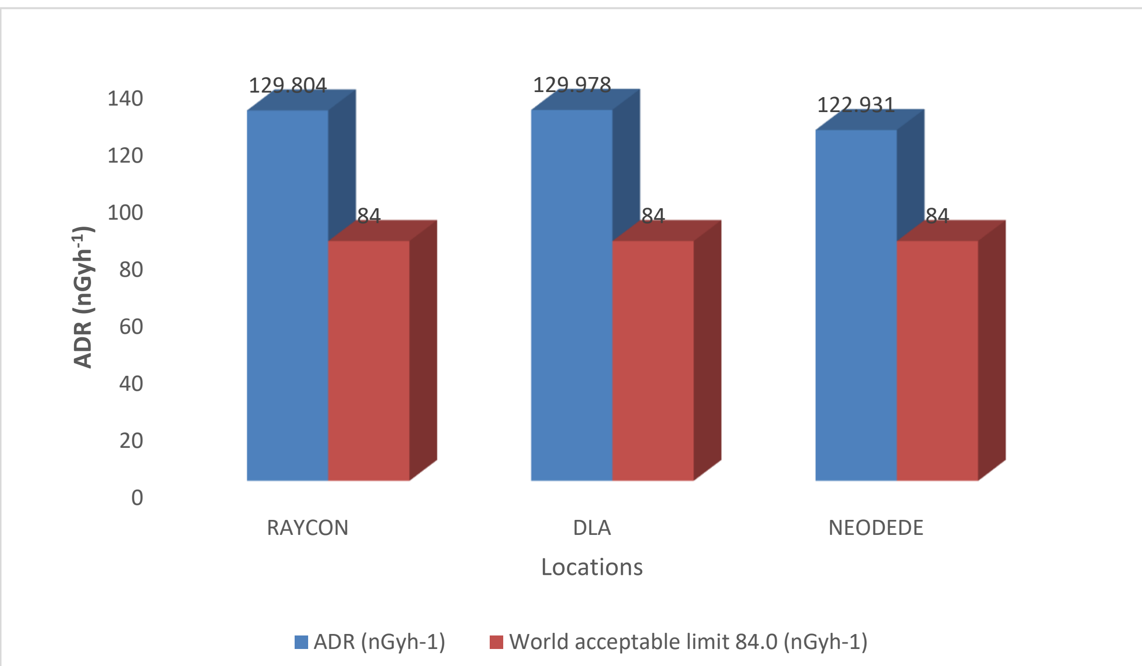

Figure 2: Comparison of ADR ($nGyh^{-1}$) with UNSCEAR world standard limit.

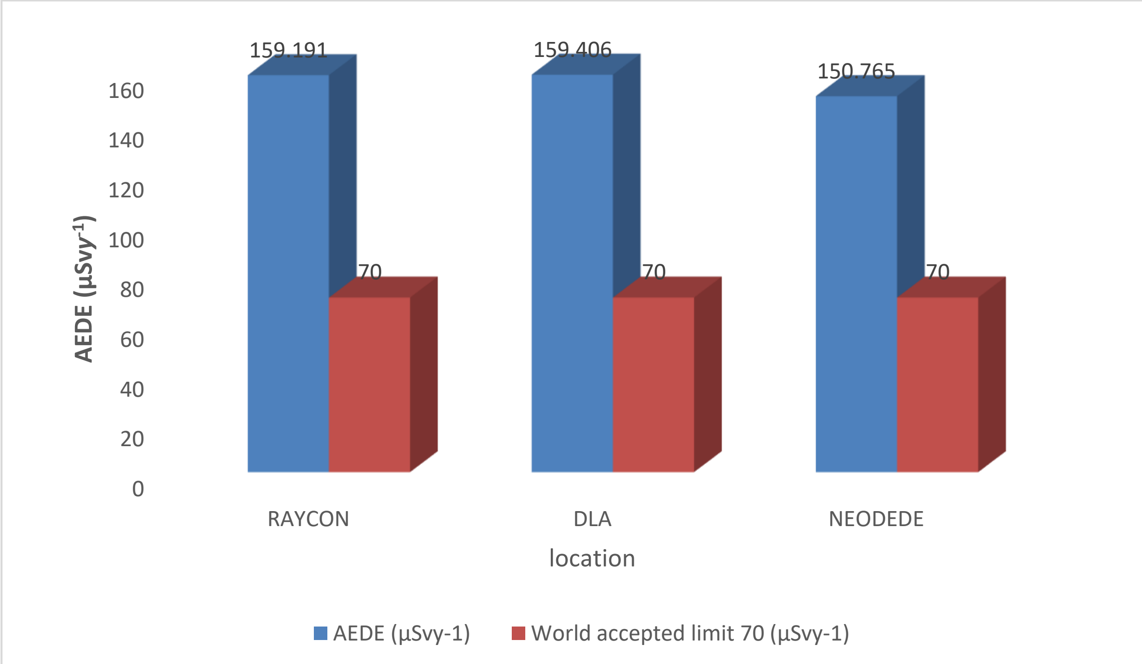

Figure 3: Comparing BIR AEDE (µSvy^{-1}) with UNSCEAR world standard limit.

Table 2: The Activity Concentrations of Naturally Occurring Radionuclides (^{40}K, ^{238}U and ^{232}Th) in Soil

S/NO.	SAMPLE	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
1.	RAYCON	603.21 ± 30.94	5.70 ± 0.678	6.91 ± 0.405
	RAYCON CONTROL	423.03 ± 21.38	2.43 ± 0.24	6.88 ± 0.39
2.	DLA	844.06 ± 43.36	11.69 ± 1.34	9.39 ± 0.49
	DLA CONTROL	440.77 ± 22.93	3.08 ± 0.39	4.31 ± 0.26
3.	NEODEDE	586.01 ± 29.88	4.036 ± 0.47	9.67 ± 0.57
	NEODEDE CONTROL	32.22 ± 1.69	0.48 ±0.067	5.09 ± 0.30
	WORLD STANDARD	420.00	33.00	45.00

(UNSCEAR, 2000)	

Table 3: Radiometric parameters such as Absorbed Dose Rate (ADR), AEDE, ELCR, $I_{\gamma r}$, H_{ex} and Ra_{eq} for soil Samples

S/NO.	LOCATION	**ADR ($nGyh^{-1}$)**	**AEDE (μSvy^{-1})**	**ELCR ($x10^{-3}$)**	**$I_{\gamma r}$**	**H_{ex}**	**Ra_{eq}**
1.	RAYCON	35.30	43.28	0.15	0.67	0.62	102.77
	CONTROL	22.92	28.11	0.10	0.35	0.12	42.93
2.	DLA	50.59	62.03	0.22	0.73	0.24	221.96
	CONTROL	22.41	27.48	0.10	0.36	0.12	43.18
3.	NEODEDE	36.36	44.58	0.16	0.51	0.17	100.93
	CONTROL	4.64	5.69	0.02	0.08	0.03	10.24
	WORLD STANDARD (UNSCEAR, 2000)	84.00	70.00	0.29	1.00	1.00	370.00

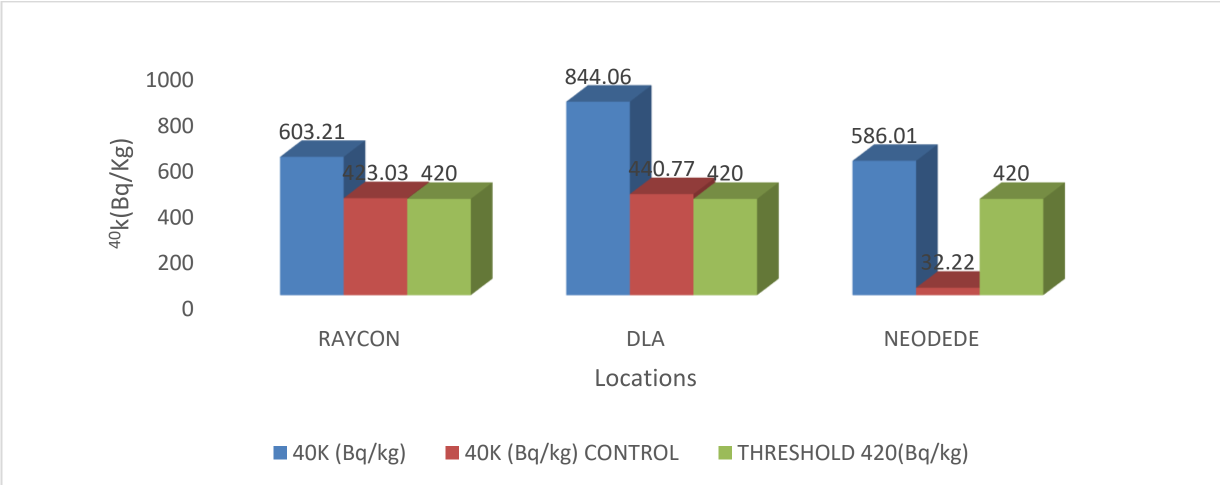

Figure 4: Comparison of the activity concentration of ^{40}k (Bq/Kg) of all the locations with that of the control soil sample and world recommended limit

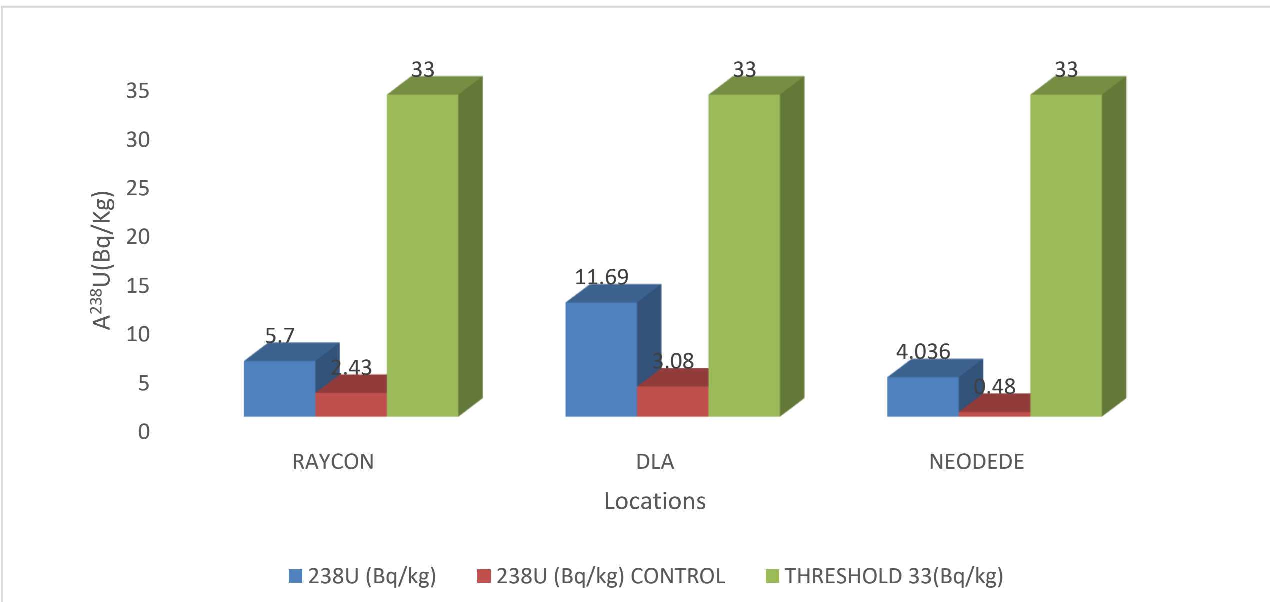

Figure 5: Comparison of the activity concentration of ^{238}U (Bq/Kg) of all the locations with that of the control soil sample and world recommended limit.

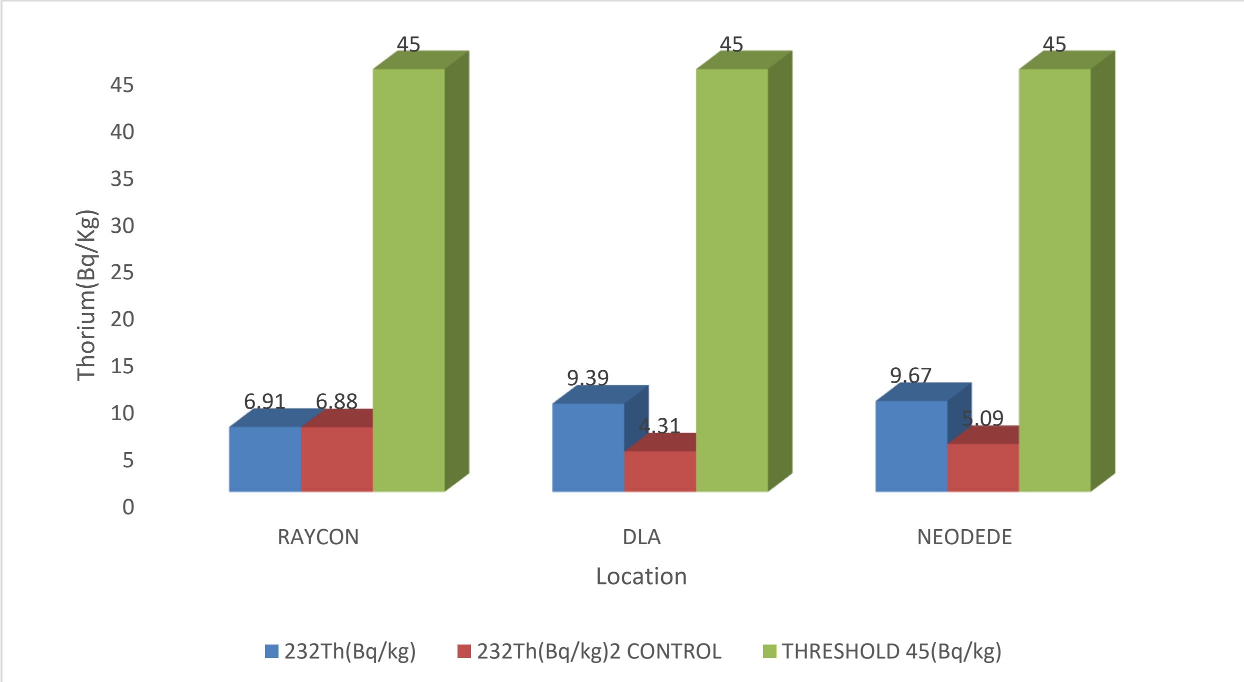

Figure 6: Comparison of the activity concentration of ^{232}Th (Bq/Kg) of all the locations with that of the control soil sample world recommended limits.

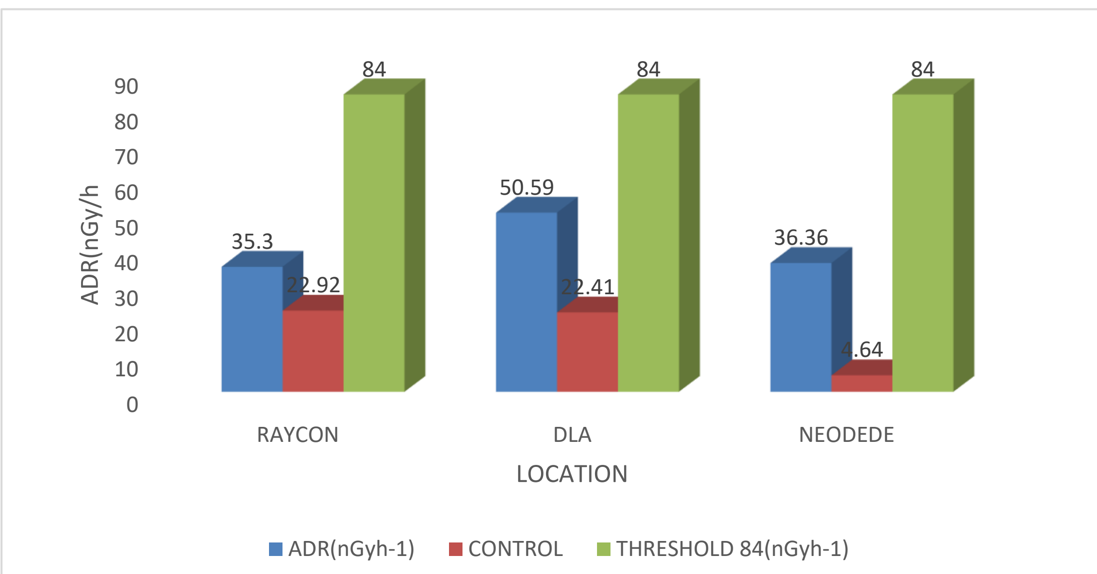

Figure 7: Comparison of ADR of soil Samples with the ADR of the control soil sample

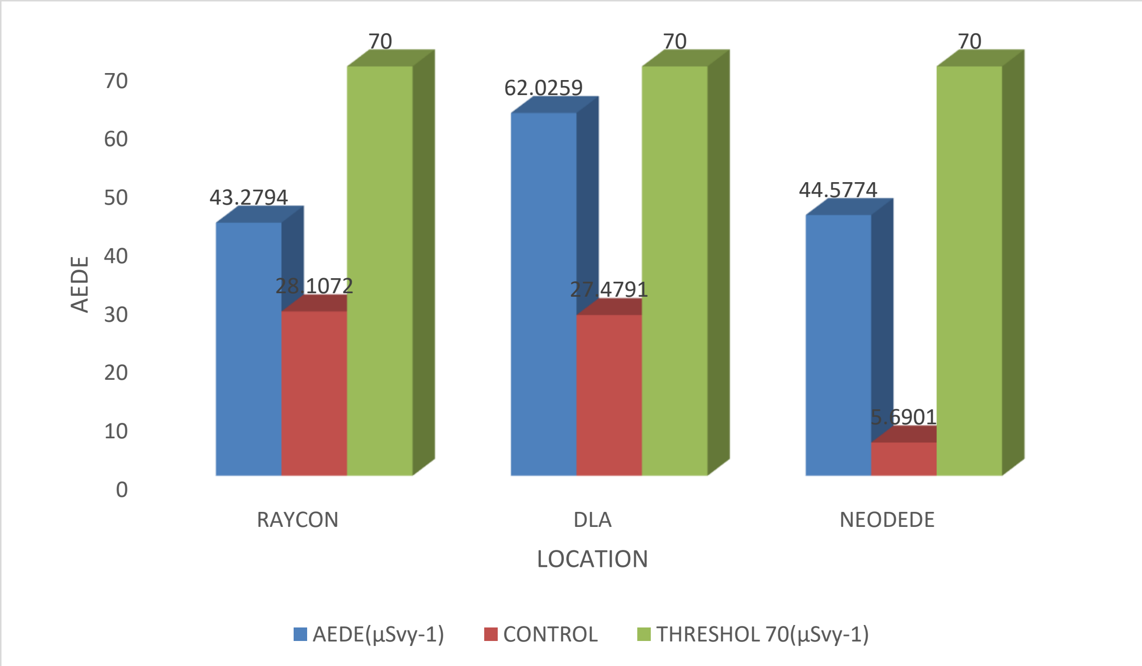

Figure 8: Comparison of AEDE of Soil Samples of the Different Locations with the AEDE of control sample of locations.

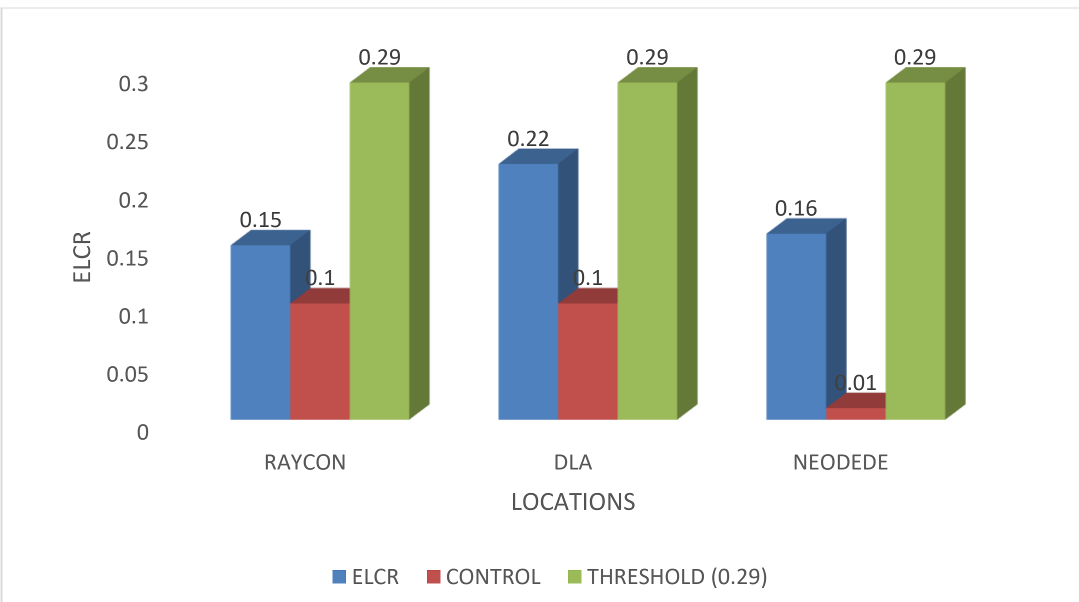

Figure 9: Comparison of ELCR of soil samples of the different locations with the ELCR of the control samples of the locations.

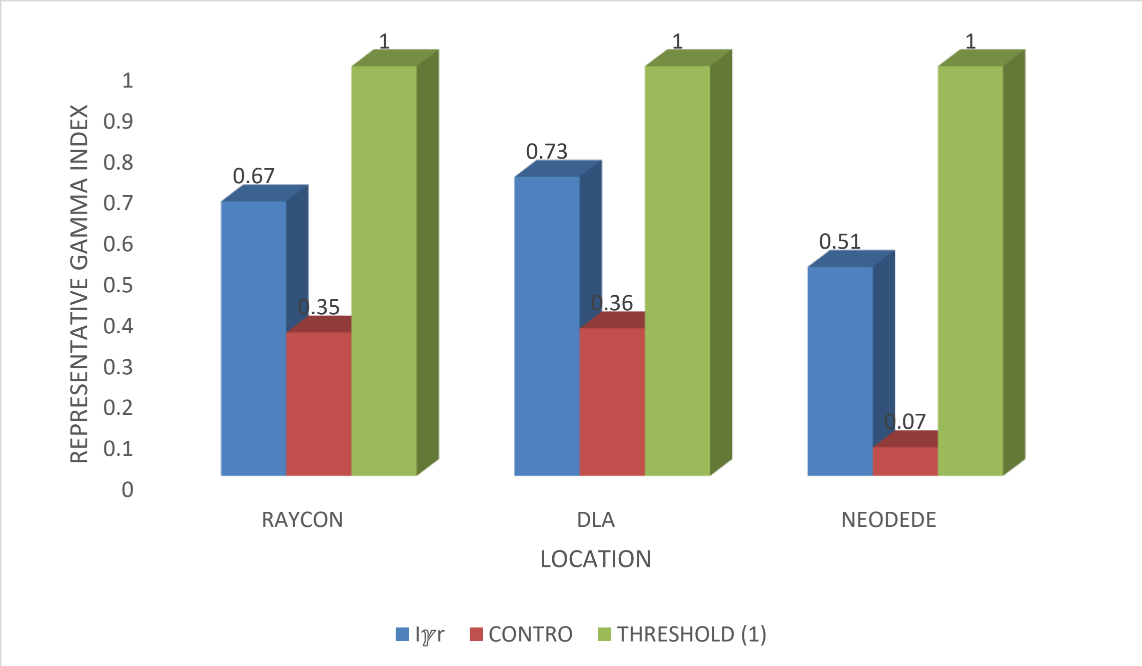

Figure 10: Comparison of Gamma Index of the different locations with the Gamma index of the control samples of all locations.

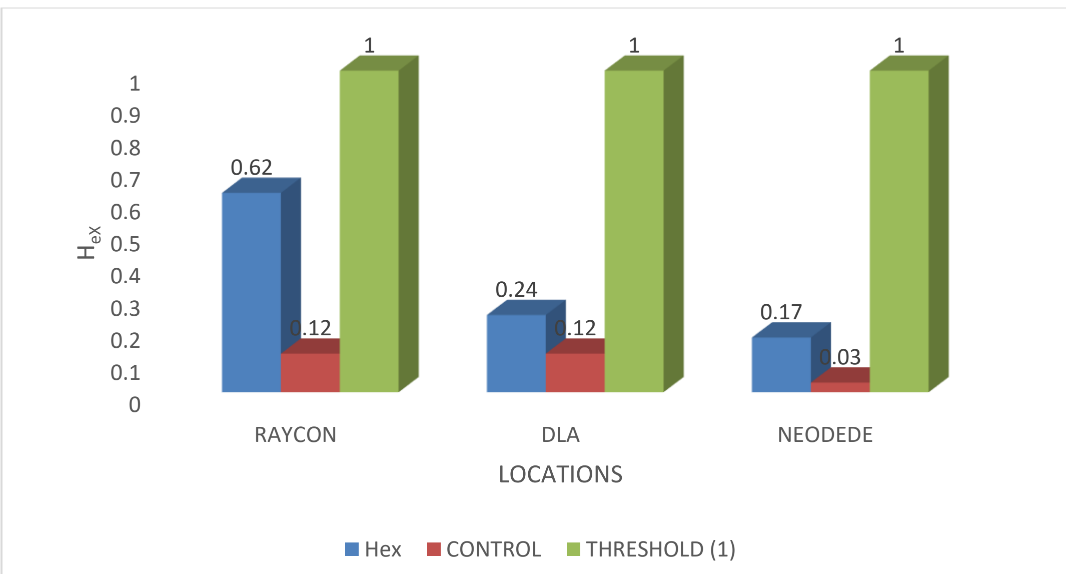

Figure 11: Comparison of H_{eX} of the study areas with that of the control soil sample of each study area.

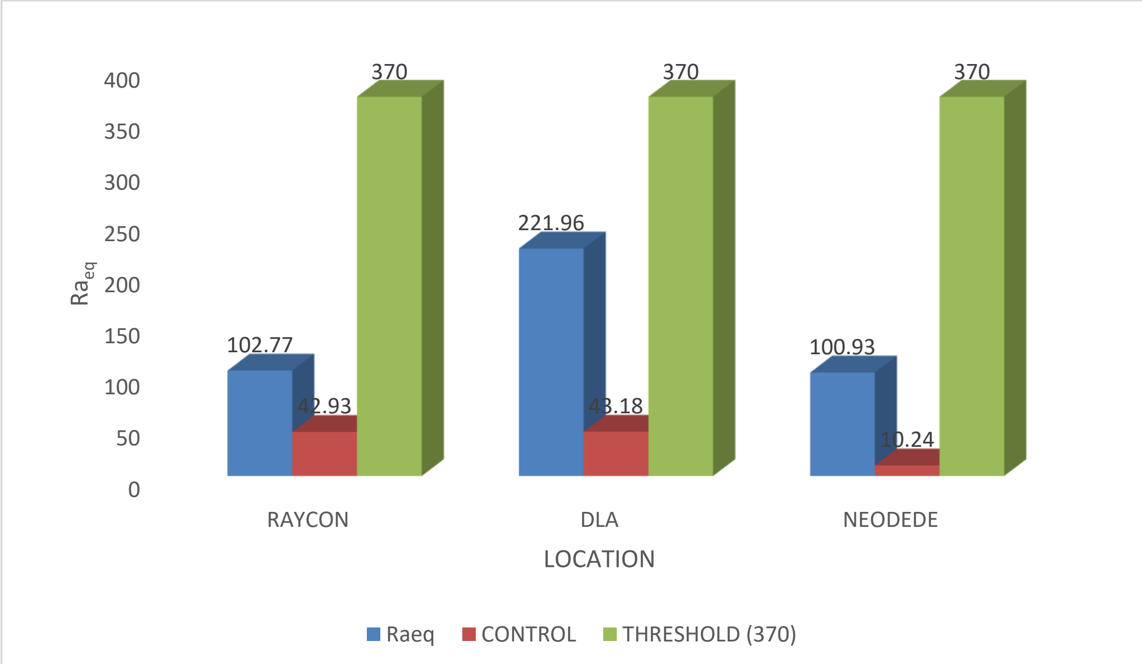

Figure 12: Comparison of the Ra_{eq} of soil samples of the different locations with the control soil samples of each location.

Table 4: Average Values of water Samples

S/NO.	SAMPLE	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th(Bq/kg)
1.	RAYCON	70.65 ± 3.64	6.28 ± 0.61	5.35 ± 0.31
2.	DLA	21.71 ± 1.11	4.39 ± 0.55	2.82 ± 0.16
3.	NEODEDE	29.29 ± 1.52	3.57 ± 0.42	3.90 ± 0.23
4.	WORLD RECOMMENDED LIMIT (UNSCEAR, 2000)	10.00	10.00	1.00

Table 5: Some the Radiometric parameters such as Absorbed Dose Rate (ADR), AEDE, ELCR, $I_{\gamma r}$, H_{ex} and Ra_{eq} for water Samples.

S/NO.	LOCATION	ADR ($nGyh^{-1}$)	AEDE ($mSvy^{-1}$)	ELCR ($x10^{-3}$)	$I_{\gamma r}$	H_{ex}	Ra_{eq}
1.	RAYCON	79.82	97.90	0.34	0.142	0.052	19.37
2.	DLA	25.48	31.25	0.11	0.071	0.027	10.09

3.	NEODEDE	33.35	40.90	0.14	0.082	0.100	11.42`
	WORLD RECOMMENDED STANDARD (UNSCEAR 2000)	57.00	1.00	$0.2x10^{-3}$	1.00	1.00	370.00

Table 6: Comparing the Radiometric Parameters of the work with other work within and outside Delta State

Sample	LOCATION	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	REFRENCE
Bitumen	Gbeleju-Loda	320.46	24.33	12.36	Abiola et al. (2018)
White cement		30.2	24.60	51.30	Agbalagba et al. (2016)
Soil	Agbabu	16.09	18.71	17.99	Isinkaye (2018)
Soil	Illubirin	33.98	38.90	29.82	Isinkaye (2018)
Soil	Iju-oke	35.01	36.08	21.52	Isinkaye (2018)
Bitumen	Ondo	42.20	27.20	40.00	Ademula et al. (2010
Water	Ondo	40.14	8.15	5.71	Ibikunle et al. (2018)
Soil	Accra, Ghana	13.61	24.22	162.08	Faanu et al. (2017)
Water	Tanke, Ilorin	0.81	1.8	0.08	Nwankwo et al. (2019)
Rock	Precambrian Oban Massif, southern Nigeria	1073.06	160.74	250.76	Ekwok et al (2022)
Sand	Ekalakala river, Kenya	820.00	24.00	26.20	Lucia et al. (2020)

Raw cement	Gaza, Palistine	65.00	27.00	13.80	Mona et al (2020)
Soil	Raycon Ugheli North	603.21	5.70	6.91	Present Study
Soil	DLA Ughelli North	844.06	11.69	9.39	Present Study
Soil	Neodede Oshimili North	586.01	4.036	9.67	Present Study
Water	Raycon Ugheli North	70.65	6.28	5.35	Present Study
Water	DLA oshimili North	21.71	4.39	2.82	Present Study
Water	Neodede Oshimili North	29.29	3.57	3.90	Present Study
world recommended limit		420	33	45	(UNSCEAR 2000)

Discussion

The BIR exposure level: The measured BIR exposure rate ranged from 0.012 to 0.019 (mRh-1), with a mean value of 0.0149 mRh-1 at the Raycon Asphalt Plant, 0.0117 to 0.0206 (mRh-1), with a mean value of 0.0149 mRh-1 at the DLA Asphalt Plant, and 0.0107 to 0.0158 (mRh-1), with a mean value of 0.0141 mRh-1 at the Neodede Asphalt Plant.

The mean exposure rate for the investigated environment was higher than the allowed limit of 0.013mRh-1 or 20.0mSvy-1 for Public (ICRP, 2007; Osimobi et al., 2015; Agbalagba et al., 2016). The outcome, as shown in figure 4.7, shows that the majority of the sample points surpassed the BIR level permitted by UNSCEAR 2000 for the general public. The results are comparable to other related studies like the BIR results reported by Abalagba et al. (2016) around Ughelli Metropolis and Avwiri et al. (2013) near asphalt processing factories in rivers state.

The industrial operations conducted in the various sampling locations and associated geophysical characteristics are responsible for the variance and high exposure rate level. The principal raw materials used by these businesses, such as petroleum products, chemicals, and construction materials like asphalt, granite, cement, etc., have been known to include some radioactive elements that increase BIR level (Francis et al. 2011). The high BIR levels are an alarming sign that the general populace may be exposed to radioactive contamination in the environment.

Absorbed dose rate (ADR) in air: The possibility for any biochemical alterations in certain tissues is evaluated using the absorbed dose. It measures the amount of radiation energy that could be absorbed by a person who could be exposed. Equation 3.3 was used to convert the measured BIR exposure levels to the rate of radiation absorption in the air. The calculated absorbed dose rate for the three locations (Raycon, DLA and Neodede) are 129.804 ηGyh^{-1}, 129.978 ηGyh^{-1} and 122.931ηGyh^{-1}. These dose rates arising from BIR exposure in the studied locations are far higher than the recommended safe limit of 84.0ηGyh^{-1} (UNSCEAR, 2008; Ononugbo and Mgbemere, 2016) for outdoor exposure. These dose rates show a radiation contaminated environment.

Annual effective dose equivalent (AEDE): The AEDE is used in radiation assessment and protection to calculate the annual total body absorbed dose. It is employed to evaluate the likelihood of probable future long-term impacts. The calculated values of AEDE from Raycon, DLA and Neodede are 159.191**(μSvy^{-1})**, 159.404**(μSvy^{-1})** and 150.765**(μSvy^{-1})**, Table 4.7. These annual effective doses are higher than world average value of 70**(μSvy^{-1})** (ICRP, 2007; UNSCEAR). This implies that the studied location may be radiologically contaminated due to the industrial activities taking place in the area.

Excess lifetime cancer risk (ELCR): The excess lifetime cancer risk is used in radiation protection assessment to predict the probability of an individual developing cancer over his lifetime due to low radiation dose exposure, if it will occur at all. The values obtained for Raycon, DLA and Neodede are 557.178, 557.993 and 527.68 respectively. The values obtained, are higher than the world average value of $0.29\times10^{-3.}$ This high value for excess lifetime cancer risk indicates that there exist the possibilities of cancer development by residents who wish to spend all their life time in the area.

The Activity Concentrations of Naturally Occurring Radionuclides (^{40}K, ^{238}U and ^{232}Th) in Soil

Table 3, shows the individual results of the gamma spectroscopy of the analysed soil samples from the study area. The mean specific activity or mean activity concentration (activity per unit mass) of ^{40}K, ^{238}U and ^{232}Th is expressed in Bq/kg from all the study areas. The activity concentration of ^{40}K, of soil samples at Raycon, DLA and Neodede Asphalt mixing Plants ranges from 355.4 to 963.19, 440.77 to 1297.95 and 18.01 to 1594.51 respectively with mean values of 603.21 ± 30.94, 844.06 ± 43.36, and 586 .01 ± 29.8 respectively as shown in Table 4.12. The activity concentration of ^{238}U at Raycon, DLA and Neodede ranges from 2.43 to 9.41, 3.08 to 25.82 and 0.48 to 7.97 with mean values of as 5.70 ± 0.678, 11.69 ± 1.34 and 4.036 ± 0.47 respectively as shown in table 4.12. Also, the activity concentration of ^{232}Th at Raycon, DLA, and Neodede, ranges from 4.88 to 8.32, 4.31 to 13.55 with an average value of 6.91 ± 0.405, 9.39 ± 0.4, and 9.67 ± 0.57 respectively.

The average activity concentration of study areas was compared with the world recommended limit. For ^{40}K it can be seen from Figures 4.14, 4.15 and 4.16, that the average activity concentration was high and above the world recommended limit of 420 Bq/Kg (UNSCEAR 2000). ^{238}U and ^{232}Th are below the world recommended limits which are 33 Bq/Kg and 45 Bq/Kg (UNSCEAR 2000) respectively.

The activity concentration of ^{40}K, ^{238}U and ^{232}Th from the present study was compared with other research work within the country and outside the country. The comparison shows that the activity concentration of ^{40}K, in the present study was higher than all other values from other research locations except for the one from Rock samples at Precambrian Oban Massif, southern Nigeria which was 1073.06 Bq/Kg (Ekwok et al 2022). The comparison also shows that most of the result from other studies were higher than the present study for activity concentration of ^{238}U and ^{232}Th. A few of the values however falls within range.

Discussion of radiation Hazard Indices

Different known radiation health hazard indices equations were used in this study to arrive at a more reliable assessment of the health risks to irradiated personnel. The following radiation hazard indices are discussed below: equivalent dose, absorbed dose rate, annual effectivedose equivalent and excess lifetime cancer risk, Radium Equivalent Ra_{eq}, and external hazard index.

Absorbed gamma dose rate (ADR): The absorbed gamma dose rate (DR) of the study areas was calculated using equation 3.6, and the average value for each location was as follows: Raycon 35.3013(nGy/h) DLA 50.5921 (nGy/h) and Neodede 36.3600(nGy/h) as shown in table 4.12. The absorbed gamma dose rate of the study areas was compared using a histogram shown in figure 4.24. From the result, all the soil samples from the three study areas have a mean ADR value less than world recommended standard of value of 84nGy/h provided by UNSCEAR (2000).

Annual Effective Dose Equivalent (AEDE): The annual effective dose equivalent is also one of the commonly used risk indices. Equation 3.8 was used to calculate the Annual Effective Dose Equivalent using the absorbed dose rate. Table 4.12 shows the calculated values of the annual effective dose equivalent of the three study areas Raycon, DLA and Neodede as 43.2794($\mu Sv y^{-1}$), 62.0259($\mu Sv y^{-1}$), and 44.574($\mu Sv y^{-1}$), respectively. Figure 4.25 shows a comparison of the AEDE of the study areas. The calculated values shows that Raycon and Neodede have AEDE far below the world Standard but DLA is just a fraction below the world standard of 70($\mu Sv y^{-1}$), UNSCEAR (2000).

The radium equivalent (Ra_{eq}): The radium equivalent (Ra_{eq}) is a commonly used risk index. Equation 3.6 was used to calculate the radium equivalent using the specific activities of ^{40}K, ^{238}U and ^{232}Th. The radium equivalent (Ra_{eq}) of the three study areas Raycon, DLA and Neodede as shown in Table 4.12 are 102.7706 (Bq/kg), 221.9624(Bq/kg) and 100.9330(Bq/kg) respectively. Figure 4.29 shows a comparison of the radium equivalent of the study areas. The calculated values are all below the world standard of 370 Bq/kg UNSCEAR (2000).

Excess Life Cancer Risk (ELCR): The excess life cancer risk is one of the risk indices in radionuclides exposure. Equation 3.11 was used to calculate the excess life cancer risk using the Effective Dose Equivalent. Table 4.7 shows the calculated values of the excess life cancer risk of the three study areas which are Raycon, DLA and Neodede as 151.4779, 217.0907, and 156.0209, respectively of the study areas. The calculated values shows that they are all below the world standard of 0.29×10^{-3}, UNSCEAR (2000).

Hazard Indices (H_{ex}): The external hazard (Hex) indices were evaluated using the relations (Ramasamy et al., 2009); Equation 3.12 was used to calculate the external Hazard Index using the specific activities of ^{40}K, ^{238}U and ^{232}Th. The external hazard index of the three study areas Raycon, DLA and Neodede as shown in table 4.12 are 0.617492, 0.243329 and 0.170076 respectively. The calculated values are all below the world standard of 1 UNESCEAR (2000).

CONCLUSION

Background ionizing radiation is part of the natural environment and as such, humans and other living organisms are continuously exposed. From this work, it can be seen that fabricated radiation related activities of asphalt mixing have contributed immensely to the rise in background radiation exposure at the environment around asphalt plants.

Even though the activity concentration of ^{40}K, ^{238}U, and ^{232}Th is still very low in all of the study areas, it has been demonstrated that there is an abundance of ^{40}K in all the study areas, which can cause serious radiological health issues for the workers as well as contamination of drinking water and surface water used for agricultural activities in the area.

The activity of asphalt mixing has an effect on the radionuclide's concentration in both the soil and water in the surround environment where asphalt plants are located. This may affect the workers in the environments and even the public.

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