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# Influence of the Soil types on the Terrestrial Gamma Radiation Dose Rate (TGRD) at Dange-Shuni and its Mining sites

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***Abstract***
*Terrestrial gamma radiation dose is among the major contributors to the mean dose rate received by the population of the world. This work aimed at assessing the level of terrestrial gamma radiation due to long live occurring radionuclides ($^{232}$Th, $^{238}$U and $^{40}$K) from two identified soil types (Arenosol and Acrisol soil) at different locations of the study area using γ-ray spectrometry. Measurements of Terrestrial gamma radiation dose rates (TGRD) of Dange-Shuni Local Government Area (L.G.A) were carried out using a Geiger Muller (GM) Detector handheld radiation survey meter (RADOS RDS-31). The range of the TGDR from the Arenosol soil falls between 40 - 190 nGyh$^{-1}$ with arithmetic mean of 93.5 nGyh$^{-1}$. While the range of measured TGRD from the Acrisol soil type is 100 - 170 nGyh$^{-1}$, with arithmetic mean of 130 nGyh$^{-1}$. The overall result from the study area shows that the measured TGRD rates at the majority of the locations is higher than the worldwide reference value of 59 nGyh$^{-1}$ However the result from locations covered by Acrisol soil shows higher radiation dose than the ones covered by Arenosol soil. The calculated annual effective doses for the locations covered by Arenosol soil range from 0.07 - 0.35 mSvy$^{-1}$ with an average value of 0.17 mSv y$^{-1}$. While for the locations covered by Acrisol soil range from 0.18 – 0.31 mSv.y$^{-1}$ with an average value of 0.24 mSv.y$^{-1}$. The worldwide average annual effective dose is approximately 0.5 mSv.y$^{-1}$. The distribution of these measurements in various settlements of the L.G.A shows the influence of soil types on the dose rate values. The data obtained could be used in formulating safety standard and radiological guidelines.*

***Keywords:*** *gamma, dose rates, effective dose, Arenosol, Acrisol, Mines*

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## I. Introduction

Measurement of radiation dose and its distribution is very vital in assessing the health risk to a population [1]. The exposure of human beings to radiation from natural and artificial sources of radiation in the environment is continuous and unavoidable. Environmental. Cosmic and terrestrial radiation are the major source of ionizing radiation to the public. Much of concern are primordial radionuclides ($^{238}$U, $^{232}$Th and their decay products as well as $^{40}$K), which serve as the major contributors of terrestrial background radiation [2 - 6]. Uranium ($^{238}$U) and thorium ( $^{232}$Th) are in sufficient quantity to contribute significant radiation dose, being them radionuclides with very long half-lives compared to age the of the earth. Gamma radiation from these radionuclides represents the main external source of irradiation to the human body [7 - 9].

Soil is formed as a result of weathering processes of lithosphere and rocks. In that way rocks and minerals are converted to major constituents of soil; consequently, the primordial radioactive elements are taken from their parent rocks and deposited in to soil. The nature of the parent rocks and their abundance as well as physical and geochemical processes (i.e. weathering, transportation and deposition), determine the concentration of primordial radionuclides in soil largely [10, 11]. Igneous rocks, such as granites, are known to contain much radionuclides than sedimentary rocks. Also, sedimentary processes sorting weathered materials lead to variations of radionuclide concentrations in different types of sedimentary rocks [12].

Furthermore, human activity, such as mining and milling [13], coal burning [14, 15], oil and natural gas production [16, 17], agricultural fertilizer application [18] and power generation [19, 20] lead to elevated concentrations of natural radionuclides in soils. Soil therefore served as one of the major sources of external exposure to natural ionizing radiation in humans [21 - 23]. Evaluation of external radiation (gamma) dose and its radiological side effect have been done by various researchers [24 – 30].

Different types of soil exist in the landscape that cover the geographical area of Sokoto State. However only two quaternary types of soil exist in Dange-Shuni L.G.A (Study area) Fig 1. The two types of soil are: Arenosol and Acrisol soil. Arenosol, one of the 30 soil groups in the classification system of the Food and Agriculture Organization (FAO). Arenosols are sandy-textured soils that lack any significant soil profile development. They exhibit only a partially formed surface horizon (uppermost layer) that is low in humus. They occupy about 7 percent of the continental surface area of the Earth, and they are found in arid regions such as the Sahel of western Africa and the deserts of western Australia. Acrisol is a Reference Soil Group of the World Reference Base for Soil Resources (WRB). It has a clay-rich subsoil and is associated with humid. Acrisols form on old landscapes that have an undulating topography and a humid tropical climate. They occupy just under 8 percent of the continental land surface on Earth, covering areas throughout central and northern Latin America, Southeast Asia, and West Africa. The age, mineralogy, and extensive leaching of these soils have led to low levels of plant nutrients, excess aluminum, and high erodibility, all of which make agriculture problematic [31].

This work therefore aimed at assessing the terrestrial gamma radiation dose due to radionuclides in different type of soil that covers the area of Dange-Shuni Local Government Area Sokoto State Nigeria.

## II. Materials And Methods

### 2.1 Study Area

Dange-shuni is a local government area in Sokoto State. It geographically lies between longitude $5^0$10'00'' E and $5^0$40'02''E and latitude $12^0$39'00'' N and $13^0$0'00''N. Dange-shuni share boundaries with Sokoto south and kware local government in the north. Shagari and Bodinga in the west and Rabah Local government in the east [32]. The climate of Sokoto state, is characterized by annual rain fall ranges from 30-40 inches, May/June to September/October with the heaviest rainfall in August and some part of September, in the long dry season (6 - 8 months) the air is very dry with relative humidity constantly between 40% and the temperature as high as $40^0$. As per the latest census 2006, the population of Dange-Shuni L.G.A is 0. 19 million, with an estimated projection reaching 0.26 million by 2016, which is contributing 44% to the total population of the Sokoto. State The density of the L.G.A population is 232 persons per $km^2$ with 1,126 $km^2$ area [34].

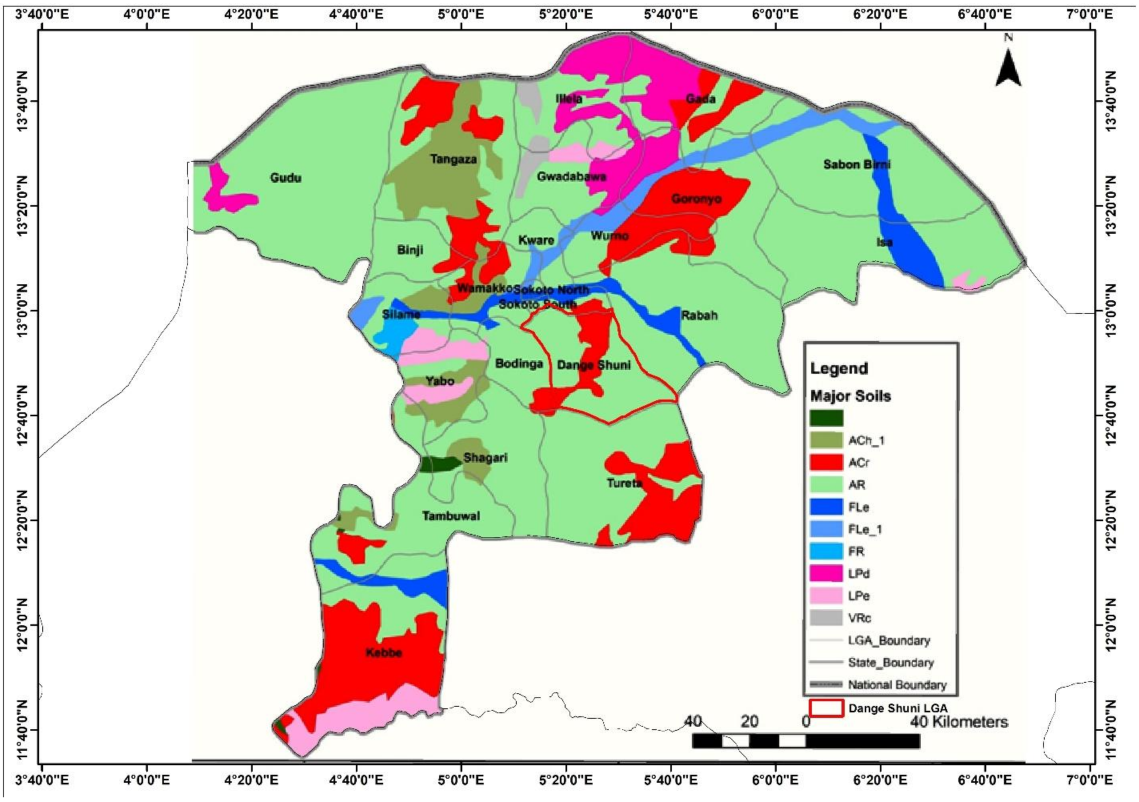


Fig 1: Soil Map of Sokoto State

**2.2 SURVEY METRE (RADOS RDS-31)**

Measurements were carried out using a GM Detector handheld radiation survey metre (RADOS RDS-31), developed by Mirion Technologies. The device is designed for a wide range of applications including the in situ dose rate measurements in field conditions, in nuclear industry and for protection against radiological hazards by personnel in working environment. The meter readings were in micro sievert per hour, and the mean TGRD readings were converted to $nGyh^{-1}$ using the recommended conversion factor of 1 $\mu Sv\ h^{-1}$ to 1000 $nGyh^{-1}$. The meter has a linear response to ionizing radiation between 48 keV and 3 MeV which cover majority of the emitted gamma radiation from terrestrial sources [33]. The facility was obtainable at the Nigerian Nuclear Regulatory Authority North-East Zonal office Gombe State.

**2.3 Measurements of Terrestrial Gamma Radiation Dose Rates**

The terrestrial gamma radiation dose (TGRD) rates within the study area were measured at various locations (Fig 2) based on soil types. Measurements were carried out using a handheld radiation survey metre (RADOS RDS-31), developed by Mirion Technologies (Canberra), In USA.

A measurement campaign was conducted for duration of 2 weeks, starting from 29 January 2022 to 14 February 2022. The data was taken approximately 1 m above the ground at each of the locations. Measurements were recorded when the reading on the survey meter was stable. The set of three readings were taken from each point with 5- min interval, and an average of these values was recorded in order to minimize the error. Global positioning system (GPS) Garmin (GPS Map76). was used to record the geographical coordinates of each measurement point.

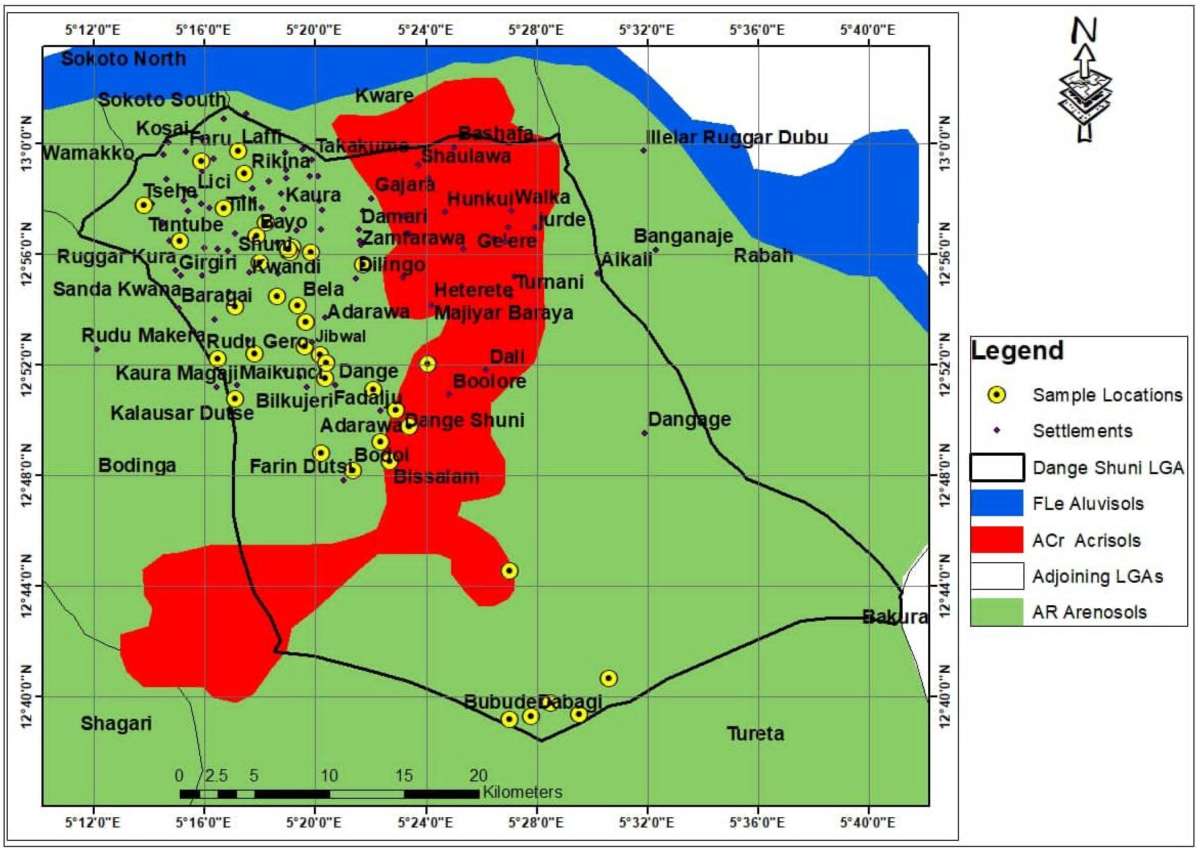


Figure 2: Map Showing Sampling Locations in Dange-Shuni L.G.A

**2.4 Annual Effective Dose (AED)**

Calculating the expected annual effective dose received by the population attributable to radioactivity in soil is very important. Two factors are important in the course of estimating the effective dose in any environment: the conversion coefficient from $Gy\ h^{-1}$ to $Sv\ h^{-1}$; and the occupancy factor. Occupancy factor vary base on the prevailing environmental condition in a certain location and it has been estimated for the rural and urban dwellers in Nigeria as 0.3 and 0.22 respectively [34]. The AED will be calculated using Equation 1.

$$A_{out}\ (mSvy^{-1}) = D\ (nGyh^{-1}) \times 8760h \times 0.3 \times 0.7\ (SvGy^{-1}) \times 10^{-6} \quad (1)$$

Where $A_{out}$ is the annual effective dose for the outdoor environments respectively and D is the absorbed dose rate. 0.7 Sv $Gy^{-1}$ is the conversion coefficient and 0.3 is the occupancy factor for the rural dwellers in Nigeria.

## III. Results

**Table 1**: Gamma Dose Rate in air from Arenosols soil

| S/N | Location | Soil Type | Latitude (N) | Longitude (E) | Dose Rate ($nGyh^{-1}$) |
|---|---|---|---|---|---|
| 1 | Amanawa | **Arenosols Ar (**Sandy Soil) | 12.90816$^0$ | 005.30987$^0$ | 50 |
| 2 | Asarara | **Arenosols Ar (**Sandy Soil) | 12.66306$^0$ | 005.47459$^0$ | 50 |
| 3 | Asarara majema | **Arenosols Ar (**Sandy Soil) | 12.65522$^0$ | 005.46274$^0$ | 40 |
| 4 | Bayo | **Arenosols Ar (**Sandy Soil) | 12.94455$^0$ | 005.29777$^0$ | 90 |
| 5 | Majia bela | **Arenosols Ar (**Sandy Soil) | 12.90241$^0$ | 005.32258$^0$ | 90 |
| 6 | Budude | **Arenosols Ar (**Sandy Soil) | 12.64671$^0$ | 005.45360$^0$ | 90 |
| 7 | Dabagi – lafiya | **Arenosols Ar (**Sandy Soil) | 12.74270$^0$ | 005.44973$^0$ | 50 |
| 8 | Dange | **Arenosols Ar (**Sandy Soil) | 12.85882$^0$ | 005.33917$^0$ | 110 |
| 9 | Galankawa | **Arenosols Ar (**Sandy Soil) | 12.86809$^0$ | 005.33965$^0$ | 170 |
| 10 | *Galankawa – south | **Arenosols Ar (**Sandy Soil) | 12.86809$^0$ | 005.33965$^0$ | 170 |
| 11 | *Galankawa – west | **Arenosols Ar (**Sandy Soil) | 12.87272$^0$ | 005.33558$^0$ | 80 |
| 12 | Kalausar dutsi | **Arenosols Ar (**Sandy Soil) | 12.84641$^0$ | 005.28474$^0$ | 50 |
| 13 | Kwanan kwandi | **Arenosols Ar (**Sandy Soil) | 12.43552$^0$ | 005.30301$^0$ | 90 |
| 14 | Kwanan lofa | **Arenosols Ar (**Sandy Soil) | 12.67822$^0$ | 005.50991$^0$ | 80 |
| 15 | Kwandi | **Arenosols Ar (**Sandy Soil) | 12.92846$^0$ | 005.29949$^0$ | 160 |
| 16 | Kwannawa | **Arenosols Ar (**Sandy Soil) | 12.98957$^0$ | 005.26442$^0$ | 90 |
| 17 | Liffi | **Arenosols Ar (**Sandy Soil) | 12.99548$^0$ | 005.28663$^0$ | 60 |
| 18 | *Lungu | **Arenosols Ar (**Sandy Soil) | 12.93538$^0$ | 005.31701$^0$ | 100 |
| 19 | Makera – east | **Arenosols Ar (**Sandy Soil) | 12.93459$^0$ | 005.33003$^0$ | 70 |
| 20 | *Lungu – south | **Arenosols Ar (**Sandy Soil) | 12.93473$^0$ | 005.31825$^0$ | 190 |
| 21 | *Lungu – west | **Arenosols Ar (**Sandy Soil) | 12.93650$^0$ | 005.31671$^0$ | 90 |
| 22 | Mallandi | **Arenosols Ar (**Sandy Soil) | 12.65648$^0$ | 005.49174$^0$ | 40 |
| 23 | Rikina | **Arenosols Ar (**Sandy Soil) | 12.98211$^0$ | 005.29038$^0$ | 80 |
| 24 | Rudun gero | **Arenosols Ar (**Sandy Soil) | 12.87358$^0$ | 005.29636$^0$ | 100 |
| 25 | Rudun makera | **Arenosols Ar (**Sandy Soil) | 12.86740$^0$ | 005.27013$^0$ | 120 |
| 26 | Sabon garin banganange | **Arenosols Ar (**Sandy Soil) | 12.92710$^0$ | 005.36160$^0$ | 100 |
| 27 | Tilli | **Arenosols Ar (**Sandy Soil) | 12.96124$^0$ | 005.27807$^0$ | 70 |
| 28 | Tsefe | **Arenosols Ar (**Sandy Soil) | 12.96322$^0$ | 005.22967$^0$ | 90 |
| 29 | Tuntube | **Arenosols Ar (**Sandy Soil) | 12.94147$^0$ | 005.25156$^0$ | 70 |
| 30 | Lugga | **Arenosols Ar (**Sandy Soil) | 12.90175$^0$ | 005.28488$^0$ | 120 |
| 31 | Gidan gara | **Arenosols Ar (**Sandy Soil) | 12.87810$^0$ | 005.32687$^0$ | 100 |
| 32 | Marina | **Arenosols Ar (**Sandy Soil) | 12.95286$^0$ | 005.30317$^0$ | 120 |
| 33 | Bodai kaura | **Arenosols Ar (**Sandy Soil) | 12.81355$^0$ | 005.33674$^0$ | 140 |
| 34 | *Lungu mining site | **Arenosols Ar (**Sandy Soil) | 12.93754$^0$ | 005.31933$^0$ | 60 |
| | | **Mean** | | | **93.5** |
| | | **Min** | | | **40** |
| | | **Max** | | | **190** |

**Note: ( * ) Means locations at mine and its environs**

**Table 2**: Gamma Dose Rate in air from Acrisols soil

| S/N | Location | Soil Type | Latitude (N) | Longitude (E) | Dose Rate ($nGyh^{-1}$) |
|---|---|---|---|---|---|
| 1 | Bissalam | **Acrisols ACr (**Clay Soil) | 12.80884$^0$ | 005.37773$^0$ | 150 |
| 2 | Bodai magaji sajo | **Acrisols ACr (**Clay Soil) | 12.80336$^0$ | 005.35563$^0$ | 170 |
| 3 | Dandutsi | **Acrisols ACr (**Clay Soil) | 12.82973$^0$ | 005.38961$^0$ | 170 |
| 4 | Fajaldu | **Acrisols ACr (**Clay Soil) | 12.83970$^0$ | 005.38138$^0$ | 110 |
| 5 | Illela bissalam | **Acrisols ACr (**Clay Soil) | 12.82050$^0$ | 005.37231$^0$ | 120 |
| 6 | *Majia | **Acrisols ACr (**Clay Soil) | 12.89273$^0$ | 005.32710$^0$ | 100 |
| 7 | *Majia – east | **Acrisols ACr (**Clay Soil) | 12.89273$^0$ | 005.32710$^0$ | 100 |
| 8 | Wababe | **Acrisols ACr (**Clay Soil) | 12.86724$^0$ | 005.40078$^0$ | 120 |
| | | **Mean** | | | **130** |
| | | **Min** | | | **100** |
| | | **Max** | | | **170** |

**Note: ( * ) Means locations at mine and its environs**

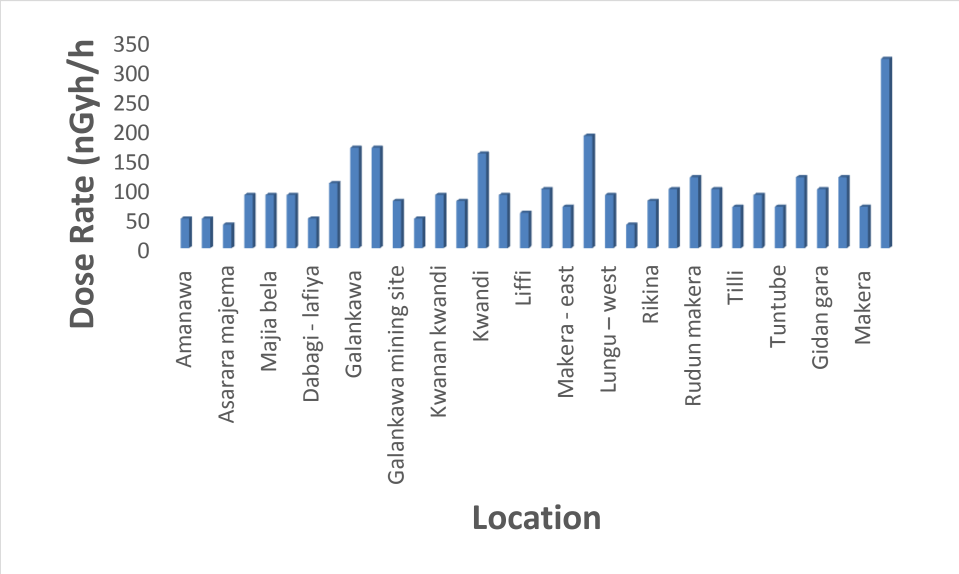


**Fig 3** : Gamma Dose Rate in Air from Arensols soil

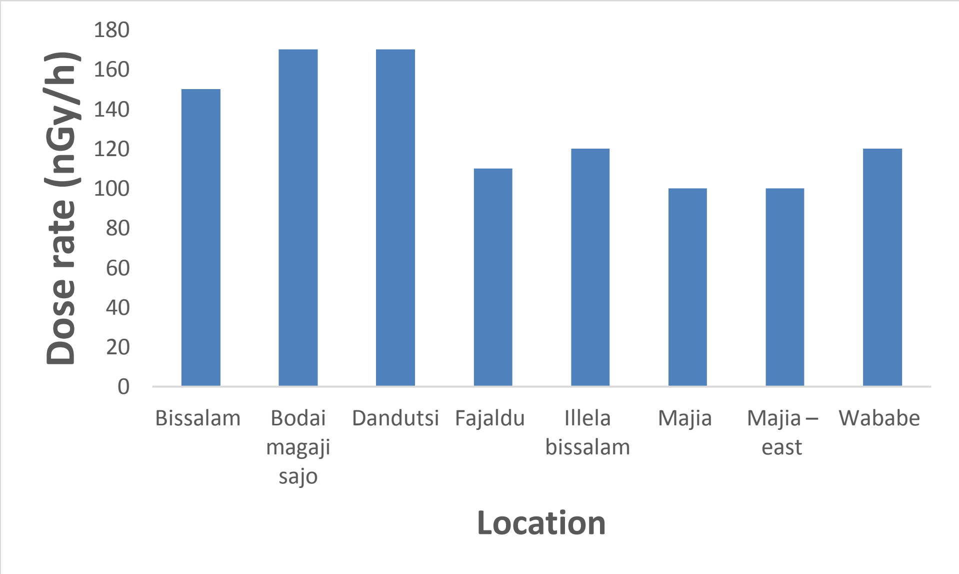


**Fig 4** : Gamma Dose Rate in Air from Acrisols soil

**Table 3:** Population Weighted Annual Effective Dose (due to Arenosols soil type)

| S/N | Location | Soil Type | Latitude (N) | Longitude (E) | Annual Effective Dose ($mSvy^{-1}$) |
|---|---|---|---|---|---|
| 1 | Amanawa | Arenosols | $12.90816^0$ | $005.30987^0$ | 0.09198 |
| 2 | Asarara | Arenosols | $12.66306^0$ | $005.47459^0$ | 0.09198 |
| 3 | Asarara majema | Arenosols | $12.65522^0$ | $005.46274^0$ | 0.073584 |
| 4 | Bayo | Arenosols | $12.94455^0$ | $005.29777^0$ | 0.165564 |
| 5 | Majia bela | Arenosols | $12.90241^0$ | $005.32258^0$ | 0.165564 |
| 6 | Budude | Arenosols | $12.64671^0$ | $005.45360^0$ | 0.165564 |
| 7 | Dabagi – lafiya | Arenosols | $12.74270^0$ | $005.44973^0$ | 0.09198 |
| 8 | Dange | Arenosols | $12.85882^0$ | $005.33917^0$ | 0.202356 |
| 9 | Galankawa | Arenosols | $12.86809^0$ | $005.33965^0$ | 0.312732 |
| 10 | Galankawa – south | Arenosols | $12.86809^0$ | $005.33965^0$ | 0.312732 |
| 11 | Galankawa mining site | Arenosols | $12.87272^0$ | $005.33558^0$ | 0.147168 |
| 12 | Kalausar dutsi | Arenosols | $12.84641^0$ | $005.28474^0$ | 0.09198 |
| 13 | Kwanan kwandi | Arenosols | $12.43552^0$ | $005.30301^0$ | 0.165564 |
| 14 | Kwanan lofa | Arenosols | $12.67822^0$ | $005.50991^0$ | 0.147168 |
| 15 | Kwandi | Arenosols | $12.92846^0$ | $005.29949^0$ | 0.294336 |
| 16 | Kwannawa | Arenosols | $12.98957^0$ | $005.26442^0$ | 0.165564 |
| 17 | Liffi | Arenosols | $12.99548^0$ | $005.28663^0$ | 0.110376 |
| 18 | Lungu | Arenosols | $12.93538^0$ | $005.31701^0$ | 0.18396 |

| | | | | | |
|---|---|---|---|---|---|
| 19 | Makera – east | Arenosols | $12.93459^{0}$ | $005.33003^{0}$ | 0.128772 |
| 20 | Lungu – south | Arenosols | $12.93473^{0}$ | $005.31825^{0}$ | 0.349524 |
| 21 | Lungu – west | Arenosols | $12.93650^{0}$ | $005.31671^{0}$ | 0.165564 |
| 22 | Mallandi | Arenosols | $12.65648^{0}$ | $005.49174^{0}$ | 0.073584 |
| 23 | Rikina | Arenosols | $12.98211^{0}$ | $005.29038^{0}$ | 0.147168 |
| 24 | Rudun gero | Arenosols | $12.87358^{0}$ | $005.29636^{0}$ | 0.18396 |
| 25 | Rudun makera | Arenosols | $12.86740^{0}$ | $005.27013^{0}$ | 0.220752 |
| 26 | Sabon garin banganange | Arenosols | $12.92710^{0}$ | $005.36160^{0}$ | 0.18396 |
| 27 | Tilli | Arenosols | $12.96124^{0}$ | $005.27807^{0}$ | 0.128772 |
| 28 | Tsefe | Arenosols | $12.96322^{0}$ | $005.22967^{0}$ | 0.165564 |
| 29 | Tuntube | Arenosols | $12.94147^{0}$ | $005.25156^{0}$ | 0.128772 |
| 30 | Lugga | Arenosols | $12.90175^{0}$ | $005.28488^{0}$ | 0.220752 |
| 31 | Gidan gara | Arenosols | $12.87810^{0}$ | $005.32687^{0}$ | 0.18396 |
| 32 | Marina | Arenosols | $12.95286^{0}$ | $005.30317^{0}$ | 0.220752 |
| 33 | Bodai kaura | Arenosols | $12.81355^{0}$ | $005.33674^{0}$ | 0.128772 |
| 34 | Lungu mining site | Arenosols | $12.93754^{0}$ | $005.31933^{0}$ | 0.110376 |
| | | **Mean** | | | **0.168269** |
| | | **Min** | | | **0.073584** |
| | | **Max** | | | **0.349524** |

**Table 4:** Population Weighted Annual Effective Dose (due to Acrisols soil type)

| S/N | Location | Soil Type | Latitude (N) | Longitude (E) | Annual Effective Dose ($mSvy^{-1}$) |
|---|---|---|---|---|---|
| 1 | Bissalam | Acrisols ACr (Clay Soil) | $12.80884^{0}$ | $005.37773^{0}$ | 0.27594 |
| 2 | Bodai magaji sajo | Acrisols ACr (Clay Soil) | $12.80336^{0}$ | $005.35563^{0}$ | 0.312732 |
| 3 | Dandutsi | Acrisols ACr (Clay Soil) | $12.82973^{0}$ | $005.38961^{0}$ | 0.312732 |
| 4 | Fajaldu | Acrisols ACr (Clay Soil) | $12.83970^{0}$ | $005.38138^{0}$ | 0.202356 |
| 5 | Illela bissalam | Acrisols ACr (Clay Soil) | $12.82050^{0}$ | $005.37231^{0}$ | 0.220752 |
| 6 | Majia | Acrisols ACr (Clay Soil) | $12.89273^{0}$ | $005.32710^{0}$ | 0.18396 |
| 7 | Majia – east | Acrisols ACr (Clay Soil) | $12.89273^{0}$ | $005.32710^{0}$ | 0.18396 |
| 8 | Wababe | Acrisols ACr (Clay Soil) | $12.86724^{0}$ | $005.40078^{0}$ | 0.220752 |
| | | | | **Mean** | **0.239148** |
| | | | | **Min** | **0.18396** |
| | | | | **Max** | **0.312732** |

## IV. Discussion

An important quantity to consider in the analysis of radiation risk to humans and the rest of biota is the absorbed dose rate. The absorbed dose rate, D ($nGy\ h^{-1}$), at a height of 1 m above the ground surface due to the concentrations of radioactive materials most likely $^{238}U$, $^{232}Th$ and $^{40}K$ in the soil was measured at different locations of different settlements of the study area. The recorded measurements were presented in Table 1 and 2 and depicted in Fig. 3 and 4 according to the existing soil type in the study area.

The different soil type that exists are the Arenosol and Acrisol soil type. The Arenosols are sandy-textured soils that exhibit only a partially formed surface horizon (uppermost layer) that is low in humus. Arenosols are found in arid regions such as the Sahel of western Africa and the deserts of western Australia. While the Acrisols form on old landscapes that have an undulating topography and a humid tropical climate. It has a clay-rich subsoil and is associated with humid. Acrisol soil type covers areas throughout central and northern Latin America, Southeast Asia, and West Africa.

The TGRD rate from forty-two (42) settlements of the study area was assessed. Arenosol soil type covers the land of thirty-four (34) locations. While the remaining eight locations were covered by Acrisol soil type. The range of the TGRD from the Arenosol soil falls between 40 - 190 $nGyh^{-1}$ with minimum of 40 $nGyh^{-1}$ at Asarara Majeama and Mallandi, maximum of 190 $nGyh^{1}$ at Lungu South and average of 93.5 $nGyh^{1}$. On the other hand, the range of measured TGRD from the Acrisol soil type is 100 - 170 $nGyh^{1}$, with minimum of 100 $nGyh^{1}$ at Majia and Majia East, maximum of 170 $nGyh^{1}$ at Bodai Magaji Sajo and Dandutsi. and mean of 130 $nGyh^{1}$. The overall result from the study area shows that the measured TGRD rates at the majority of the locations is higher than the worldwide reference value of 59 $nGyh^{-1}$ (UNSCEAR 2000). However, the result from locations covered by Acrisol soil shows higher radiation dose than the ones covered by Arenosol soil. TGRD is mainly due to presence of long live radionuclides ($^{238}U$, $^{234}Th$ and $^{40}K$) in the soil.

Two factors are important in the course of estimating the effective dose in any environment: the conversion coefficient from $Gy\ h^{-1}$ to $Sv\ h^{-1}$; and the occupancy factor. The absorbed dose to effective dose conversion coefficient gives the equivalent human dose in $Sv\ y^{-1}$ from the absorbed dose rate in air ($Gy\ h^{-1}$) while the occupancy factor gives the part of the time a person is expected to be exposed to outdoor radiation. Occupancy factor vary base on the prevailing environmental condition in a certain location and it has been estimated for the rural and urban dwellers in Nigeria as 0.3 and 0.22 respectively [34]. The settlements assessed in this work are mainly rural areas. The rural outdoor occupancy factor is therefore 50% above the world average [2]. The conversion coefficient and the occupancy factor given as 0.7 Sv $Gy^{-1}$ and 0.3 respectively were therefore used for the calculation of the annual effective dose and the result is shown Table 3 and 4.

The calculated annual effective doses for the locations covered by Arenosol soil range from 0.07 - 0.35 $m$Sv$y^{-1}$ with an average value of 0.17 $m$Sv $y^{-1}$. While for the locations covered by Acrisol soil range from 0.18 – 0.31 $m$Sv.$y^{-1}$ with an average value of 0.24 $m$Sv.$y^{-1}$. The worldwide average annual effective dose is approximately 0.5 mSv.$y^{-1}$ (11) and the results for individual countries being generally within the 0.3 - 0.6 mSv range. Therefore, the population weighted average annual effective dose from the Arenosol soil is about three times less than the average worldwide control limits, but only about two times less for the AED from Acrisol soil type of the study area.

Two mining sites were traced in the study area: the Galankawa; and Lungu mines. The TGRD rates at and around these mines were also assessed. The radiation dose rates in and around the mines were found not different from other locations where there is no mining activities. This may be because those mines were abandoned for long and possibly the effect of mining in bringing out radioactive materials to the surface of the earth has been vanished.

## V. Conclusion

The measured TGRD rates at the majority of the locations is higher than the worldwide reference value of 59 nGy$h^{-1}$. However, the result from locations covered by Acrisol soil shows higher radiation dose than the ones covered by Arenosol soil.

The population weighted average annual effective dose from the Arenosol soil is about three times less than the average worldwide control limits, but only about two times less for the AED from Acrisol soil type of the study area.

The radiation dose rates in and around the mines were found not different from other locations where there is no mining activities.

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