https://dx.doi.org/10.4314/dujopas.v8i1a.3
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490

Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 8 No. 1a March 2022*

Estimation of Public Radiological Dose from Mining Activities in some Selected Cities in Nigeria.

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Abstract
Mining activities is one of the most significant sources of radiation exposure from long-lived naturally occurring radioactive materials (NORMs), and have resulted in unjustifiable public exposure doses which contravene radiation protection standards. As a result, estimating the extent of such exposure is essential for keeping the recommended public dose limit. This study therefore aims at estimating the public radiation dose around mining areas and its environs in some selected cities across Nigeria. Data on measured activity concentration of NORMs radionuclides comprising of U-238, Ra-226, Th-232 and K-40 from soil round mining areas in some selected cities in Nigeria were extracted from previous literatures and are used for public dose estimation using RESRAD computer code. From the calculated mean activity concentration, the results from each mining locations shows the maximum dose are lower than International Commission on Radiological Protection (ICRP), commended public dosage boundary of 1 mSv/yr with highest dose of 0.91 mSv/yr from Ra-226, Th-232 and K-40 over the period of 47.9 years reported from Gura Top mining site in Jos, Plateau State, while the lowest dose of 0.09 mSv/yr each over the period of 14.06 and 20.27 years occurred at Itagunmodi and Arufu sites for U-238, Th-232 and K-40. The highest dose recorded in Gura Top was due to numerous mining activities in the region. According to the ICRP, there is no safe level of radiation exposure. Therefore, there is need for competent authorities to conduct periodic assessment of radiation exposure from mining sites to ensure that all exposure emanating as a result of such activities are kept below the prescribed dose limit in accordance to the principle of As Low As Reasonably Achievable (ALARA), thereby ensuring public protection from unjustified radiation exposure.

Keywords: Mining, NORMs, activity concentration, radiation dose, RESRAD Code,

INTRODUCTION
Naturally Occurring Radioactive Materials (NORMs) can be found mostly in rocks and minerals on the planet which can be widely distributed in the soil's environs, mainly influenced by environmental and physical factors which can be found at various levels in the soils (Ademola *et al.,* 2014). Such primordial radionuclides includes Uranium, Thorium, and

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Potassium with various concentrations in all rare resources constituting natural sources of background radiation in our environment generally referred to as naturally occurring radioactive materials (NORMs) (Furuta *et al.,* 2011). The activity concentrations (AC) of these NORMs radionuclides are low in natural form but can be enhanced and rise above background levels through human activities, posing a radiological risk and putting the public at risk (UNSCEAR, 2000). Environmental issues linked with NORMs arises in a variety of processes and typically result in contamination of the environment, potentially exposing members of the public to radiation. Because of the health concerns connected with NORM exposure and inhalation of radon's short-lived decay products (Laniyan and Adewumi, 2021). Mining activities constitutes one of the most vital sources of exposure from such radionuclides with extended half-lives and involves the extraction of minerals from the ground's surface through a sequence of physical procedures (Ademola *et al.,* 2014). External radiation from rocks, inhalation of radon and thoron emanating from the decay product of U-238 and Th-232 are all sources of radiation exposure arising from mining activities. Poor aerated mining environment might culminate in radiation exposures that exceed current limits, thereby causing a extraordinary frequency of lung malignancy amongst mining personnel and general public (Furuta *et al.,* 2011).

Notable international organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and ICRP has set standard and taken strict measures to prevent such exposure for both employees and the general public (UNSCEAR, 2000 & ICRP, 2007). ICRP modern recommendations are established on careful research stating no amount of radiation is safe, and that even the slightest amount of radiation has the potential to generate stochastic effects such as cancer. While keeping exposure below public dose limits, the basic standard of protection at all levels of exposure is ALARA. The purpose of this study is estimation of radiologocal exposure dosage to members of the public due to mining activities in some selected cities in Nigeria. Using RESidual RADioactivity computer code, the estimation was performed using the average AC data for U-238, Ra-226, Th-232 and K-40 from soil around mining spots of some selected cities across Nigeria.

Previous literatures have reported the measured activity concentration of NORMs radionuclides resulting from mining activities with values above or below the baseline limits. This is due to the variation in the amount of minerals and the unique geology for every location, which makes natural radioactivity differs from one place to another, (Shitu *et al.,* 2015; Jibiri *et al.,* 2011; Ibrahim *et al.,* 2013; Samuel *et al.,* 2018; Mbet *et al.,* 2019; Sunday *et al.,* 2019; Illeoma *et al.,* 2016). Estimation of the public dose resulting from the residual radioactivity arising from such mining activities is vital to ascertain the likelihood of public exposure resulting thereof and to provide public assurance that such exposure is below the recommended dose limit of 1mSv/yr as set by notable organization. A study conducted by Agbalagba *et al*., (2017) in Delta state on radiological assessment of NORMs from the production of oil and gas indicated that soil radioactivity levels for within the study area have superseded the ICRP commended public dose of 1mSv/yr. Doyi *et al.,* (2013) reiterated that accessing the dispersal of such radionuclides in the environs provides insides about its harmful level even at low dose, which has the tendency of resulting to stochastic effects; therefore, the study will serve as reference point in estimating public dose from mining activities in Nigeria for future reference. This is to ensure strict adherence to radiation protection standard which was designed to keep workers and the general public safe from undue radiation exposure.

METHODOLOGY

Study Area.

A total of Nine (9) mining locations in some selected cities across Nigeria and their respective geographical locations were considered and presented in Table 1 alongside map showing the location within the selected cities is presented in Figure 1.

Table 1. Geographical Coordinates of some selected mining locations in Nigeria

State	Mining Locations	Geographical coordinates	
		Latitude	Longitude
Osun	Itagunmodi	7° 31′ 00″ N	4° 39′ 00″ E
Taraba	Arufu	7° 50′ 59″ N	9° 5′ 00″ E
Ekiti	Ijero	7° 46′ 00″ N	5° 5′ 00″ E
Zamfara	Anka	12° 06′ 30″ N	5° 56′ 00″ E
Nasarawa	Central Nasarawa	08° 32′ 59″ N	08° 05′ 19″ E
Plateau	Gura Top, Jos	09° 49′ 51″ N	08° 54′ 48″ E
Oyo	Iwajowa, Ibarapa north and south	07° 30′ 00″ N	03° 02′ 24″ E
Kogi	Okobo	07° 21′ 14″ N	07° 37′ 31″ E
Abia	Umuahia	5° 51′ 66″ N	7° 41′ 39″ E

Figure 1. Map showing mining locations within some selected cities in Nigeria

Determination of Measured Activity Concentration and sample Size

For the purpose of this study, data on measured AC of U-238, Ra-226, Th-232 and K-40 radionuclides from some selected mining sites across Nigeria cities were obtained from previous research. The mean AC from soil within the vicinity of mining locations across some selected cities in Nigeria were calculated from the measured AC. Details of mining locations alongside method of analysis and radionuclides analyzed for each locations and are presented in Table 2.

Table 2. Sampling Locations and Method of Analysis for NORMs Radionuclides

Mining Location	State	Method of Analysis	Radionuclides	Reference
Itagunmodi	Osun	Gamma-ray Spectrometry	^{238}U	Ademola *et al.,* (2014).
			^{232}Th	
			^{40}K	
Arufu	Taraba	HPLC–ICPMS*	^{238}U	Laniyan & Adewumi, (2021).
			^{232}Th	
			^{40}K	
Ijero	Ekiti	HPLC–ICPMS*	^{238}U	Laniyan & Adewumi, (2021).
			^{232}Th	
			^{40}K	
Anka	Zamfara	Gamma-ray Spectrometry	^{226}Ra	Akpanawo *et al.,* (2020).
			^{238}U	
			^{232}Th	
			^{40}K	
Central Nasarawa	Nasarawa	Na(TI) detector**	^{226}Ra	Ibrahim *et al.,* (2013).
			^{232}Th	
			^{40}K	
Gura Top	Jos	Na(TI) detector**	^{226}Ra	Abdulkarim *et al.,* (2020).
			^{232}Th	
			^{40}K	
Iwajowa, Ibarapa north and south	Oyo	Na(TI) detector**	^{226}Ra	Joshua (2021).
			^{232}Th	
			^{40}K	
Okobo	Kogi	HPGe detector***	^{226}Ra	Itodo *et al.,* (2020).
			^{232}Th	
			^{40}K	
Umuahia	Abia	Na(TI) detector**	^{238}U	Echeweozo & Okeke, (2021).
			^{232}Th	
			^{40}K	

* High-Performance Liquid Chromatography with Inductive Coupled Plasma Mass Spectrometry
** Gamma spectroscopy using sodium iodide with thallium (Na(TI)).
*** High purity germanium (HPGe).

Scenario Description

The structural diagram for dose estimation to members of the public using RESidual RADioactivity computer code using the average AC for U-238, Ra-226, Th-232 and K-40 radionuclides around some selected mining sites in Nigeria is presented in Figure 2.

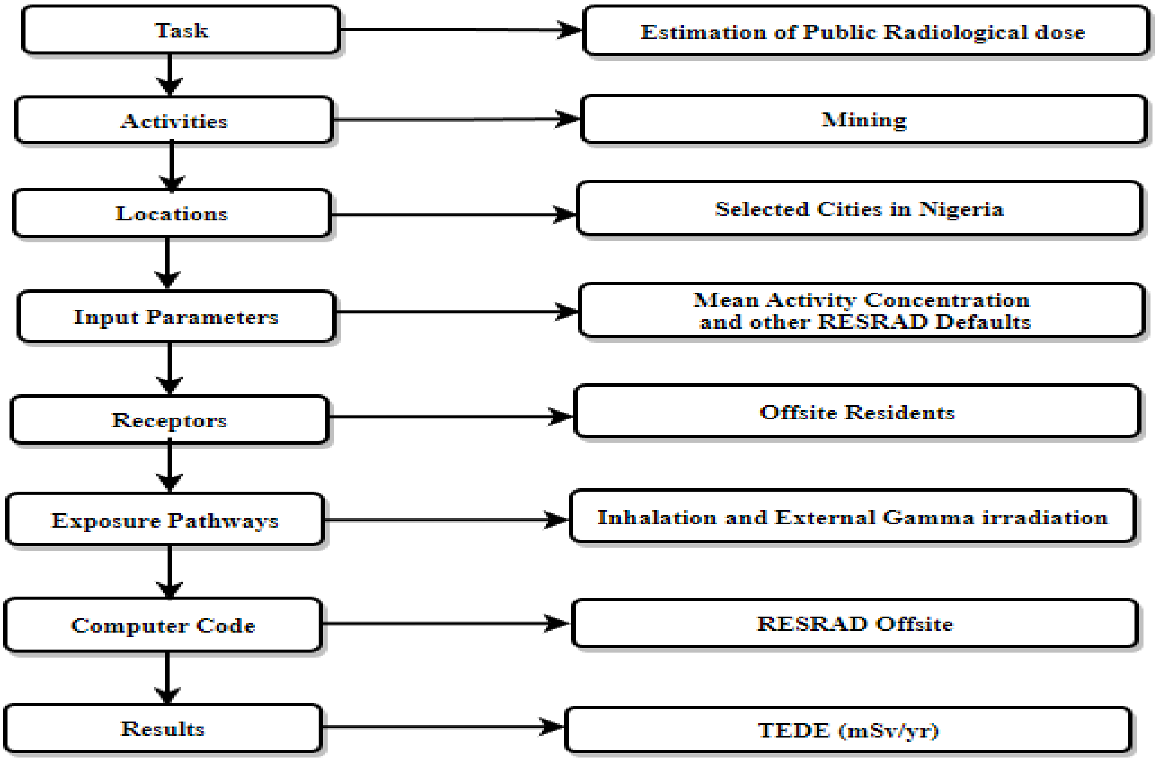

Figure 2. Summary of Dose Estimation Scenario.

RESidual RADioactive (RESRAD) Computer Code

The RESRAD family of codes was created in the 1980s by the United State Department of Energy science and engineering research laboratory to investigate possible radioactivity exposure dose to human resulting from residual radioactivity in our environment. The codes uses pathway analysis to calculate radiation exposure and risks, as well as to determine criteria for radioactive concentrations in the contaminated environment and estimate how these radionuclides reach the receptor through various exposure pathways. RESRAD OFFSITE calculates the radioactivity exposure doses and excessive life cancer risk for person located near a radionuclide-contaminated location. The code uses the Gaussian plume model, in which the radionuclide concentration and plume remain constant over time (Yu e*t al.,* 2001). When radioactive materials are released into the atmosphere, they have the potential to contaminate the environment and the general public in a variety of ways. To model air dispersion, atmospheric dispersion models are employed, the most prominent of which is the straight-line steady-state Gaussian plume model.
2.5 Input Paramaters for RESRAD Computer Code

The values of the input parameter used for the purpose of the study in RESRAD offsite computer code are showned in Table 3.

Table 3. Input parameters used in RESidual RADioactivity Offsite Code.

Input parameter	Value	Source
Mean Activity Concentration (Bq.Kg-1)		
^{238}U	Specific for each	As detailed in Table 1
^{226}Ra	mining location	
^{232}Th		
^{40}K		
Exposure duration	60 years	(Statista, 2021)
Area of contamination zone	10000 m^2	Default Value
Cover Material Density	1.5 $g.cm^{-3}$	Default Value
Depth Cover	0 m	Default Value
Contaminated Zone Thickness	2 m	Default Value
Contaminated Zone Density	1.5 $g.cm^{-3}$	Default Value
Wind Speed	2 m/s	Default Value
Precipitation	1 m/yr	Default Value
Inhalation rate for offsite resident	8400 m^3/yr	Default Value
Mass Loading for Inhalation	0.0001 g/m^3	Default Value
Cover radon diffusion coefficient	0.000002 m^2/s	Default Value
Contaminated diffusion coefficient of radon	0.000002 m^2/s	Default Value
Distribution coefficient of contaminated zone		
	100 $cm^3.g^{-1}$	Default Value
Transport factors		
^{238}U		
^{226}Ra		
^{232}Th	50 $cm^3.g^{-1}$	Default Value
^{40}K	70 $cm^3.g^{-1}$	
Release height	60000 $cm^3.g^{-1}$	
Outdoor fraction	5.5 $cm^3.g^{-1}$	
Indoor fraction	2 m	Assumed Value
	0.25	Default Value
	0.5	Default Value

RESULTS AND DISCUSSION

Activity Concentration

Table 4 presents the breakdown of the mean activity concentration of NORMs radionuclides including U-238, Ra-226, Th-232 and K-40 obained from mining sites across some selected cities in Nigeria.

Table 4. Average AC of NORMs Radionuclides from selected Mining Locations in Nigeria.

Mining Location	Radionuclides	Mean AC (Bq.Kg-1)	World Standard (Bq.Kg-1) UNSCEAR (2000)	Reference
Itagunmodi, Osun	^{238}U	53 ± 1.2	35	Ademola *et al.,* (2014).
	^{232}Th	26 ± 2.7	45	
	^{40}K	505 ± 7.1	420	
Arufu, Taraba	^{238}U	78 ± 3	35	Laniyan & Adewumi, (2021).
	^{232}Th	31 ± 1	45	
	^{40}K	341 ± 19	420	
Ijero, Ekiti	^{238}U	76 ± 7	35	Laniyan & Adewumi, (2021).
	^{232}Th	32 ± 2	45	
	^{40}K	593 ± 34	420	
Anka, Zamfara	^{226}Ra	37.9 ± 6.01	32	Akpanawo *et al.,* (2020).
	^{238}U	41.60 ± 11.06	35	
	^{232}Th	151.15 ± 21.09	45	
	^{40}K	380.34 ± 116.41	420	
Central Nasarawa	^{226}Ra	32.52 ± 4.65	32	Ibrahim *et al.,* (2013).
	^{232}Th	56.23 ± 2.30	45	
	^{40}K	403.963 ± 7.29	420	
Gura Top, Jos	^{226}Ra	46.47 ± 5.19	32	Abdulkarim *et al.,* (2020).
	^{232}Th	396.17 ± 7.69	45	
	^{40}K	161.96 ± 7.56	420	
Iwajowa, Ibarapa north and south, Oyo	^{226}Ra	3.16 ± 1.91	32	Joshua (2021).
	^{232}Th	56.70 ± 8.78	45	
	^{40}K	381. 69 ± 12.53	420	
Okobo, Kogi	^{226}Ra	32.66 ± 2.12	32	Itodo *et al.,* (2020).
	^{232}Th	54.00 ± 1.50	45	
	^{40}K	158.78 ± 3.14	420	
Umuahia, Abia	^{238}U	76.31 ± 2.21	35	Echeweozo & Okeke, (2021)
	^{232}Th	47.15 ± 2.16	45	
	^{40}K	173 ± 4.07	420	

The average activity concentration of U-238, Ra-226, Th-232 and K-40 from some selected mining locations across Nigeria cities are presented in Figure 4.

The Mean activity concentration of ^{238}U from Itagunmodi, Arufu, Ijero, Anka and Umuahia mining locations were 55.30 ± 1.20Bq.Kg-1, 78 ± 3.0Bq.Kg-1, 76 ± 7Bq.Kg-1, 41.60 ± 11.06Bq.Kg-1 and 76.31 ± 2.21Bq.Kg-1. All the values are above the UNSCEAR's standard value of 35 Bq.Kg-1 with the highest mean of 78 ± 3.0Bq.Kg-1 occurred at Arufu and Lowest mean of 41.60 ± 11.06Bq.Kg-1 at Anka mining sites. The concentration of ^{238}U above the recommended standard value implies that there is high tendency of significant exposure.

The Mean activity concentration of ^{226}Ra from Anka, Central Nasarawa, Gura Top, Iwajowa and Okobo mining locations were 39.9 ± 6.01Bq.Kg-1, 32.52 ± 4.65Bq.Kg-1, 46.47 ± 5.19Bq.Kg-1, 3.16 ± 1.91Bq.Kg-1 and 32.66 ± 2.21Bq.Kg-1. The AC values from Anka, Central Nasarawa, Gura Top and Okobo mining locations are above the UNSCEAR's standard value of 32Bq.Kg-

1 while that of Iwajowa is below the standard value with the highest mean AC of 46.47 ± 5.19Bq.Kg-1 occurred at Gura Top.

The Mean activity concentration of ^{232}Th from Itagunmodi, Arufu, Ijero, Anka, Central Nasarawa, Gura Top, Iwajowa, Okobo and Umuahia mining locations were 26 ± 2.7Bq.Kg-1, 31 ± 1Bq.Kg-1, 32 ± 2Bq.Kg-1, 151.15 ± 21.09Bq.Kg-1, 56.23 ± 2.30Bq.Kg-1, 396.17 ± 7.69Bq.Kg-1, 56.70 ± 8.78Bq.Kg-1, 54.00 ± 1.50Bq.Kg-1 and 47.15 ± 2.16Bq.Kg-1. The mean AC values from Anka, Central Nasarawa, Gura Top, Iwajowa, Okobo and Umuahia are above the UNSCEAR's standard value of 45Bq.Kg-1 while those from Itagunmodi, Arufu and Ijero mining locations are lower than the UNSCEAR's value with the highest and lowest values of AC occurred at Gura Top and Itagunmodi.

The Mean activity concentration of ^{40}K from Itagunmodi, Arufu, Ijero, Anka, Central Nasarawa, Gura Top, Iwajowa, Okobo and Umuahia mining locations were 505 ± 7.1Bq.Kg-1, 341 ± 19Bq.Kg-1, 593 ± 34Bq.Kg-1, 380.34 ± 116.41Bq.Kg-1, 403.96 ± 7.29Bq.Kg-1, 161.96 ± 7.56Bq.Kg-1, 381.69 ± 12.53Bq.Kg-1, 158.78 ± 3.14Bq.Kg-1 and 173 ± 4.07Bq.Kg-1. The mean AC values from Itagunmodi, and Ijero are above the UNSCEAR's standard value of 420Bq.Kg-1 while those from Arufu, Anka, Central Nasarawa, Gura Top, Iwajowa, Okobo and Umuahia mining locations are lower than the UNSCEAR's value with the highest and lowest values of AC occurred at Ijero and Okobo.

The Mean activity concentration values above the recommended UNSCEAR's world standard value implies that the host communities have high tendency of being prone to radiation exposure.

Radiation Dose from Selected Mining Sites in Nigeria

The result of dose from selected mining sites across Nigeria cities are presented in Figure 3 to Figure 11.

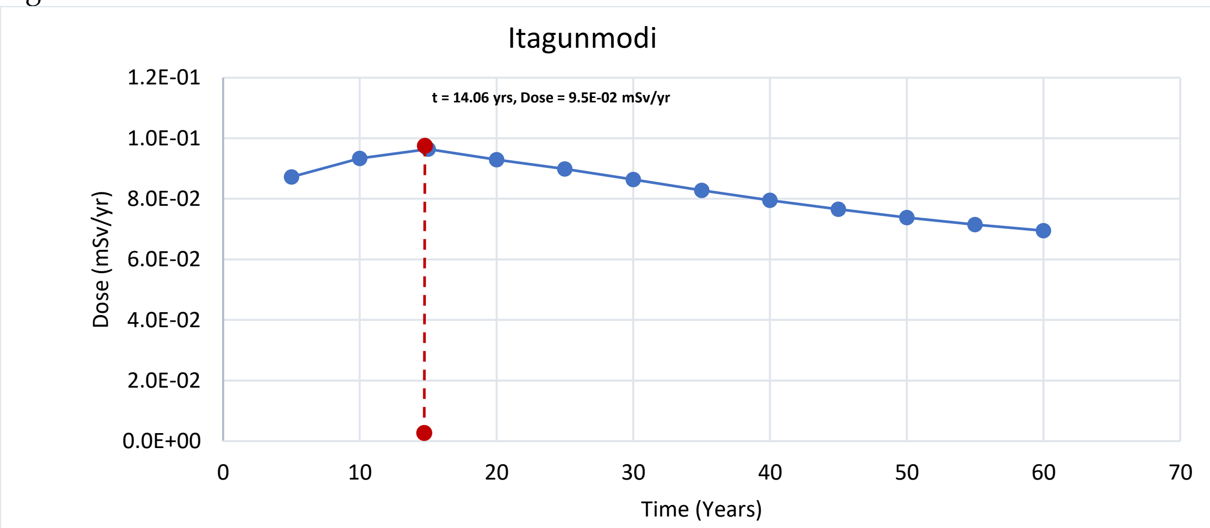

Figure 3. Dose from Itagunmodi Mining site, Osun State

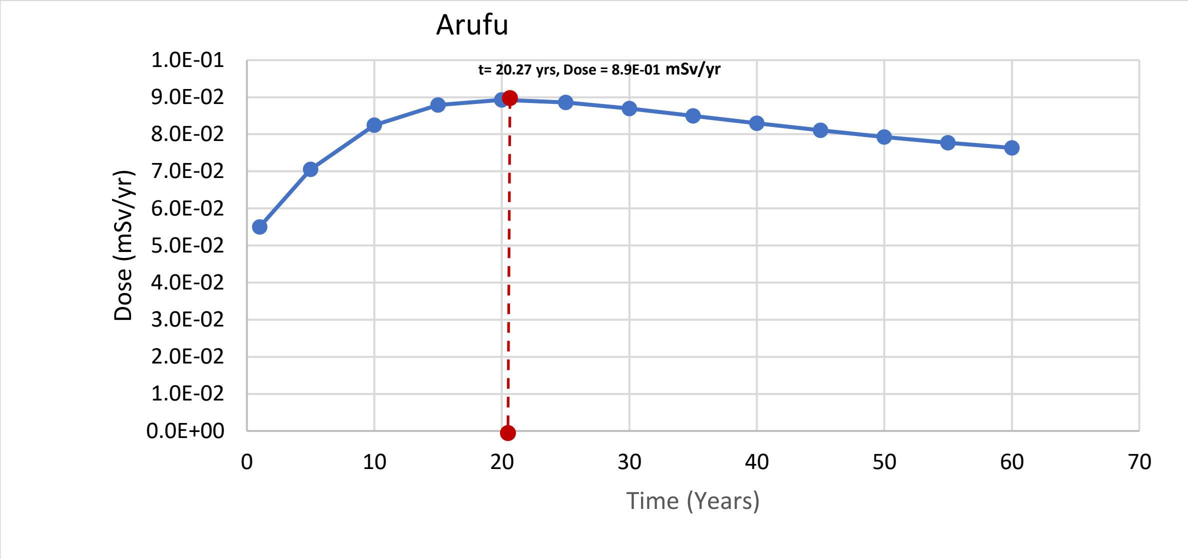

Figure 4. Dose from Arufu Mining site, Taraba State

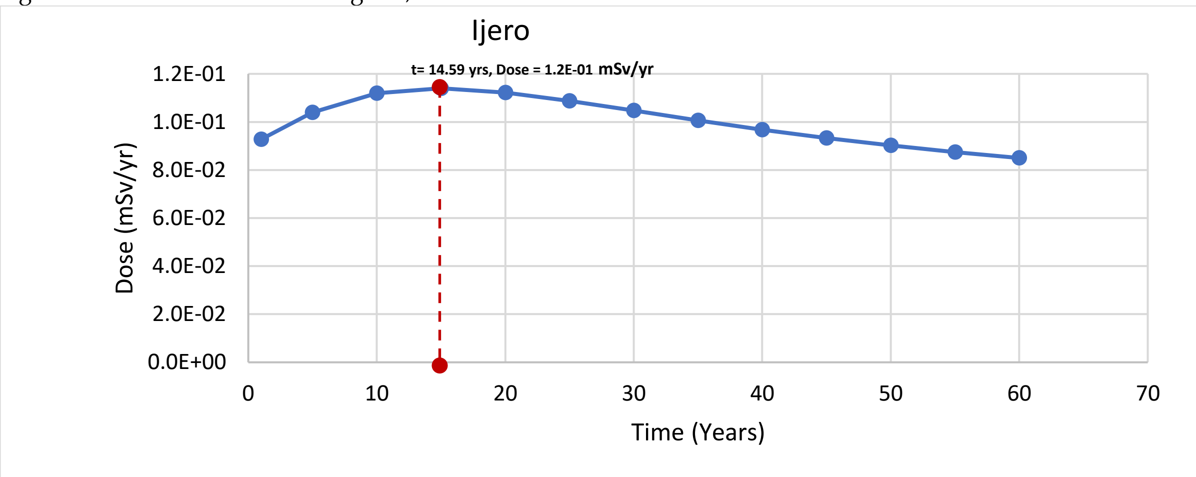

Figure 5. Dose from Ijero Mining site, Ekiti State

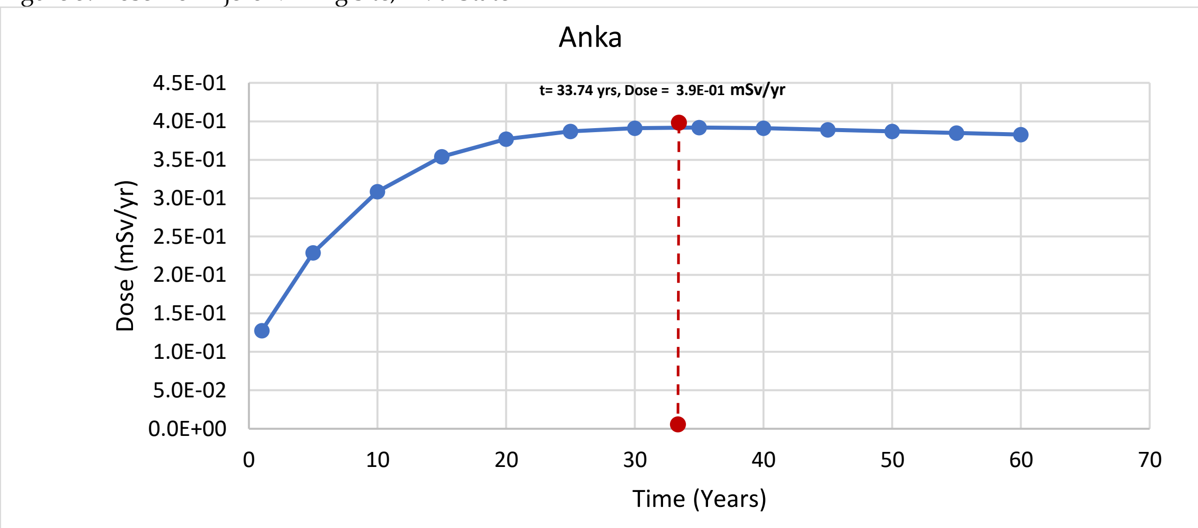

Figure 6. Dose from Anka Mining site, Zamfara State

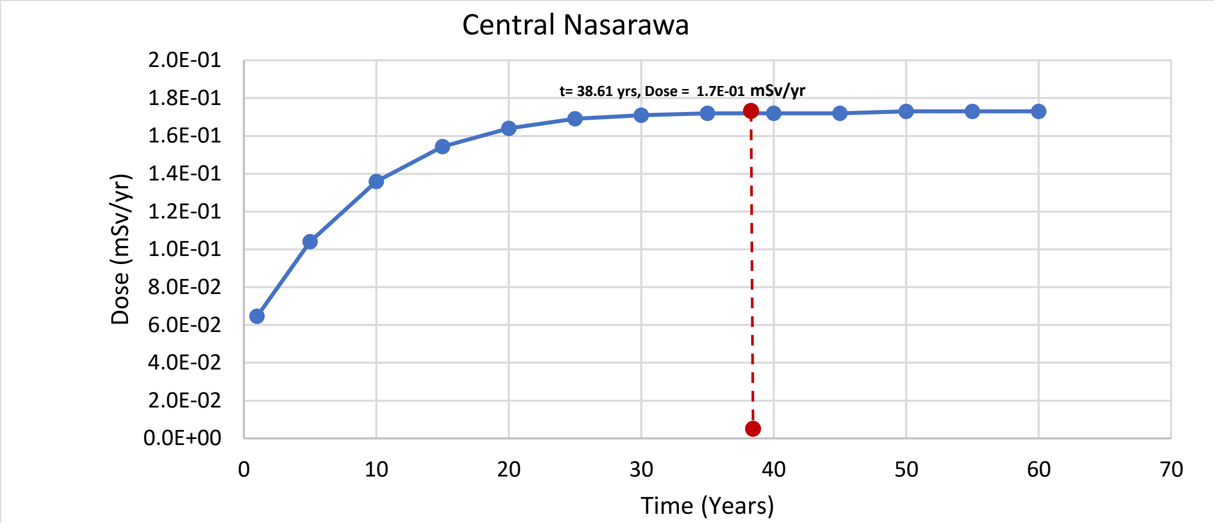

Figure 7. Dose from Central Nasarawa Mining site, Nasarawa State

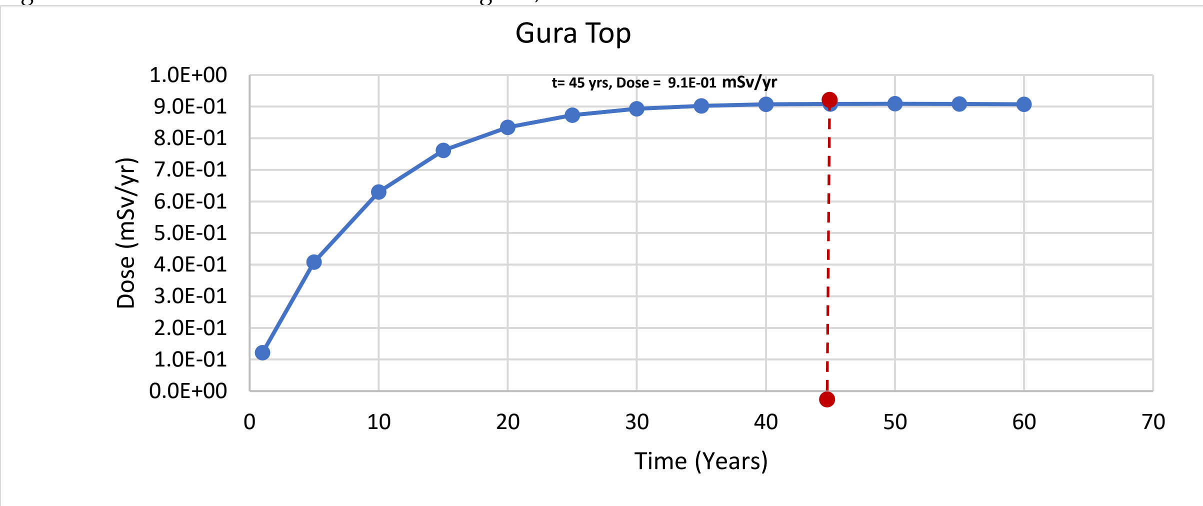

Figure 8. Dose from Gura Top Mining site, Plateau State

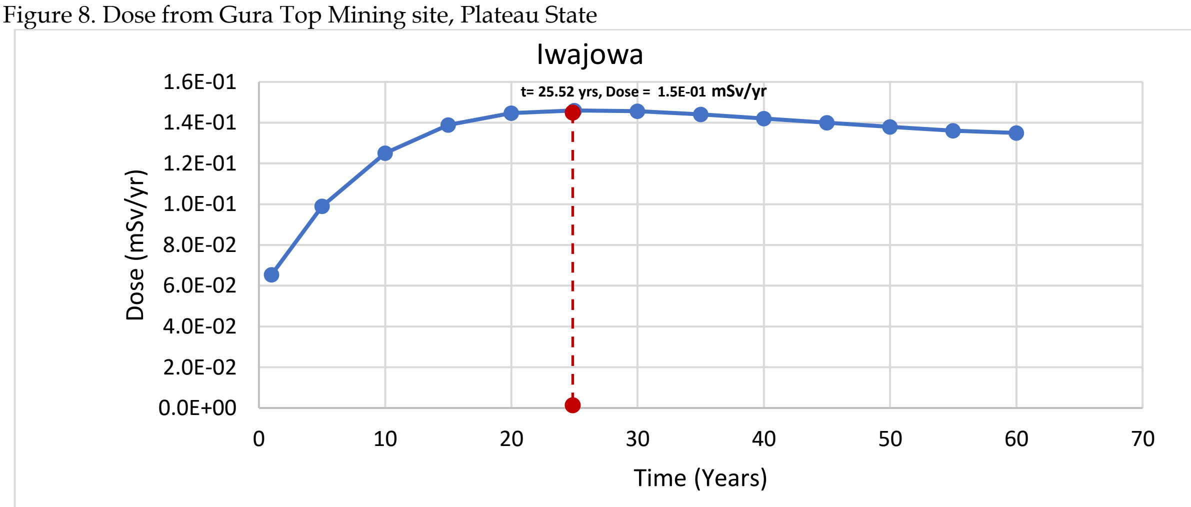

Figure 9. Dose from Iwajowa Mining site, Oyo State

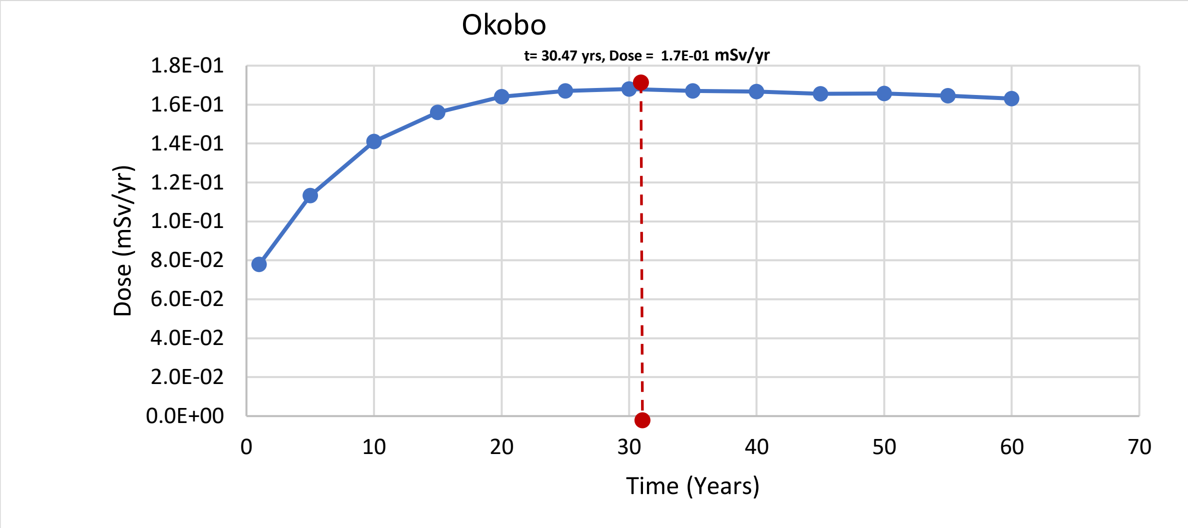

Figure 10. Dose from Okobo, Kogi State

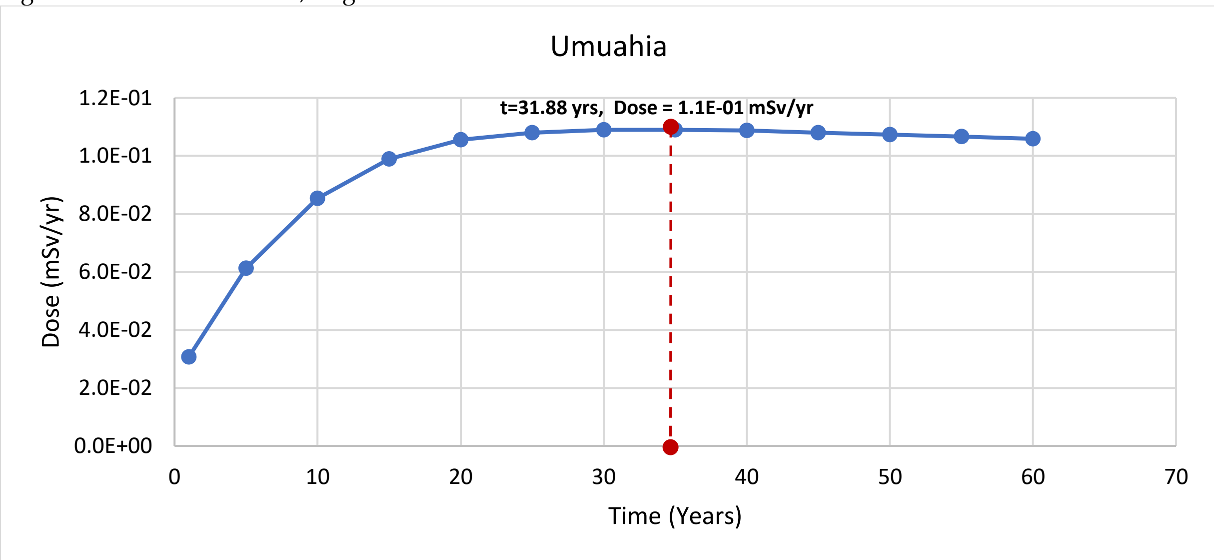

Figure 11. Dose from Umuahia, Abia State

The analysis of public exposure dose results using RESRAD Offsite computer code and mean activity concentration of the measured radionuclides from selected mining sites within Nigeria cities as showned from Figure 3 to Figure 11 are as follows:- The result of dose estimation from mining activities in Itagunmodi and Arufu sites shows radiation dose of 0.09 mSv/yr each over the period of 14.06 and 20.27 years; Ijero and Umuahia mining sites shows highest radiation dose of 0.11 mSv/yr each over the period of 14.59 and 31.88 years; Central Nasarawa and Okobo mining sites shows highest radiation dose of 0.17 mSv/yr each over the period of 38.61 and 30.37 years; Iwajowa, Anka and Gura Top mining sites shows highest radiation doses of 0.15 mSv/yr, 0.39 mSv/yr and 0.91 mSv/yr over the periods of 25.52, 33.74 and 47.9 years. Although the results fall lower than the ICRP suggested public dosage boundary of 1 mSv/yr, the highest dosage of 0.39 and 0.91 mSv/yr reported in Anka and Gura Top mining sites in Zamfara and Jos, Plateau states are due to abundance of mining activities going on in the regions.

The variation in total exposure doses reported is due to difference in mean activity concentration from selected mining sites. The overall yearly radiation dose from mining activities include contributions from external exposure pathway via direct gamma irradiation, and internal radiation through inhalation and ingestion pathways. The inhalation dosage is ascribed to gaseous decay radon and thoron from U-238 and Th-232 while the external dose is attributed to direct gamma irradiation from K-40 which decays by releasing 89 percent beta and 11 percent gamma radiation with low external dose contribution. The estimation of public radiation doses around mining sites in some selected cities across Nigeria was conducted using the determined average AC of U-238, Ra-226, Th-232 and K-40 radionuclides of soil samples obtained from previous studies alongside RESRAD Offsite computer code and other input parameters as detailed in Table 2.

Comparison of total radiation dose (mSv/yr) from mining locations in some selected cities of Nigeria are presented in Figure 12.

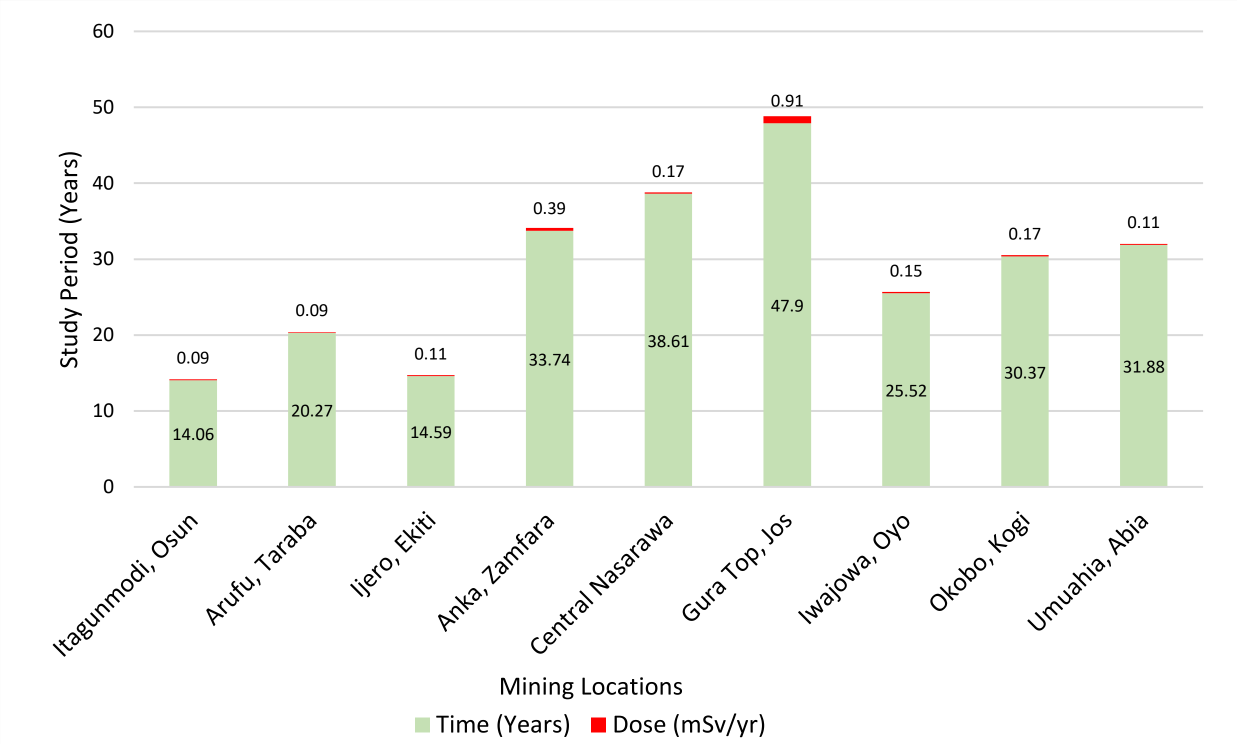

Figure 12. Comparison of dose from Mining Locations in Nigeria

Figure 12 shows dose comparison in mining locations of some selected cities in Nigeria. The highest dose of 0.91 mSv/yr reported from Gura Top mining location in Jos Plateau State over the period of 47.9 years while the lowest doses of 0.09 mSv/yr occurred at Itagunmodi and Arufu over the periods of 14.06 and 20.27 years . The highest dose in Gura Top is due to the abundance of mining activities going on in the city, which might results to long-term stochastic effects to the public. The dose from Gura Top is within the commended ICRP public dosage boundary of 1 mSv/yr, and all doses recorded from other study sites are below the recommended public dose boundary respectively. Due to the tendency of low dose accumulation over a long period of time, which might results to stochastic effects, the ICRP reaffirms that there is no safe level of radiation exposure. The highest dose obtained from Gura Top mining site is in line with the dose reported by Faanu *et al.*, (2016) with annual dose of 0.918 mSv/yr from mining in central region of Ghana, and lower than the annual dose of 0.12 mSv/yr reported by Nwankwo *et al.*, (2015) from findings of public dose assessment around mining sites in Komu, Oyo State.

CONCLUSION

The ICRP recommended dose bounds aimed to act as a parameter by preventing deterministic effects while minimizing stochastic impacts. If the dose is exceeding 1 mSv/yr, public safety measures need to be applied by the responsible Authority. The results of dose estimation from mining sites each city considered in this study shows the highest annual dosages are lower the commended ICRP public dosage boundary of 1 mSv/yr with highest measure of 0.91 mSv/yr over the period of 47.9 years reported from Gura Top mining site due to numerous mining activities going on in the region. In adherence to the principle of "As Low As Reasonable achievable" (ALARA), the Competent Authority need to conduct a periodic assessment of radiation exposure from mining sites to ensure that any exposure resulting from such activities is kept below the authorized dose limit, thereby protecting the public and the environment from unwarranted radiation exposure and contamination.

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