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Offsite Dose Assessment to the Public from Residual Radioactivity due to Mining Activities in Adamawa State, Nigeria.

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Abstract: Mining activities in Adamawa State is uncontrolled and can increase the background radiation to members of the public around the mining area. This study assessed the Offsite Dose to the public using the RESRAD Offsite code from residual radioactivity concentrations (AC) of ^{226}Ra, ^{232}Th and ^{40}K in soil samples due to mining activities from four selected Mining sites in Adamawa State, Nigeria. The AC was obtained using the sodium Iodide (NaI) detector at the Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria, Nigeria. Result shows that the order of AC in soil samples were: ^{226}Ra > ^{232}Th > ^{40}K. Though ^{40}K constitute the highest total mean AC of 466 Bq/kg in soil, the public are more pruned to ^{226}Ra and ^{232}Th than ^{40}K due to AC ratio of 3.03, 2.8 and 1.17 respectively. Also, the total offsite doses due to inhalation after 30years from the four mining sites are 2.62E-04mSv/yr, 2.97E-04mSv/yr, 2.42E-04mSv/yr, and 2.168E-04mSv/yr for mining sites S-A, S-B, S-D, and S-C respectively. These doses were all lower than EPA dose limit of 0.1mSv/yr, indicating that the inhalation doses emanating from residual radioactivity from all the mining site in this study has less impact on offsite residents in a short time. However, the danger of radiation exposure and its impacts must be understood by the population living near the mining sites as no radiation exposure is safe since accumulation of low exposure dose can result to stochastic effects. Routine assessment and a setback of at least 800 meters for residential will be required to reduce the magnitude of exposure.

Keywords: Activity Concentration; RESRAD-OFFSITE; Atmospheric Dispersion Models; Gaussian Plume Model; Radiation Exposure; Offsite Dose Assessment.

1 Introduction

Even at low concentrations, mining activities have resulted to a harmful impact on humans and the surroundings, which facilitates the release of radioactive elements from the host material and posing some undue risk to human health due to the nature of the daughter radioactive products generated via gaseous decay [1]. Naturally occurring radionuclides constitutes both sources of external and internal radiation exposure to humans, and they can be found in the air we breathe through contamination of aerosol, the food we eat from contamination due to fall out of radionuclides and transfer factors of natural radionuclides from soil to plants, and the water we drink from contaminated sources which has resulted to public health problems [2]. The largest contributor to radiation exposure are Radon and Thoron (^{222}Rn and ^{220}Th) which are alpha emitters and are the decay products of ^{238}U and ^{232}Th commonly found in rocks and soils. These decay products released might contaminate the air and deliver radiation dose to the public residing around the mining sites and the environs mainly through inhalation pathway resulting to offsite dose [3]. Contaminant reaches an individual or population via several routes of exposure [4]. Inhalation, ingestion, or wound exposure are the three most common pathways of exposure. Breathing air contaminated with radioactive particle dust or aerosols causes inhalation exposure. Offsite residents become vulnerable to radioactive contaminated air through breathing process through a range of external and internal events. Internal receptors may also be vulnerable to external contaminants that enter the internal surrounding through a variety of ventilation pathways [5]. The purpose of this research is to estimate the offsite dose from Residual Radioactivity arising from mining activities to the public.

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In the present research, the measured mean activity concentration (AC) level of ^{226}Ra, ^{232}Th and ^{40}K in soil obtained in four selected mining sites was used as an input for analysis. Such mining activities are potential sources of radiation and radioactivity, contaminating the environment and exposing people to radiation. Current ICRP references are established on the rational postulation that no radiation exposure dose is harmless, even the least radiation dose has the potential to cause stochastic effects such as cancer. However, in addition to maintaining below the dose limitations, the underlying objective was to maintain all such exposure levels "as low as reasonably attainable" (ALARA) [6].

2 Materials and Methods

2.1 Study Area

Adamawa State is located in the north-eastern section of Nigeria, with a land mass of 39,742.12 square kilometres, accounting for around 4.4 percent of Nigeria's total land mass. It is located between latitudes 80 and 110 north, and longitudes 11.50 and 13.50 east. Figure 1 presents the map of Nigeria showing Adamawa State while Figure 2 presents the map of Adamawa State showing the study area. All the maps were obtained from google search and redesigned using editing tools of Microsoft word to suit the study location.

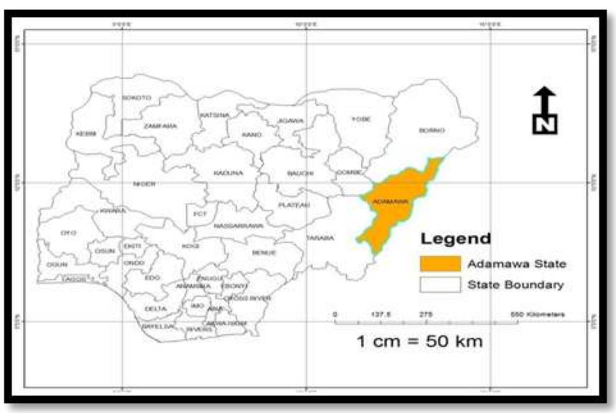

Fig. 1: Map of Nigeria showing Adamawa State and State Boundary [7].

2.2 Sample and Sampling Technique

Using systematic sampling techniques, fifteen (15) soil samples were collected from four quarry mining sites located 500 meters apart. To avoid cross contamination during transit, composite samples were collected using a shovel at a depth of about 10cm and placed in a sealed labeled polythene bag. To eliminate moisture, open air drying at room temperature for seven days was used, and stone samples were ground into powdery form with a mortar and pestle and sieved with a wire mesh with holes of thickness 0.5mm to achieve uniformity of sample size.

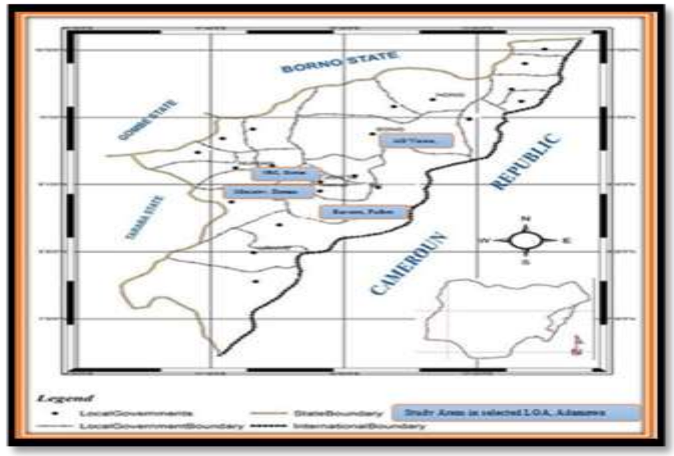

Fig. 2: Map of Adamawa State showing Boundaries point and study Areas [8].

Before going to the lab for examination, about 400g of mass were held in polythene bags for 28 days to achieve secular equilibrium between ^{226}Ra, ^{232}Th, and ^{40}K and their progeny. Table 1 shows the sample points for each quarry mining location, as well as their coordinates and sample identification numbers.

Table 1: Sample coordinates and sample codes.

Mining Locations	Soil Sample Code	Sampling Coordinates	
		Latitude	Longitude
Raycon Fufore	S - A1	09^0 08' 36"	12^0 19' 09"
Raycon Fufore	S - A2	09^0 08' 29"	12^0 19' 19"
Raycon Fufore	S - A3	09^0 08' 23"	12^0 19' 04"
Raycon Fufore	S - A4	09^0 08' 39"	12^0 19' 14"
NRC Demsa	S - B1	09^0 21' 48"	12^0 11' 32"
NRC Demsa	S - B2	09^0 21' 42"	12^0 11' 28"
NRC Demsa	S - B3	09^0 21' 36"	12^0 11' 22"
NRC Demsa	S - B4	09^0 21' 53"	12^0 11' 19"
Ministry Demsa	S - C1	09^0 21' 55"	12^0 11' 23"
Ministry Demsa	S - C2	09^0 21' 51"	12^0 11' 20"
Ministry Demsa	S - C3	09^0 21' 45"	12^0 11' 17"
Ministry Demsa	S - C4	09^0 21' 59"	12^0 11' 13"
AG Vision Song	S - D1	09^0 56' 15"	12^0 37' 46"
AG Vision Song	S - D2	09^0 56' 19"	12^0 37' 39"
AG Vision Song	S - D3	09^0 56' 11"	12^0 37' 44"

2.3 Description of Dose Assessment Scenario

The structural diagram for the offsite dose assessment scenario using the mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil from selected mining sites in Adamawa State is shown in Figure 3.

Fig. 3: Summary of Scenario Description for Offsite Dose Assessment.

2.4 RESRAD-OFFSITE Computer Code

The RESidual RADioactivity (RESRAD) Offsite estimates radiological exposure dose and excess cancer risk to receptors within and/or outside the primary contamination boundary. The sources of polluted exposure can be outdoor the border of the prime contamination and could be entirely within the boundary. Some exposure scenes can be onsite, offsite, and even straddle the site boundary [9]. The main contagion, being the source of all exposure examined by the code, is presumed to be within a cover of soil. The code reflects dispersion of pollutants from the prime contamination to the air, to outward runoff, and to groundwater. It simulates the movement of the pollutants from the primary contamination to the receptors by simulating the buildup of contaminants at those sites, where suitable. Any influence of pollutants from the environment are also modeled. Direct exposure from soil contamination, inhalation of particulates, inhalation of short-lived radon progeny, ingestion of plant food (i.e., vegetables, grains, and fruits), ingestion of meat, ingestion of milk, ingestion of aquatic foods, ingestion of water, and (incidental) ingestion of soil are all considered in RESRAD-OFFSITE [9]. Its computational algorithm differed from the RESRAD-ONSITE which analyzes the analytical expressions for concentration, dosage, and risk at any moment after the site inspection, while RESRAD-OFFSITE quantifies the concentration, dose, and risk numerically throughout period. To simulate radiological dose using RESRAD OFFSITE, we use the offsite scenario, whereby assuming that the public are within the vicinity of a landfill. Exposure pathway considered is inhalation. The code uses a Gaussian plume model, where the radionuclide concentration and plume remain constant over time.

2.4.1 Atmospheric Dispersion Model (ADM)

Atmospheric dispersion is important to study the dispersion models in order to estimate accurately the off-site radiological consequences [10]. Prediction of the dispersion of radioactive materials into the environment is very important because it can assist in planning for emergency preparedness and evacuation. It is important to define the atmospheric condition of the release location because these condition help to predict accurately the atmospheric dispersion [11]. When the radioactive materials are released to the atmospheres they can contaminate the environment and public through various pathways. The models are used to mimic the atmospheric dispersion, the most common used one is the straight-line steady-state Gaussian model [12]. A dispersal model is a kind of mathematical equation that represents the discharge and dispersion of air contaminants in the atmosphere. There are several types of air dispersion models used in atmospheric dispersion modeling. These models can be classified into four categories namely Gaussian, Numerical, statistical or empirical, and physical. Gaussian Plume Model (GPM) is most widely to predict dispersal from the continuous release, also used for estimating the impact of nonreactive pollutants [13].

2.4.2 Governing Equations of RESRAD-OFFSITE

RESRAD-OFFSITE uses a Gaussian plume model derived from a three-dimensional (3-D) equation for atmospheric diffusion to evaluate radionuclide concentration. The 3-D diffusion equation for atmospheric diffusion is given as:

$$\frac{\partial X}{\partial t} = \frac{\partial}{\partial x}\left[C_x \left(\frac{\partial X}{\partial x}\right)\right] + \frac{\partial}{\partial y}\left[C_y \left(\frac{\partial X}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[C_z \left(\frac{\partial X}{\partial z}\right)\right] \quad \textbf{(1)}$$

where,:

x, y and z = downwind, cross-wind and vertical directions, and C_x, C_y, C_z = diffusivity in x-, y- and z-directions.
Gaussian plume model is expressed by the equation:

$$\boldsymbol{Q(x,y,z)} = \frac{Q}{2\pi\sigma_y(x)\sigma_z u}\,\boldsymbol{exp}\left\{-\frac{1}{2}\left[\frac{y}{\sigma_y}\right]^2\right\} \times \left(\boldsymbol{exp}\left\{-\frac{1}{2}\left[\frac{z-H}{\sigma_z}\right]^2\right\} + \boldsymbol{exp}\left\{-\frac{1}{2}\left[\frac{z\mp H}{\sigma_z}\right]^2\right\}\right) \mathbf{exp}\left[\frac{\lambda x}{u}\right] \mathbf{DF}\,(x) \quad (2)$$

However, if the σ_z exceeds the inversion height (L), the following relation is used:

$$\boldsymbol{P(x,y,z)} = \frac{R}{2\pi\sigma_y L u}\,\boldsymbol{exp}\left\{-\frac{1}{2}\left[\frac{y}{\sigma_y}\right]^2\right\} \mathbf{exp}\left[-\frac{\lambda x}{u}\right] \mathbf{PF}\,(x) \quad (3)$$

Where:
P = time-integrated atmospheric concentration (Ci-s)/ (m^3),
R = source term (Ci),
H = effective release height (m),
λ = decay constant (s–1),
x = downwind distance (m),
y = crosswind distance (m),
z = vertical axis distance (m),
σ_y = standard deviation (SD) of integrated concentration distribution in the crosswind direction (m),

σ_z = standard deviation (SD) of the integrated concentration distribution in the vertical direction (m),
u = mean wind speed at the effective release height,
L = inversion layer height (m),
PF(x) = plume depletion factor (PDF).

2.4.3 *Input Parameters Used in RESRAD-OFFSITE Code*

The input parameters that were used in the RESidual RADioactivity Code are presented in Table 2.

Table 2: Input Parameters used in RESidual RADioactivity Computer Code.

Input parameter	Value	Source
Mean AC Raycon (Bq/g)		
^{226}R	0.109 Bq/g	AC of soil obtained from Mining site
^{232}Th	0.085 Bq/g	
^{40}K	0.859 Bq/g	
Mean AC NRC (Bq/g)		
^{226}R	0.114 Bq/g	AC of soil obtained from Mining site
^{232}Th	0.097 Bq/g	
^{40}K	0.397 Bq/g	
Mean AC Ministry (Bq/g)		
^{226}R	0.116 Bq/g	AC of soil obtained from Mining site
^{232}Th	0.079 Bq/g	
^{40}K	0.279 Bq/g	
Mean AC AG Vision (Bq/g)		
^{226}R	0.087 Bq/g	AC of soil obtained from Mining site
^{232}Th	0.076 Bq/g	
^{40}K	0.328 Bq/g	
Exposure duration	30 years	RESRAD default
Area of the contamination zone	100 m^2	Assumed value
Cover material density	1.5 g/cm3	RESRAD default
Depth of cover	0 m	RESRAD default
Thickness of the contaminated zone	2 m	RESRAD default
Density of the contaminated zone	1.5 g/cm^3	RESRAD default
Inhalation rate for onsite resident	8400 m^3/year	RESRAD default
Cover radon diffusion coefficient	0.000002 m^2/s	RESRAD default
Contaminated radon diffusion coefficient	0.000002 m^2/s	RESRAD default
Distribution coefficient of contaminated zone	100 cm^3/g	RESRAD default
Transport factors		
^{226}R	5.5 cm^3/g	RESRAD default
^{232}Th	60000 cm^3/g	
^{40}K	50 cm^3/g	
Release height	10 m	Assumed value
Outdoor and Indoor fraction	0.25 & 0.5	RESRAD default

3 Results and Discussion

3.1 Mean Activity Concentration

Mean activity concentration level of ^{226}Ra, ^{232}Th and ^{40}K in soil obtained using Sodium Iodide (NaI) detector around four designated mining locations in Adamawa State serves as an input for offsite dose assessment to the public and the data are presented in Table 3 and Figure 4.

Table 3: Mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K (Bq/kg) in soil.

Mining Locations	Sample Code	Mean AC (Bq/kg) Ra-226	Th-232	K-40
Raycon site Fufore	S-A	109	85	860
NRC site Demsa	S-B	114	97	397
Ministry site Demsa	S-C	116	79	279
AG Vision site Song	S-D	87	76	328
Grand Mean	**S**	**106**	**84**	**466**
UNSCEAR Standard		**35**	**30**	**400**
AC Ratio		**3.03**	**2.8**	**1.17**

Table 3 and Figure 4 shows the mean specific AC of ^{226}Ra, ^{232}Th and ^{40}K in soil obtained from four designated mining locations considered in this study. The measured activity concentration in soil were analyzed using sodium iodide (NaI) detector at the Centre for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria.
The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil around Raycon mining site were 109Bq/kg, 85Bq/kg, and 860Bq/kg. These values were all above the UNSCEAR (2000) world standard of 35Bq/kg, 30Bq/kg and 400Bq/kg respectively [14]. That of NRC mining site were 114Bq/kg, 97Bq/kg, and 397Bq/kg. The mean values of ^{226}Ra, and ^{232}Th were all above the UNSCEAR (2000) world standard of 35Bq/kg and 30Bq/kg while that of ^{40}K is less than world standard of 400Bq/kg respectively. Mean AC values from Ministry mining site were 116Bq/kg, 79Bq/kg, and 279Bq/kg, with ^{226}Ra, and ^{232}Th were all above the UNSCEAR (2000) world standard of 35Bq/kg and 30Bq/kg

while that of ^{40}K is less than the world standard of 400Bq/kg respectively. The mean AC from AG Vision mining site were 87Bq/kg, 76Bq/kg, and 328Bq/kg. The mean values of ^{226}Ra, and ^{232}Th were all above the UNSCEAR (2000) world standard of 35Bq/kg and 30Bq/kg while that of ^{40}K is less than world standard of 400Bq/kg respectively. The grand mean from all the mining sites were all above the UNSCEAR (2000) world standard values.

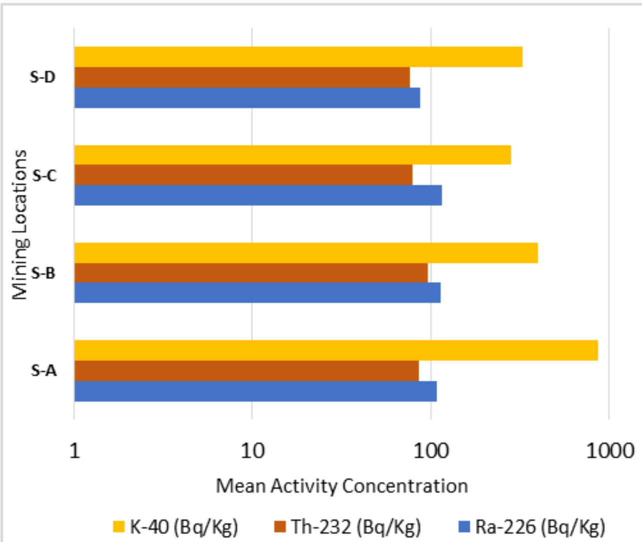

Fig. 4: Mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil.

3.2 Offsite Dose Assessments

The only exposure pathway considered for this site is the inhalation of gaseous decay products of NORMs over a period of 30 years. However, there is no contribution of inhalation dose from ^{40}K as it is less harmful for internal exposure and more harmful for external exposure because of the nature of its decay process ^{40}K emit 89% betta and 11% gamma. Since dose contribution from ^{226}R and ^{232}Th are due to gaseous decay of daughter products with high inhalation dose from ^{232}Th than ^{238}U, the inhalation of gaseous decay product of ^{226}R and ^{232}Th over a 30 years period is the exposure pathway for this investigation.

3.2.1 Raycon Mining Site

The result of offsite dose rate (mSv/yr) obtained using RESRAD-OFFSITE from the average AC of ^{226}Ra, ^{232}Th and ^{40}K from soil around Raycon mining sites Fufore LGA, Adamawa State is presented in Figure 5.

From Figure 5, the highest total offsite dosage is 2.62e-04mSv/yr after 30 years. Although the total dose is below the EPA dose limit of 0.1mSv/yr for inhalation as suggested by [15] the dose is slightly stable after 30 years and remains stable due to long half-lives of NORM radionuclides. These results show that it is safe for offsite residents to reside within a vicinity of a mining site.

3.2.2 NRC Mining Site

The result of offsite dose rate (mSv/yr) obtained using RESRAD-OFFSITE from the average AC of ^{226}Ra, ^{232}Th and ^{40}K from soil around NRC mining sites in Demsa LGA, Adamawa State is presented in Figure 6.

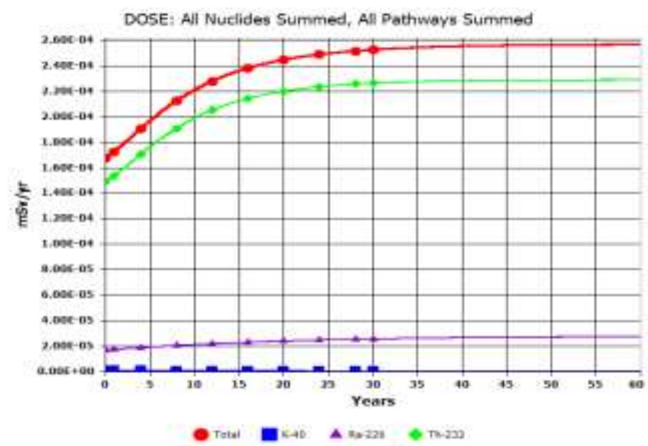

Fig.5: Offsite dose from Raycon Mining Site.

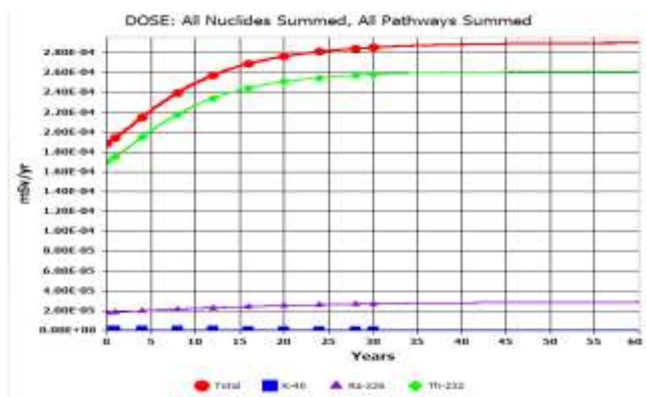

Fig. 6: Offsite dose from NRC Mining Site.

From Figure 6, the highest total offsite dose is 2.97E-04mSv/yr after 30 years and the dose remains stable after 30 years un-ward due to long half-lives of ^{226}Ra, ^{232}Th and ^{40}K radionuclides. Although the total dose is below the EPA dose limit of 0.1mSv/yr for inhalation as suggested by [15.], the result shows that the offsite dose from residual radioactivity from the mining site to the public residing within the vicinity of the mining site shows no significant effect. However, the modern ICRP recommendations had stated that accumulation of low level of exposure from radiation has the tendency of resulting to stochastic effects in the end [6].

3.2.3 Ministry Mining Site

The result of offsite dose rate (mSv/yr) obtained using RESRAD-OFFSITE from the average AC of ^{226}Ra, ^{232}Th and ^{40}K from soil around Ministry mining sites in Demsa

LGA, Adamawa State is presented in Figure 7.

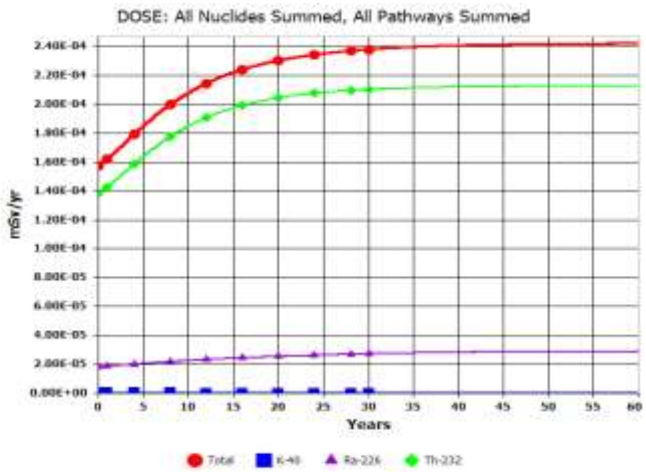

Fig.7: Offsite dose from Ministry Mining Site.

From Figure 7, the highest total dose is 2.42E-04mSv/yr after 30 years with slow increase over the years due to long half-lives of NORM's radionuclides. The total dose is below the EPA dose limit of 0.1mSv/yr for inhalation as suggested by [15], which shows that the inhalation dose emanating from residual radioactivity from NRC mining site has less impact on offsite residents.

3.2.4 AG Vision Mining Site

The result of offsite dose rate (mSv/yr) obtained using RESRAD-OFFSITE from the average AC of ^{226}Ra, ^{232}Th and ^{40}K from soil around AG Vision mining sites Song LGA, Adamawa State is presented in Figure 8.

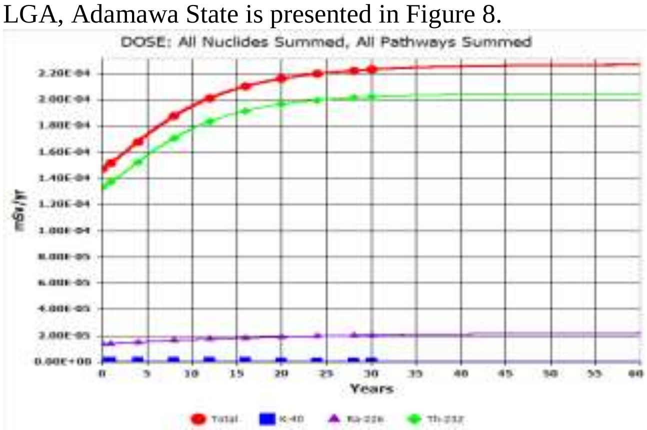

Fig. 8: Offsite dose from AG Vision Mining Site.

From Figure 8, the highest total dose is 2.168E-04mSv/yr after 30 years with slow increase over the years due to long half-lives of ^{226}Ra, ^{232}Th and ^{40}K. The total dose is still below the EPA dose limit of 0.1mSv/yr for inhalation as suggested by [15], which shows the inhalation dose from residual radioactivity from AG Vision mining site, has less impact on offsite inhabitants.

Findings from this study have shown that the order of activity concentration in soil samples were: ^{226}Ra > ^{232}Th > ^{40}K. Even though ^{40}K constitute the highest total mean activity concentration of 466Bq/kg in soil, findings from this research have shown that the public are more pruned to ^{226}Ra and ^{232}Th than ^{40}K as shown by the activity concentration ratio of 3.03, 2.8 and 1.17 respectively. This is because ^{226}Ra and ^{232}Th undergo alpha decay which are hazardous when inhaled even at low concentration and the accumulation could results to stochastic consequences. This finding is in line with previous researchers such as [16], from beryllium and gold mining sites in Kwara State, Nigeria, and [17], from gold mining sites in Itagunmodi, Ogun State Nigeria, but different from that of [18], from Olode mining sites in Oyo State.

Findings from this study have also revealed that, the total offsite doses due to inhalation after 30years from the four mining sites are 2.62E-04mSv/yr, 2.97E-04mSv/yr, 2.42E-04mSv/yr, and 2.168E-04mSv/yr for mining sites S-A, S-B, S-D, and S-C respectively. The total doses are below the EPA dose limit of 0.1mSv/yr for inhalation as suggested by [15], which shows that the inhalation doses emanating from residual radioactivity from all the mining sites in this study has less impact on offsite residents in the short long than in the long run. This findings are well comparable with that of [19], who reported public dose of 7.43E-02mSv/yr from Mujuni River in Tanzania using RESRAD Offsite computer code which is much higher than those reported in this study but still lower than recommended limit. Also, in line with [20], who reported offsite dose of 3.15E-02mSv/yr at 30 year from Wonderfonteinspruit in South Africa using RESRAD OFFSITE code.

4 Conclusions

In this study, offsite dose assessment arising from residual radioactivity due to mining activities to the public was assessed using RESRAD-OFFSITE computer code from the mean AC of ^{226}Ra, ^{232}Th and ^{40}K from soil around four selected mining sites in Adamawa State. The results of the assessments using inhalation pathway varies from each mining sites with high inhalation rates observed in ^{226}R and ^{232}Th radionuclides due to the gaseous decay of its daughter product thoron (^{220}Th). Results from all mining sites are all below the EPA dose limit of 0.1mSv/yr for inhalation as suggested by Environment, Health, Safety and Security. This value acts as a barrier between deterministic and stochastic effects, preventing deterministic impacts while minimizing the likelihood of stochastic effects. If the dose is greater than 0.1mSv/yr, public protection measures must be implemented. Although, the ICRP affirms that there is no safe level of radiation exposure, however, the lowest exposure has a tendency of yielding stochastic effects. Estimating radioactivity levels is very critical in protecting the population from inappropriate radiation exposure, which can fluctuate depending on human and natural activities. Therefore, it is recommended that all exposure be kept as low as reasonably achievable while maintaining the dose limit. The dangers of radiation exposure and the impacts that could produce severe effects, must be understood by populations living near mining sites. Effective protection, routine assessment and a setback of at least 800 meters for residential will be required to reduce the magnitude of exposure based on radiation protection principle of maximizing distance thereby minimizing radiation exposure.

Footnotes

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Competing Interests: All authors have declared that there is no financial relationships with any organizations that might have an interest in the submitted work and no other relationships or activities that could appear to have influenced the submitted work.

Ethical Approval: Ethical Requirement of Research Ethics Board approval for this project was formally waived by the institution.

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