Original Research Article

Evaluation of Radiation Hazard Indices and Excess Lifetime Cancer Risk in Mining Sites of Nasarawa State Nigeria

Abstract

This work evaluates the radiation hazard indices from some selected mining sites in Nasarawa West, using Sodium Iodide Thallium Gamma Spectrometry. Ra_{eq} ranged from 100.39-197.40Bq/Kg with a mean 161.44Bq/Kg, which is lower than the average of 370Bq/Kg. The GADR ranged from 44.85nGy/hr-90.71nGy/hr with the mean 73.68nGy/hr. which is also below the average of 89 nGy/hr for soil. The AGED ranged from 315.77 - 640.91 mSv/yr with the mean 519.19 mSv/yr. Which is above the threshold value of 300 mSv/yr. ACI ranged from 0.73-1.45 with the mean value 1.18 which is above the standard of unity. The AEDE (outdoor) ranges from 0.055 - 0.111 mSv/yr with the mean 0.090mSv/yr which is above the 0.07mSv/yr standard permissible limit. The AEDE (indoor) ranged from 0.220 - 0.445mSv/yr, with the mean value 0.361mSv/yr, a value below the 0.45mSv/yr threshold. The ELCR ranged from 00.770-1.558 with the mean value 1.265 and from 0.193 - 0.389 with the mean value 0.317 for outdoor and indoor respectively, which exceed the 0.29 X 10^{-3} threshold limit. The External and Internal Hazard indices ranges from 0.271 - 0.533 and 0.289 - 0.675 as well as mean values 0.435 and 0.512 respectively, which are below the threshold. Therefore, there may be serious radiological effects to the populace.

Keywords: Radionuclide, Radiation, Hazard Indices, Excess Lifetime Cancer Risk, Nasarawa State.

1. INTRODUCTION

The measurement of natural radioactivity in our environment allows the determination and assessment of population exposure to radiation. The occurrence of natural radionuclides in water depends on the waters origin as well human activities in the area, such as the geology of the area, tin mining and use of fertilizers in agriculture [4]. For groundwater (boreholes and wells), it depends on their presence and contents in lithological of solids aquifers or rocks known as geological materials particularly the Jos Plateau rock types amounts of radioactive elements such as Uranium, thorium and potassium which may dissolve into ground water system during water/rock –soils interaction mechanism [5].Consumption of ground water with elevated amounts of natural radionuclides may increase the radio-toxicity to human and internal exposure to radiation caused by the decay of the natural radionuclides taken into the body through ingestion as well as inhalation. The decay process leads to the release of several alpha and beta particles which are responsible for the total radiation dose received from natural radioactivity as well as artificial [3]. The aim of this study was to Evaluation of Radiation Hazard Indices and Excess Lifetime Cancer Risk in Mining Sites of Nasarawa State. Nigeria.

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This work evaluates the radiation hazard indices from some selected mining sites in Nasarawa West, using Sodium Iodide Thallium Gamma Spectrometry. Ra_{eq} ranged from 100.39 - 197.40 Bq/Kg with a mean of 161.44 Bq/Kg while the GADR ranged from 44.85 - 90.71 nGy/hr with a mean of 73.68 nGy/hr respectively. The Ra_{eq} and GADR were lower than the recommended values of 370Bq/Kg and 89 nGy/hr for soil.

Comment [O2]: The AGED ranged from 315.77 - 640.91 mSv/yr with the mean 519.19 mSv/yr, a value above the threshold value of 300 mSv/yr.

Comment [O3]: Therefore, the values reported indicated a possible serious radiological effects to the populace within the studied area.

2. MATERIALS AND METHODS

2.1 Materials

In the course of the radiometric study, the following items or materials were used as shown in Table 1.

Materials	Specifications
Inspector Alert Nuclear Radiation Monitor	This is a health and safety instrument that is optimized to detect the physical levels of activity concentration of the radionuclides present in the environment.
Global Positioning System (G.P.S)	This is a space-based satellite navigation system that provides location and time information in all weather, anywhere or near the earth. This was used to locate the mining sites.
Disposable Hand Glove	This is a shielding material used to protect the hands and fingers from contacting any radioactive source.
Measuring Tape	This was used to measure the depth of the pit and also to measure the distance between two points.
Masking Adhesive Tape	This was used to label the samples for easier identification.
Marker pen	This was used to mark the masking tape attached to the polythene bag for easy identification of the soil samples.
Polythene Bags	To avoid mixing up of the samples, each of the collected samples were parked into a labeled polythene bag.
Sacks	The labeled polythene bags containing the collected samples were parked together into a single sack for easy transportation.
Mortar and Pestle	This was used to ground the collected samples after being dried at 60^{0}C to 80^{0}C for 24 hours in order to maintain the radioactive equilibrium.
5mm-Mesh Sieve	This was used to sieve the grounded samples in order to remove any larger particles in it and make it a powder.
Cylindrical Plastic Container	The sieved powder was packed into a cylindrical plastic container and the cover will be sealed with a masking tape to prevent it from any external radiation.
Electronic Analytical Balance	The sealed containers were placed on the electronic analytical balance to measure its weight in grams.
Cutlass	This was used for clearing of the mining sites also for shallow digging.
Sealer	This was used to seal the sieved and labeled samples in their respective container in order to avoid leakage also to prevent the escape of gaseous ^{222}Rn from the sample.
Sodium Iodide-Thalium Gamma Spectroscopic System	This is an instrument set in the laboratory, which was used to analyze the soil samples.

2.1 Study Area

Four villages were chosen in Mararraba-Udege Area. The villages are Eyenu, OPanda, Okereku and Udegen-Mbeki abbreviated as NW1, NW2, NW3 and NW4 respectively. The villages NW1, NW2, NW3 and NW4 are located at $08^{0}24^{'}38.2^{''}$N and $007^{0}52^{'}59.2^{''}$E, $08^{0}21^{'}24.9^{''}$N and

007^{0}54'29.6"E, 08^{0}24'04.1"N and 007^{0}52'10.6"E and 08^{0}25'56.3"N and 007^{0}53'49.3"E respectively. Columbite was mined in all the four villages as represented in Figure 1:

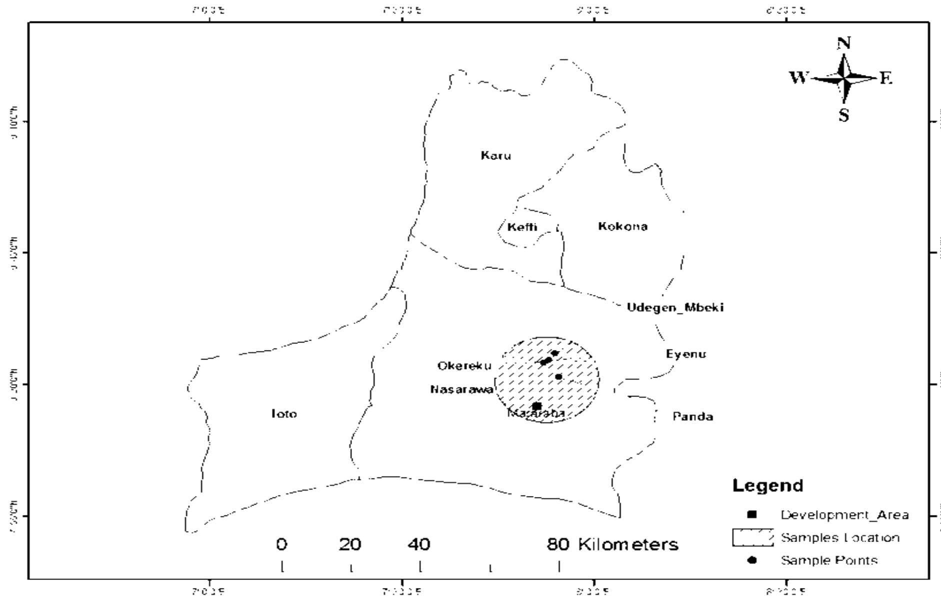

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Fig: 1. Map of Study Area

2.2 Sampling and Analysis

2.2.1 Samples Collection

Four sample locations were visited from all over Nasarawa West, Nigeria, to conduct the radiometry study. Three samples will be collected from each sample area to make twelve samples of soil. The samples were collected at 0.5m depth level from the surface of the soil. From each area, as stated earlier, three samples were collected as follows. Firstly from the mining spot, secondly from a distance of 100m away from the mining spot, and thirdly, from the river area within the mining spot. The collected samples were sealed in a labeled polythene bags and enclose into one sack for easiest transportation from the mining or sample point to the house. Meanwhile, when collecting the sample from the mining spot, Inspector Alert Nuclear Radiation Monitor was set at one meter above the ground to measure the physical activity concentration of the radionuclides present in the soil. In addition, Global Positioning System (GPS) was used to take the elevation and altitude of the area, and thermometer to measure the atmospheric temperature of the mining spot.

2.2.2 Sample Preparation Techniques

The collected samples (soil or sediment) was brought into the laboratory to be left open (if wet) for a minimum of 24 hours to dry under ambient temperature. They will be grounded using mortar and pestle and allowed to pass through 5mm-mesh sieve to remove larger object and make it fine powder. The samples will be packed to fill a cylindrical plastic container of height 7cm by 6cm diameter. This satisfied the selected optimal sample container height. Each container will accommodate approximately 300g of sample. They will be carefully sealed (using

Comment [O5]: Be specific, were the samples wet? Thus left for minimum of 24 hours?

Vaseline, candle wax and masking tape) to prevent radon escape and then stored for a minimum of 24 days. This is to allow radium attain equilibrium with the daughters.

2.2.3 Sample Analysis

Gamma-ray spectrometry technique was employed in the spectral collection of the prepared sample using the higher energy region of the gamma-lines.

2.3 Data Analysis

The principal primordial radionuclides that would be discuss for all the radiological parameters (Radium Equivalent Activity Ra_{eq}, Absorbed Dose Rate, Effective Dose Rate, External Hazard Index $H_{(ex)}$ and Internal Hazard Index $H_{(in)}$) in this case are ^{226}Ra, ^{232}Th and ^{40}K.

2.3.1 Radium Equivalent Activity (Ra_{eq})

This first index can be calculated using[2] relation:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (1)$$

Where A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. The Ra_{eq} is related to the external Γ-dose and internal dose due to radon and its daughters. The values must be less than 370Bq/kg, for the area to be acceptable to the public

2.3.2 Absorbed Dose Rate

According to [7], conversion factors to transform specific activities A_{Ra}, A_{Th} and A_K of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in absorbed dose rate at 1meter above the ground (in nGy/hr by Bq/kg) are calculated by Monte Caro method as:

$$D(nGy/hr) = 0.0417A_K + 0.462A_{Ra} + 0.604A_{Th} \quad (2)$$

Where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. The world average value for the Absorbed Dose Rate is 89nGy/hr for public.

2.3.3 Annual Gonadal Equivalent Dose (AGED)

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). According to [1], AGED is calculated with given activity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) using the relation:

$$AGED\ (mSv/yr) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (3)$$

Where, A_{Ra}, A_{Th}, and A_K are the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) in soil samples respectively.

2.3.4 Activity Concentration Index (Representative Gamma Index).

According to [1], the activity concentration index is given by:

$$I_{\gamma r} = \frac{Ara}{150} + \frac{Ath}{100} + \frac{Ak}{1500} \quad (4)$$

Where, A_{Ra}, A_{Th}, and A_K are the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) in soil samples respectively.

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 $I_{\gamma r} \leq 1$ corresponds to an annual effective dose of less than or equal to 1 mSv, while $I_{\gamma r} \leq 0.5$ corresponds to annual effective dose less or equal to 0.3 mSv.

2.3.5 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 [8], [9].

According to [8] & [9], AEDE is determined by the equations below.

$$AEDE\ (Outdoor)\ (mSv/y) = D\ (nGy/h) \times 8760h \times 0.7\ Sv/Gy \times 0.2 \times 10^{-6} \quad (5)$$

And

AEDE (Indoor) (mSv/y) = D (nGy/h) ×8760h × 0.7 Sv/Gy× 0.8 × 10^{-6} (6)

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, ^{232}Th and ^{40}K. The standard AEDE (Outdoor) value is 0.07 $mSvyr^{-1}$ and that for AEDE (Indoor) is 0.45 $mSvyr^{-1}$. These indices measure the risk of stochastic and deterministic effects in the irradiated individuals.

2.3.6 Excess Lifetime Cancer Risk (ELCR)

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. According to [6], Excess lifetime cancer risk (ELCR) is given by;

ELCR = AEDE × DL × RF (7)

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 with the ELCR UNSCEAR standard being 0.29 X 10^{-3}.

2.3.4 External Hazard Index

This hazard denoted in terms of External Hazard Index or outdoor radiation hazard index and denoted by H_{ex}, according to [2], can be calculated using the equation:

$$H_{ex} = \frac{Ara}{370} + \frac{Ath}{259} + \frac{Ak}{4810} \leq 1 \qquad (8)$$

Where A_{ra}, A_{th} and A_k are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively. The value of the internal hazard index must be less or equal to unity in order for the radiation hazard to be negligibly hazardous to the respiratory organs of the public.

2.3.5 Internal Hazard Index

The Internal hazard Index (H_{in}) gives the internal exposure to carcinogenic radon and according to [2], is given by the formula

$$H_{in} = \frac{Ara}{185} + \frac{Ath}{259} + \frac{Ak}{4810} \leq 1 \qquad (9)$$

Where A_{ra}, A_{th} and A_k are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively. The value of the internal hazard index must be less or equal to unity in order for the radiation hazard to be negligibly hazardous to the respiratory organs of the public [2].

3. RESULT

3.1 Result

This shows the experimental results obtained from the spectra of twelve soil samples under investigation. For the effective computation of the experimental data from Count Dose Rate (cpm) to Exposure Dose Rate ($\mu Svhr^{-1}$), Absorbed Dose Rate ($nGyhr^{-1}$), Annual Effective Dose Rate ($mSvyr^{-1}$), Annual Gonadal Equivalent Dose Rate (mSv/yr), Activity Concentration Index (representative gamma index), Excess Lifetime Cancer Risk, External Hazard Index (Bq/Kg) and Internal Hazard Index (Bq/Kg); Equation 1 to 9 was used and the results are presented in the table below.

Table 2 Evaluated Results for Radiation Hazard Indices

Sample Code	Ra_{eq} (Bq/kg)	G.A.D.R (nGy/hr)	A.G.E.D (mSv/yr)	Iγr (Bq/kg)	AEDE Outdoor (mSv/yr)	AEDE Indoor (mSv/yr)	E.L.C.R Indoor (mSv/yr)	E.L.C.R Outdoor (mSv/yr)	H_{ex} (Bq/kg)	H_{in} (Bq/kg)
NW1A	177.54	80.99	572.87	1.31	0.099	0.397	1.390	0.347	0.479	0.532
NW1B	162.74	74.65	527.55	1.20	0.092	0.366	1.281	0.322	0.439	0.507

NW1C	164.62	75.73	534.00	1.21	0.093	0.372	1.302	0.326	0.445	0.535
NW2A	100.39	44.85	315.77	0.73	0.055	0.220	0.770	0.193	0.271	0.289
NW2B	102.27	46.47	326.26	0.74	0.057	0.228	0.798	0.200	0.276	0.332
NW2C	197.40	90.71	640.40	1.45	0.111	0.445	1.558	0.389	0.533	0.529
NW3A	153.54	67.08	460.64	1.07	0.082	0.329	1.152	0.287	0.415	0.536
NW3B	170.95	78.70	556.02	1.26	0.097	0.386	1.351	0.340	0.462	0.552
NW3C	189.00	89.13	640.91	1.43	0.109	0.437	1.530	0.382	0.505	0.554
NW4A	181.35	83.03	584.22	1.32	0.102	0.407	1.425	0.357	0.489	0.592
NW4B	195.30	87.27	605.22	1.38	0.107	0.428	1.498	0.375	0.527	0.675
NW4C	142.16	65.55	466.44	1.06	0.080	0.322	1.127	0.280	0.384	0.415
Range	**100.39-197.40**	**44.85-90.71**	**315.77-640.91**	**0.73-1.45**	**0.055-0.111**	**0.220-0.445**	**0.770-1.558**	**0.193-0.389**	**0.271-0.533**	**0.289-0.675**
Mean	**161.44**	**73.68**	**519.19**	**1.18**	**0.090**	**0.361**	**1.265**	**0.317**	**0.435**	**0.512**

3.2 Result Analysis

The data in Table 2 were used to plot chats (see Figure 2 to 11) so as to analyze the results and compare them with those of regulatory bodies.

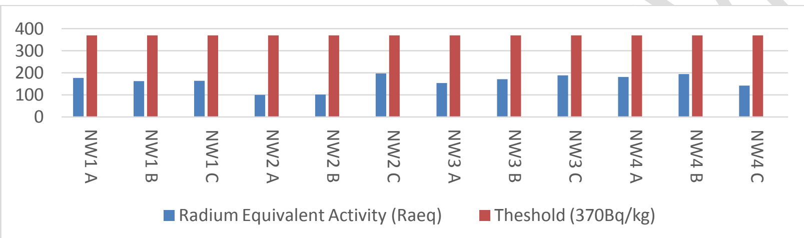

Figure 2: Radium Equivalent Activity (Ra_{eq}) Compared with the Threshold

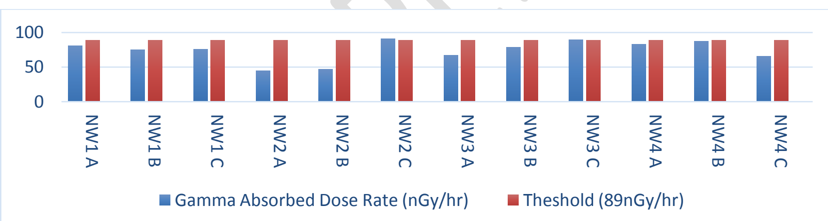

Figure 3: Gamma Absorbed Dose Rate Compared with the Threshold

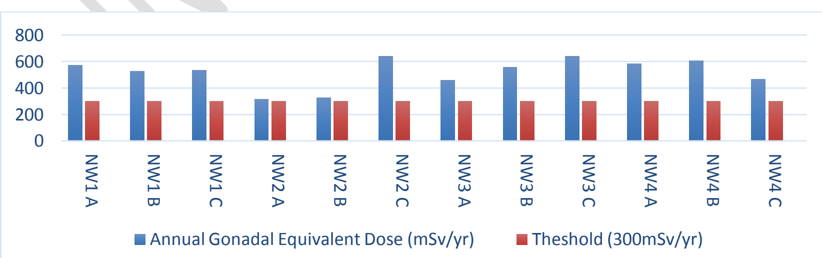

Figure 4: Annual Gonadal Equivalent Dose (AGED) Compared with the Threshold

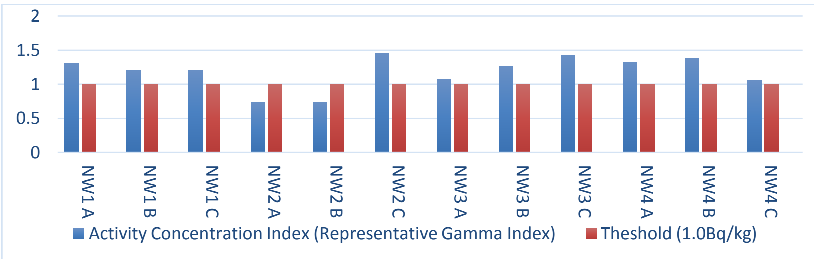

Figure 5: Activity Concentration Index (ACI) Compared with the Threshold

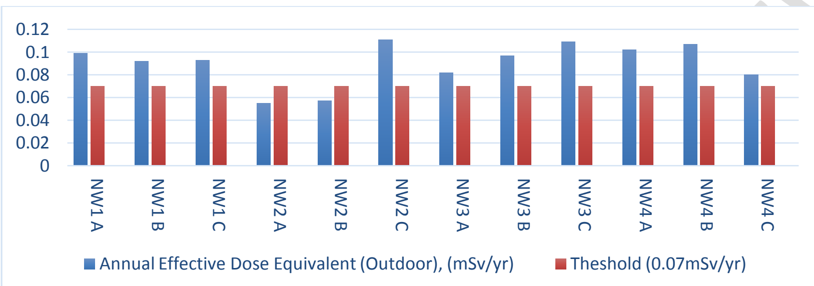

Figure 6: Annual Effective Dose Equivalent, AEDE (Outdoor) Compared with the Threshold

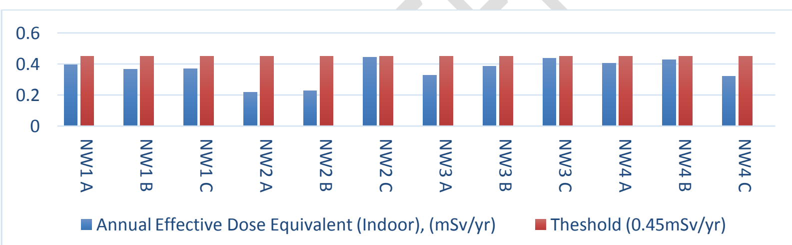

Figure 7: Annual Effective Dose Equivalent, AEDE (Indoor) Compared with the Threshold

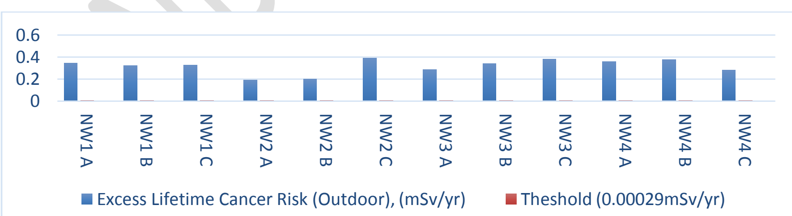

Figure 8: Excess Lifetime Cancer Risk (Outdoor), Compared with the Threshold

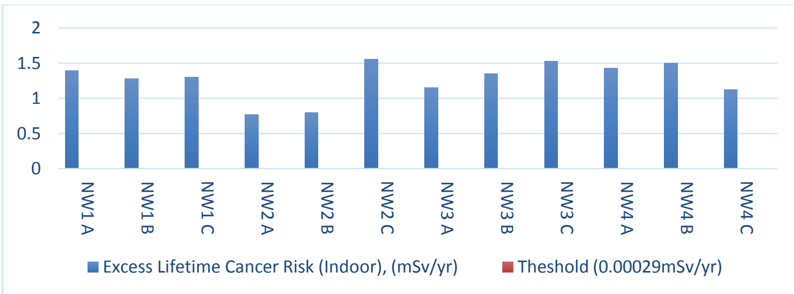

Figure 9: Excess Lifetime Cancer Risk (Indoor) Compared with the Threshold

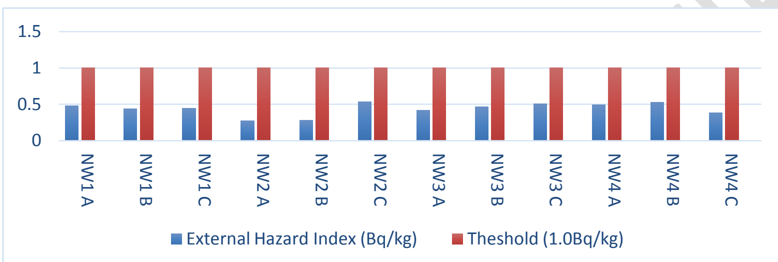

Figure 10: External Hazard Index (H_{ex}) Compared with the Threshold

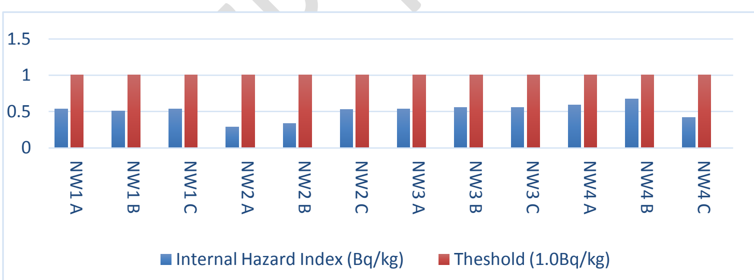

Figure 11: Internal Hazard Index (H_{in}) Compared with the Threshold

3.3 Discussion

According to Table 2 and Fig 2, all the locations have their Radium Equivalent Activity values ranged from 100.39-197.40 Bq/Kg with a mean value of 161.44 Bq/Kg. This mean value obtained is lower than the world average of 370 Bq/Kg as reported by regulatory bodies.

According to Table 2, the gamma absorbed dose rates calculated using the gamma spectrometry results ranged from 44.85 - 90.71 nGy/hr with the mean of 73.68 nGy/hr. The mean value obtained is below the world average of 89 nGy/hr for soil. Even though Figure 3 has obviously showed that the values for some of the areas like “NW2 C and NW3 C” were higher than the world average of 89 nGy/hr for soil as reported by regulatory bodies.

Comment [O6]: However, it was obviously showed that the values for some of the areas like “NW2 C and NW3 C” were higher than the world average of 89 nGy/hr for soil as reported by regulatory bodies. (Fig 3).

According to Table 2, Annual Gonadal Equivalent Dose (AGED) obtained ranged from 315.77mSv/yr to 640.91mSv/yr with the mean of 519.19. The mean value of AGED for the locations is above the threshold value of 300 mSv/yr.

Figure 4 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.

According to Table 2, Activity Concentration Index (ACI) calculated for the locations ranged from 0.73 to 1.45 with the mean value of 1.18 which is above the standard of unity. Even though figure 4 have obviously showed that the values for some of the areas like “NW2 A and NW2 B” are lower than the world average.

The Annual Effective Dose Equivalent (for outdoor) was also calculated for the locations and shown in Table 2. The AEDE (outdoor) value ranges between 0.055 to 0.111 mSv/yr with the mean of 0.090 mSv/yr which is above the 0.07 mSv/yr standard permissible limit. The reason might be attributed to high absorbed dose rate values due to high radionuclides concentration in those areas. Even though figure 6 have obviously showed that the values for some of the areas like “NW2 A and NW2 B” are lower than the world average.

On the other hand, the AEDE (indoor) value ranged from 0.220 to 0.445 mSv/yr, with the mean value of 0.361 mSv/yr. The mean value obtained is below the 0.45 mSv/yr threshold. All the locations are below the AEDE (Outdoor) threshold.

Excess Lifetime Cancer Risk Index (ELCR) obtained ranged from 00.770 to 1.558 with the mean value of 1.265 and from 0.193 to 0.389 with the mean value of 0.317 for outdoor and indoor respectively. These values exceed the 0.29 X 10^{-3} threshold limit. All the locations have ELCR values above the permissible threshold.

External and Internal Hazard indices are below the unity threshold for all the locations (as shown in Table 2 and Figures 10 and 11), with the ranges from 0.271 to 0.533 and 0.289 to 0.675 as well as mean values of 0.435and 0.512 respectively.

The results showed trends that are generally high for most radiation hazard indices calculated except for few indices whose values are below the recommended thresholds.

Therefore, there may be serious immediate radiological effects to the populace and the environment in these areas except for few locations where the risk due to radiation is less significant even though, all the locations may need further investigation and monitoring.

4.2 Conclusion

Soil samples from some selected mining sites in Nasarawa West have been analyzed using the Thallium Drifted Sodium Iodide Gamma Spectroscopy. The activity concentrations of ^{232}Th, ^{226}Raand ^{40}K obtained were used to determine the radiation hazards indices.

Comment [O7]: For future sake: HpGe may be used.

The hazard indices calculated revealed that, the radium equivalent activity is high for all the areas under investigation. AGED values are above the permissible threshold for all the locations. The GADR for all the samples under investigation are lower than the recommended standard except for two locations which are NW2 C and NW3 C. Two of the radiation hazard indices; ACI and AEDE (outdoor) are high for all except two locations, which are, NW2 A and NW2 B. The annual effective dose (indoor) is low for all locations. The ELCR values for both outdoor and indoor are above 0.29x10^{-3} as reported by regulatory bodies’ standard. The remaining two hazard indices; Hex and H_{in} are below the permissible standards of 1.0Bq/kg for all the locations.

4.3 Recommendation

In the course of this radiometric study, it was discovered that some places are subjected to high radiation hazard indices. These areas will strongly require regulatory control. The level of radiation in those areas is sufficiently high and can cause radiological hazard to the public of the area.

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

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Comment [O8]: It's always encouraged for scientific article to have atleast 15 references with more from the last 5 years. You may cite more relevant works.