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Environmental Radiation Studies around Jos-North, Jos, Plateau State, Nigeria

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ABSTRACT

Environmental radiation studies have been carried out in part of Jos-North in Plateau State, where the inhabitants of this area are exposed to radiation resulting from mineral-related activities in the area. Using a Gamma Scout dosimeter, radiation levels were measured within the mineral processing and outside the mineral processing areas, generally representing the background. Results obtained vary from 39.42 to 57.86 mSv/yr around Dogon Duste old mill, 123.6 to 422.76 mSv/yr around British – America Junction dump, 123.6 to 422.76 mSv/yr in the Utah mill area, and between 40.431 to 127.11 mSv/yr in the Alheri mill area; the background value is generally between 1.189 to 5.802 mSv/yr. About 22.8% of the area investigated are potential radiation hazard area as values here are well above the maximum permissible radiation dose limits. The inhabitants of the area should therefore be made aware of the potential radiation-related health problems they may face over time, while the Government should enact and enforce all necessary laws relating to the preservation of our living environment.

Keywords: Environmental radiation, mineral processing, radiation levels, radiation hazard, radiation dose

INTRODUCTION

Tin and columbite are among the first minerals found in the Jos area, and the mining and processing of these minerals has resulted in environmental problems because of the disposal of the waste product. The waste products are radioactive because they contain minerals like xenotime, zircon and monazite. This has resulted in an elevated radiation level within the Jos environs (Arogunjo et al., 2009). Radioactive minerals emit ionizing radiation, which includes alpha, beta, and gamma radiation. The radiation is dangerous to human health and, if above a certain level, can cause permanent damage to human cells. The Younger Granite province in north central Nigeria is made up of non-organic granite of the Mesozoic era (MacLeod et al, 1977), and forms a distinct metallogenic province consisting essentially of Biotite Granite, Rebeckite Biotite Granite, Hornblende Fayalite Granite, Hornblende Biotite Granite, etc., with varying amounts of natural concentration of thorium, uranium, and potassium. Some of these rocks are also associated with alluvial deposits of cassiterite (tin oxide SnO_2) and columbite (oxide of tantalum-niobiom, iron and manganese (Fe, Mn) $(Ta, Nb)_2$ O_6 as well as radioactive minerals residues such as thorite ($ThSio_4$) and monazite (Ce,La,Yt) PO_4).

Mining and processing of tin and columbite have resulted in the indiscriminate disposal of mine tailings into the environment. These tailings are also washed into the drainage and have therefore resulted in an increase in environmental radioactivity within the Jos North area. These processes continue every year and, if left unchecked, could result in major environmental radiation hazards in the area.

This project identifies and delineates the possible areas of radiation hazards within the Jos-North area.

Objective of the Study

The study is aimed at the following:

1. To measure the levels of gamma radiation in the study area.
2. To calculate the radiation dose equivalent from the measured gamma radiation in the area.
3. To prepare the map of gamma radiation, it requires rates for the study area.
4. To delineate areas of possible radiation hazard within the study area

To help create an awareness of radiation hazards resulting from the indiscriminate disposal of mine tailings.

Location of Study Area

The study area (Figure 1) is located within Latitude 9^{o} 52' N, to 9 ^{o}58' N, and Longitude 8^{O}51'E, to 8 ^{O}57' E, which covers the main Jos metropolis on Naraguta NE, topographical sheet 168 with 1:100,000 scale published by the Federal Survey Department. It covers the total area of about 121 Sq.km. The area is accessible by a network of roads and footpaths. The major roads include Jos to Zaria, Jos to Bauchi, Jos to Bukuru Abuja road, Jos to Fobur road, among others. All the roads mentioned above provide a good road network into and out of the study area.

Literature Review

The environment is exposed to various radiations, which are a result of natural and man-made radiation caused by humans. Such radiation varies largely, depending on elevation above sea level and, most importantly, the geology of the area. Most of the natural radioactivity in rocks is caused by 238U, 235U, 232Th, and to a lesser extent by 40K and 87Rb. Radioelement concentration of different classes of rocks is given in Table 1 (Killeen, 1979). Radiation absorbed rates vary from country to country and place to place. It is a function of the local and regional geology, altitude above sea level, the level of mining and processing of radioactive minerals, as well as the disposal methods for my wastes. The study observed that weathering and soil formation are the principal factors in the accumulation of uranium and thorium, and that higher concentrations of these radionuclides are found in soils compared with the underlying rocks.

Determination of the activity of natural radionuclides in soils and the resultant absorbed dose rates in air have also been carried out in countries including India, Indonesia, Iran, and Ireland using the gamma spectrometry Method. In the monazite-rich areas of India, the absorbed dose rates in air from the natural environment are 300 x 10-8Gy/hr, while in normal areas the value is. is 4.2 X 10-8Gy/hr (Chhabra, 1966). Mishra and Sadasioan (1970) studied both the non-volcanic and volcanic areas of Indonesia. In the volcanic areas, the average absorbed dose rates in air are 250 X 10-8Gy/hr, while in the non-volcanic areas, the value is 90 X 10-8Gy/hr.

According to Eisenbud (1973), the mean annual total body absorbed dose rate received by man is 10-3 mSv/yr, while the United Nations Scientific Committee on Effects of Atomic Radiation (1977) estimated the world absorbed dose to be 32mrad/yr (320uGy/yr). The United Nations Scientific Committee on the Effects of Atomic Radiation (1972) and the National Council on Radiation Protection and Measurement (1976) also gave the average dose equivalent from cosmic radiation at sea level to be 28mrem/yr (280uSv/yr).

Radiation levels from natural sources are low in some countries but could be very high in others. According to Oakley (1972), the average dose equivalent from natural radionuclide is about 26mrem/yr for the United States, while studies on the distribution of absorbed dose rate in air carried out in Norway (Strander, 1977) and Romania (Toader, 1979) have shown a value of 7.3 X 10-8Gy/hr and 8.1 X 10-8Gy/hr, respectively. Except for Bangladesh, Brazil, Indian, Indonesia, Iran, and Malaysia, the mean absorbed dose rates in air from the other countries above compare well with the world average of 5.0 X 10-8Gy/hr.

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Activity refers to the number of nuclear transformations occurring in a given quantity of material per unit time and it depends not only on the parent rock or the soil type, but also on the type of local geological work around. In areas with mine tailings containing minerals such as monazite, the activity levels are usually high. Activity concentration in soil due to 40K, 238U and 232Th has been reported for different countries. In Rio Grande do Nortre, Brazil, activity concentration for 40K, and 238U and 232Th radionuclides are 704.0, 29.2 and 47.8 Bq/Kg, while in Santana do Matos areas, the values are 1332.5, 43.7 and 116.7, respectively, (Malanca, 1996). According to Bou-Rabee and Bem (1996), activity values from 40K, 238U and 232Th for Kuwait are 829.0, 11.8 and 10.0 Bq/Kg, respectively. In Lusaka, Zambia, soil activity concentration due to 40K is 714.0 Bq/Kg, 238U is 25.0 Bq/Kg and 232Th is 26.0 Bq/Kg (Hayumbu et al, 1995)

Available information on ionizing in Nigeria includes airborne gamma ray survey carried out over most part of the country between in 1974 and 1975 by the Geological Survey Division, Federal Ministry of Mines and Power. Uwah (1993) also carried out an analysis and interpretation of the airborne gamma ray survey for the Ugep area, South-East Nigeria, for radioactive mineral recovery. He concluded that the concentrations of uranium and potassium are generally low in the area, except for a few locations where uranium concentrations are a little the average values for sedimentary and metamorphic rocks. Solomon et al. (2018) carried out a study on uranium levels in groundwater and the associated radiation doses in the Naraguta Sheet 168 area of North Central Nigeria. They analyzed water from 60 wells using inductively coupled plasma mass spectrometry (ICP-MS) to determine uranium and selected trace-element concentrations, with the aim of estimating radiation exposure from drinking-water consumption across different age groups. Their findings indicate that most groundwater sources in the area contain uranium at levels below the recommended dose limit of 0.1 mSv per year. However, higher concentrations were recorded in parts of Bukuru, Rayfield, and Bishichi, which are predominantly underlain by the Jos–Bukuru Younger Granite Complex.

Alluvial deposits of considerate and columbine have been in the Jos Plateau area of Nigeria since around the 1920s. These minerals are associated with residues such as thorite, zircon, monazite and xenotime, which are radioactive. Accumulated radioactive waste from mining and processing of cassiterite and columbite can now be seen in most parts of the plateau (Plates 1-4). Laboratory measurement of 232Th in zircon, monazite and xenotime samples collected from two mines around Jos area gave an average value of 3,600,650 and 188,00 Bq/Kg of activity, respectively. This is quite high considering the fact that substances are rationally considered radioactive above the range of a few hundred Bq/Kg -1. Babalola (1984) has also reported high activity concentrations from cassiterite collected from the tin mining and processing camps around the Plateau. In a study on zircon and monazite sands from the Jos Plateau, Umar (1995) has reported activity concentration of 732-24400 Bq/Kg-1 and 412-132600 Bq/Kg-1, respectively.

Work on the measurement of radiation levels in mining processing plants in Jos metropolis (Azu, 1995), as well as monitoring of alpha and beta particles in mine sites in Jos and environs (Ike et al, 2002a) have all shown values above those of the non-mining areas. Values well in excess of 0.034 rems/wk have also been reported.

An assessment of the radiological impact of tin mining activities in Jos and its environs carried out by Ibeanu (1999), revealed mean activity concentrations of 1251, 3867 and 8301 Bq/Kg-1 for 40K, 226Th, respectively, in soil samples collected from old tailing dumps. Publish work as part of the ongoing study on the distribution of radiation dose rate in parts of the Jos Plateau, including the work of Ike et al (2002b), where the distribution of natural gamma radiation dose rates within the Toro sheet 148, North Central Nigeria, is shown. Solomon et al (2002) also presented the natural background radiation characteristics of basalt on the Jos Plateau and the radiological implications of the use of the rock for house construction. The report shows that the gamma radiation dose rates vary from 0.3225-0.5805mSv/yr, while the dose due to Alpha/Beta radiation is from 1.575-3.15mSv/yr, making buildings constructed with the basalts radiologically safe for dwellers since external exposure to radiation is essentially from gamma rays.

The work intends to concentrate on environmental radiation studies around Jos metropolis, covering the natural terrestrial and radiation exposure distribution due to mining and mineral processing activities.

Geology of the Study Area

The basement Complex rocks and the Younger Granites are the major rock types that underlie the Jos Plateau, within which the study area is located. The basement rocks found here are essentially the undifferentiated migmatite, while the Younger Granite rocks include Dilimi Biotite Granite, Biotite microgranite, Neil’s valley Biotite Granite, Jos Biotite Granite, Hornblende fayalite porphyries and early rhyolite. The area is covered in most places by laterites resulting from the decomposition of the older basalt.

Lithological Characteristics

The rocks found here vary in their lithological characteristics in terms of the mineralogy, texture, grain size distribution, colour, and other rock parameters. These lithological characteristics allow for a clear distinction between the different rocks found in this area.

Basement Rocks

The only basement rock found in the study area is migmatite Plate 1. It is located in the north-eastern corner of the study area.

Plate 1: A Photograph of the Migmatite Found in the Study Area.

Migmatites vary in texture, ranging from coarsely mixed gneisses to more diffusely textured rocks of variable grain size and frequently porphyroblastic. Foliation is usually not well marked, but it is commonly shown by the streaky aggregates of dark minerals which wind around the porphyroblastic feldspars. The migmatite found here forms part of the Nigerian migmatite complex according to the classification of the Basement Complex of Nigeria by Rahaman (1988). The migmatites include rocks of varying lithology, texture, and structures, showing different degrees of granitization and migmatisation. They are composite rocks consisting of metamorphic host rock and acid injection, which may be pegmatitic, feldspathic, or granitic minerals.

In the hand specimen, the migmatite here appears as a medium-grained rock and is grayish in colour. Petrographically, the rock is highly deformed as evidenced by aligned minerals on the slide Plate 2. Major minerals in the slide include microcline, quartz, biotite, plagioclase feldspar, mymerkite, and sericite. The quartz crystals are fractured, and subgrains of quartz have started to form. Also, subjoins of quartz show a wavy extension. Accessory minerals include apatite, magnetite, and some small opaque minerals.

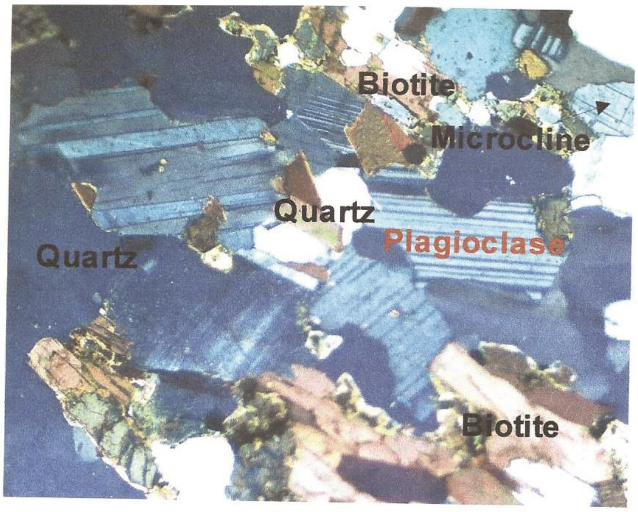

Plate 2: Photomicrograph of the Migmatite in the Study Area, Showing the Mineral Composition.

Granite Gneiss

This is a metamorphosed rock, which is a heterogeneous group of rocks predominantly granodioritic in composition with a variable amount of remnant streaks. The plagioclase content is usually higher than the potassium feldspar content. Granite-gneiss in the study area occurs towards the northwestern corner of the area. The rock is medium-grained, with poorly defined boundaries. Observable minerals in the rock include quartz, feldspars and biotite flakes. The feldspars are randomly distributed with their phenocrysts from about 0.5cm to 1cm in diameter, while the quartz and biotite crystals occur as single or in a clustered manner.

Younger Granite

The Younger Granites of the Jos Plateau occupy about one-third of the total surface area. The granites were first defined by Falconer (1911). Here, they were described as cross-cutting alkali granites containing riebeckite or biotite, characterized by chilled margins against their country rocks. As they are known today, the rocks occur as hilly massifs, sharply differentiated from the smoother topography of the surrounding basement rocks. They are a petrologically distinctive series of alkali feldspar granites, associated with rhyolite and minor gabbro and syenites, which occur in sub-volcanic intrusive complexes as ring dykes and related annular and cylindrical bodies (Turner, 1976).

Younger Granite complexes consist of a series of distinct intrusions. According to MacLeod et al. (1971), the rock types of the complexes include rhyolites, granites, syenites, and basic rocks.

The mode of emplacement of the Younger Granite is thought to be controlled by deep-seated ancient lineaments of the Basement Complex. Most hypotheses regarding the evolution of the rock suggested generation of the magma in the sub-crustal zones of the upper mantle (McCurry, 1986). The evolution can be summarized as a sequence of five main stages.

Stage 1 was the stage of pre-caldera volcanism and the probability of a central volcano. The groups of volcanic rocks recognizable in the complex (the pre-caldera and the intra-caldera groups) were formed during this stage. The pre-caldera group consists mainly of pyroclastics, and pre-caldera volcanism was violent. Turner (1976) notes that the intrusive ring-complexes are likely to have developed beneath central volcanoes. In the model paroxysmal eruption preceded up–doming, this culminated in the development of a central shield volcano with a central shield volcano with a vent. The vent was formed in the place of an initial set of cone fractures. The sealing up of the vent marked the end of the central volcano stage.

Stage 3 witnessed the formation of the ring fractures as a master cone-fracture. Renewed gas built up and began to dome the volcanic edifice and rose to the highest levels in the crust. This eventually resulted in the formation of a master cone-fracture that is inwardly dipping at depth and steepening towards the surface of a normal swarm of cone sheets.

Stage 3 involved fluidization along the ring – fractures as an agent for intraolcanism. This marked the beginning of magma evacuation along the ring fractures. The commencement of surface cauldron subsidence of the central block and overlying volcanic edifices was essentially contemporaneous. The fluidized quartz porphyries were feeders to intra-caldera IGMBrites.

Stage 4 was a quiescent ring – dyke intrusion sequence due to the warning of fluidization. The granite porphyry magma moving behind the fluidized quartz prophyry system was essentially degassed so that it was quiescent and fracture-controlled.

Stage 5 constituted the final stage, characterized by the central intrusion of the granite porphyry marked the transition from the volcanic to the plutonic phase of the intrusion. The mechanism of the granite emplacement was by piecemeal stopping through the collapsed central block of the basement. The central granite stock stopped at higher levels, pierced through the bottom of the volcanic pile, and caused widespread contact metamorphism, hydrothermal alteration, recrystallization, and mineralization.

Dilimi Biotite Granite.

The Delimi Biotite-Granite is best exposed in the eastern part of the study area in the deeply dissected headwater region of the Delimi River. Its texture is fine-grained and equigranularity with numerous drusy cavities. The Delimi Biotite-Granite has probably made substantial contributions to the alluvial tin deposits in the Delimi valley.

Biotite Microgranite

The Biotite Microgranite underlies the extreme south-western part of the study area. The rock is composed of almost equal amounts of quartz, orthoclase, and albite, with evenly dispersed flakes of biotite (MacLeod, 1999).

Neil's Valley Biotite Granite.

A part of the Naraguta area and Neil's Valley are underlain by the Neil's Valley Biotite Granite rock type. It occurs in the extreme northern part of the study area. It is considered to have initiated the "Plateau state" of Younger Granite activity, and appears first in the intrusive cycles of all the large complexes on the Jos Plateau. The granite porphyry forms the ring dyke bounding the main Jos-Bukuru complex in the north and northeast parts, and the numerous irregular radial dykes of the Jarawa and Neil's valley (Macleod, 1997).

Jos Biotite Granite.

The Jos Biotite – Granite outcrops in the northern, northwestern, central, and southeastern parts of the study area (Jos Township, parts of Gwarandok and Barkin Akawo). It has a regular joint system with two equally developed vertical sets. The only pronounced textural variation in this rock type is observed near the margins of the granite against the Basement Complex of the earlier Younger Granite intrusions. There is little compositional variation in the Jos Biotite-Granite over the greater part of its extent. The exceptionally coarse-grained size of the mineral renders it easily recognizable in the field Plate 3.

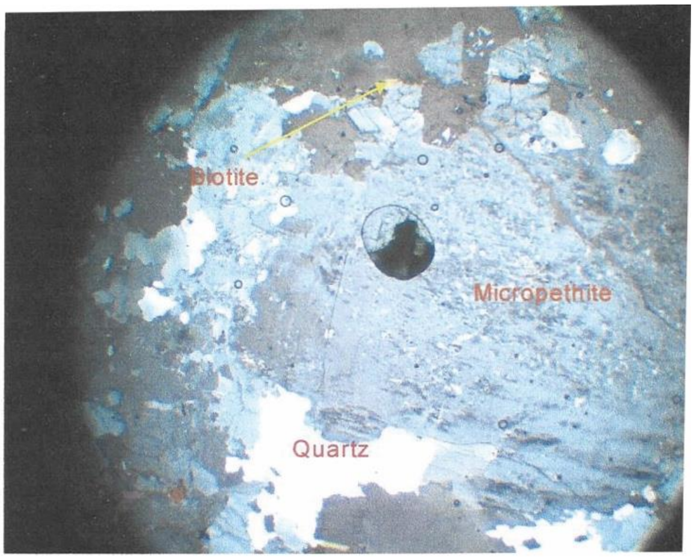

Plate 3: Photomicrography of Jos Biotite Granite showing the Mineral Composition (XPL).

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Hornblende Fayalite Granite.

It is found in the extreme south-eastern part of the study area. The granite shows considerable textural variation in different parts of the rock mass. The mafic minerals occur in coarse aggregates, and green hornblende is most abundant, but there are frequent associations with brown biotite, fayalite, and hedenbergite (MacLeod 1977).

Early Rhyolite Porphyry.

These rock types are found around Neil's Valley in the extreme north-eastern part of the study area. They display porphyritic and glassy textures and contain abundant crystals of white feldspars and some quartz. The rhyolite is grey in colour but tends to be superficially bleached by weathering (MacLeod, 1977).

Laterite.

This occurs as patches within the study area, and is predominant in the central, western and eastern parts of the area. The lateralized older basalts represent lavas now decomposed to clays and usually overlain by a thick cap of laterite ironstone (MacLeod, 1977). The lateralized Basalts occur as erosion remnants in watershed areas, and the associated fluviatile sediments include sands, gravels, and clays.

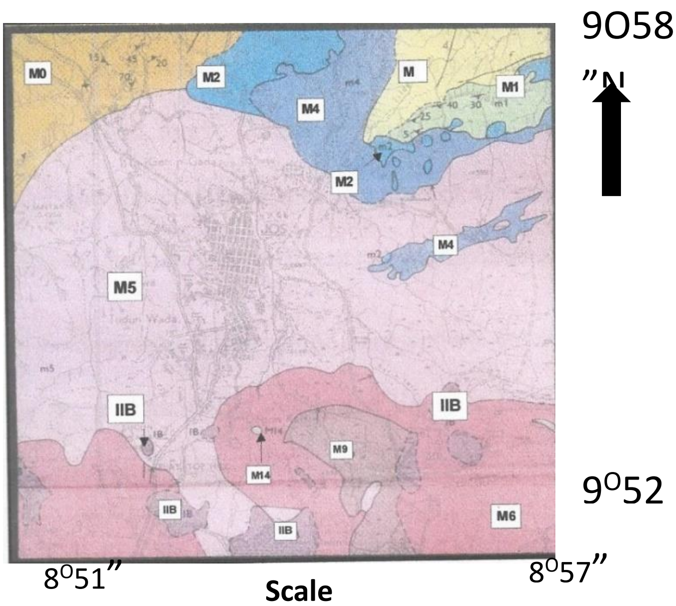

Figure 3: Geological Map of the Study Area.
Modified After the Geological Survey of Nigeria (956).

KEY:

1B LATERITE (COVERING OLDER BASALT)
M9 DILIMI-BIOTITE-GRANITE
M14 BIOTITE-MICROGRANITE (UNCLASIFIED)
M6 BIOTITE-GRANITE (NEIL'S VALLEY – BIOTITE-GRANITE)
M4 HORNBLENDE-FAYLITE-PORPHYRIES
M2 HORNBLENDE – BIOTITE-PROPHYRIES
M0 GRANITE – GNEISS
M UNDIFFERENTED MIGMATITE

Structures

Structural features are formed when rocks are subjected to varying degrees of stress and strain during tectonic events. During this period, both the original and the emplaced rock are affected structurally, and this often results in the formation of different types of structures. Geological features found here include foliation, quartz veins, and joints within the migmatite ut within the Younger Granite; they are mainly cooling joints.

Foliation is the parallel orientation of platy minerals or mineral banding in rock. They are layering in rock carried by the parallel orientation of mineral alignment. Foliation is observed in most cases in the form of segregation of mafic and felsic minerals in rocks. Foliation is formed as a result of a series of episodes of deformation, and the temperatures and pressures accompanying the Pan-African Orogeny, which was migratory (Rahaman, 1988). They could also be formed as a result of partial melting with solid-liquid segregation.

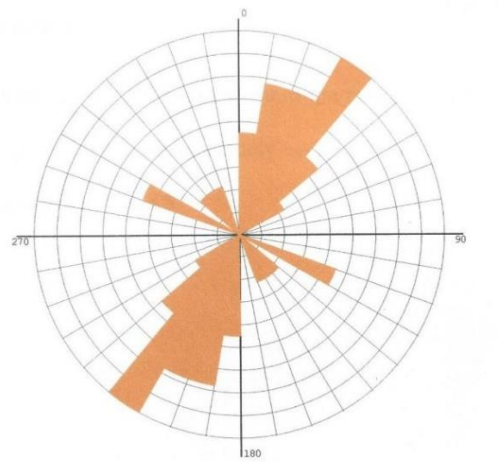

Figure 4: Rose plot for Foliation on the Migmatite in the Study Area.

A joint is a fracture in a rock between the sides of which there is no observable relative movement. They are developed in the relief of tension, or shearing "in situ" stress caused by either shrinking or contraction, compression, unequal uplift, or subsidence on a rock mass. Most of the joints are either cross-cutting or parallel to each other.

Joints found here are well developed within the migmatite Figure 4, but within the Younger granite, they are essentially cooling joints that are formed as the magma solidified Figures 5 and 6.

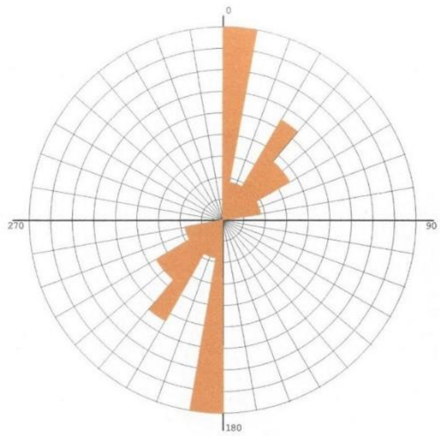

Figure 5: Orientation of Joints within the Migmatite

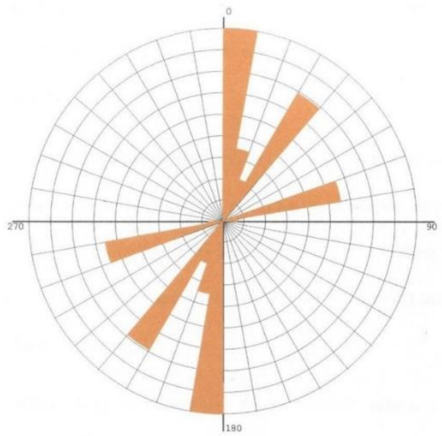

Figure 6: Orientation of Joints within the Jos Biotite Granite.

MATERIALS AND METHOD

The radiological method was used in this investigation. This involved the measurement of gross gamma counts from the mine tailings around the mineral processing mills, as well as natural radiation coming out of the rocks and soils away from those mills. Radiation is the emission and propagation of energy in the form of rays or waves from the atoms and molecules of a radioactive substance as a result of nuclear decay. It can be classified into ionizing and non-ionizing radiation. Lionizing is the most damaging as it is capable of ionizing an atom and causing different forms of damage.

Radiation effects vary considerably. Acute somatic refers to radiation effects in individuals within days or weeks of their exposure (National Council on Radiation and Measurement, 1976). It includes injuries to the brain, which cause delirium and convulsions; damage to the eye lens resulting in cataracts; gastrointestinal tract injury resulting in nausea and vomiting, as well as cancer (National Council on Radiation and Measurement, 1976). Development effects may also result from exposure to more than the recommended limits and this can result in brain damage or mental disability (National Council on Radiation and Measurement, 1976). Late somatic effects are injuries produced in an individual many years after radiation exposure.

Plate 4: Radiation Measurements Around One of the Mine Dumps.

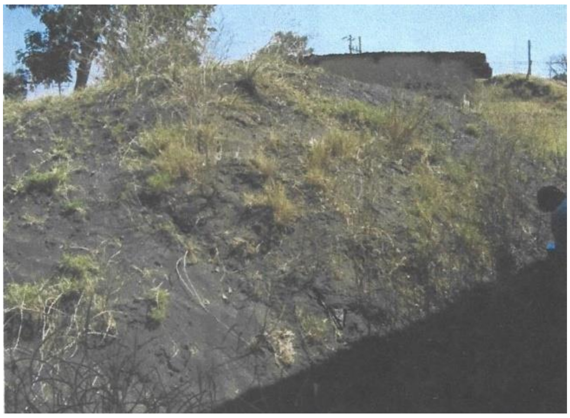

Plate 5: A Typical Mine Dump in the Area of Study.

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Plate 6: A Typical Mineral Processing Mill in the Study Area.

Three types of radiation are emitted from radioactive elements in rocks and soils. They are alpha particles, beta particles, and gamma rays. Alpha particles are composed of two protons and two neutrons that are identical to a helium atom. Alpha particles have the least penetrating power and are deflected by a magnetic field in the direction that indicates positive charge; therefore, they do not travel very far from their radioactive sources (United Nations Scientific Committee on the Effects of Atomic Radiation, 1977). They cannot pass through a piece of paper or even the layers of dead cell, which normally protects the skin. Because alpha particles cannot penetrate human skin, they are not considered an "external exposure hazard". They can only get into a human being and affect him if the water or food he eats contains some alpha particles, United Nations Scientific Committee on the Effects of Atomic Radiation (1972).

Beta particles are similar to electrons except that they come from the atomic nucleus and are not bound to any atom. They can be a stream of electrons and have been shown to consist of electrons in rapid motion with relatively small mass and carry a negative charge. Beta particles cannot travel very far from their radioactive source. For example, they can travel for only about one inch in human tissues and they may travel a few yards in the air. They are not capable of penetrating something as thin as a book or a pad of paper. It has a greater penetrating power than an alpha particle (United Nations Scientific Committee on the Effects of Atomic Radiation, 1977).

Unlike alpha and beta radiation, gamma radiation is not a particle but a ray. They are an example of electromagnetic radiation and originate from the nucleus of an atom. Gamma rays are bundles of energy that have no charge or mass. This allows them to travel a very long distance through air, body tissues and other materials. They travel so much farther than either alpha or beta radiation that the source can be relatively far away. Gamma rays have a very great penetrating power and move at the speed of light, hence they require more shielding materials such as lead or steel to reduce their number (United Nations Scientific Committee on the Effects of Atomic Radiation, 1977).

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Field Radiation Measurement

Radiation measurements in the study area were carried out using a Gamma Scout radiation equipment (Plate 4). The Gamma Scout radiation equipment detects both the low end (0.01uSv/h) and high end (100uSv/h) alpha, beta and gamma radiation either together, or separately. The equipment sees beta from 0.2MeV, gamma from 0.002 MeV, and alpha, beta, and gamma radiation combined from 4MeV (National Council on Radiation and Measurement, 1976).

The detector is an end-window alpha-beta-gamma detector counting tube, operating according to the Geiger-Muller principle. The housing is stainless steel with a neon halogen filling. The gamma sensitivity of 95.00 pulses per minute at Cobalt 60 radiation equals 1uSv/h in the energy band of ambient radiation, Plate 7. The operating temperature is between -20 to 60^{o}C, and an operating voltage of approximately 450volts, while the display is made up of a liquid crystal (LCD) type, 4-digit, numeric with a dimension, quasi-analogue logarithmic bar chart, National Council on Radiation and Measurement (1976).

Plate 7: Radiation Measurement around the Study Area.

The ray selection switch was placed at the gamma window at the center of the meter, meaning that only gamma rays were measured. Alpha and beta radiations are limited in range to a few centimeters owing to their large nucleus. They therefore do not pose problems except when ingested through food or drinks. The gamma scout was kept slightly above the points where measurements are to be made (Plate 7). Measurements of radiation were also taken directly in microsievert per hour (uSv/h) and later converted to the millisievert per year (mSv/h) standard i.e. 0.1uSv/h equals 0.876mSv/yr). The values obtained for the different locations within each outcrop are shown in Table 5. The location (Longitude and Latitude) of the points where radiation measurements are to be taken is determined using the global positioning system. Structural measurements (Strike and Dip of Planar structures) were also taken using a compass clinometer.

RESULTS AND DISCUSSION

Based on the differences in levels of radioactivity from one mill to another, as well as differences in lithology, structure, and mineralogical composition of rocks, their radiation levels differ significantly from rock to rock and from one place to another (Chong et al, 1985). It has also been observed that where such rocks are enriched in tin mineralization, they are often associated with thorium (Suleiman, 1995). Thorite (ThSi04) and zircon (ZrSi04) are radioactive and usually occur as accessory minerals in biotite granites and riebeckite granite that constitute a large percentage of the lithologies within the Younger Granite province of Nigeria. They have been recovered as by-products in cassiterite and columbite mining (Babalola, 1984; Umar, 1995) on the Jos Plateau. Radiation levels calculated from the data of field radiation measurements for the mineral processing areas are shown in Tables 1 to 4.

Table 1: Radiation Rate from Dogon Dutse Abandoned Mill

Serial	Latitude "N	Longitude "E	Site Reading (uSv/Hr)	Does Rates (mSv/Yr)
1.	$9^{O}58.952'$	$8^{O}50.585'$	5.7	49.932
2.	″	″	6.6	57.816
3.	″	″	4.8	42.048
4.	″	″	6.5	56.94
5.	″	″	4.9	42.924
6.	″	″	5.2	45.552
7.	″	″	6.6	57.816
8.	″	″	53	46.428
9.	″	″	6.5	56.94
10.	$9^{O}58.952'$	$8^{O}50.585'$	4.5	39.42

Table 2. Radiation Does Rates from British America Junction dump.

Serial	Latitude "N	Longitude "E	Site Reading (uSv/Hr)	Does Rates (mSv/Yr)
1.	$9^{O}58.952'$	$8^{O}50.585'$	14.11	123.6036
2.	″	″	16.05	140.598
3.	″	″	44.1	386.316
4.	″	″	48.26	422.7576
5.	″	″	42.24	370.0224
6.	″	″	44.26	387.7176
7.	″	″	24.32	213.0432
8.	″	″	45.6	399.456
9.	″	″	23.5	205.86
10.	$9^{O}58.952'$	$8^{O}50.585'$	35.21	308.4396

Table 3: Radiation Does Rates from Utah Road Mill

Serial	Latitude "N	Longitude "E	Site Reading (uSv/Hr)	Does Rates (mSv/Yr)
1.	9^{O}58.343'	8^{O}51.959'	129.6	1135.296
2.	"	"	31.25	273.75
3.	"	"	28.25	247.47
4.	"	"	24.75	216.81
5.	"	"	26.8	234.768
6.	"	"	40.5	354.78
7.	"	"	50.67	443.8692
8.	"	"	92.8	812.928
9.	"	"	85.97	753.0972
10.	9^{O}58.343'	8^{O}51.959'	50.68	443.9568

Table 4: Radiation Dose Rates from AlheriMillS

Serial	Latitude "N	Longitude "E	Site Reading (uSv/Hr)	Does Rates (mSv/Yr)
1.	9^{O}56.502'	9^{O}52.027'	5.32	46.6032
2.	"	"	5.56	48.7056
3	"	"	5.38	47.1288
4	"	"	6.89	60.3564
5	"	"	4.62	40.4712
6	"	"	5.98	52.3848
7	"	"	5.45	47.742
8	"	"	10.65	93.294
9	"	"	14.51	127.1076
10	9^{O}56.502'	9^{O}52.027'	7.6	66.576

Interpretations of Results

Tables 1 to 4 present the results of ionizing radiation measurements from the mineral processing sites and mine dumps within the study area, Plates 5 and 6. Values obtained around the Dogon Dutse old mill range from 4.5 to 6.6 Sv/hr, giving an absorbed dose rate of 39.42 to 57.86 mSv/yr. In the British America dump area, field readings range from 14.11 to 48.26 Sv/hr, corresponding to an absorbed dose rate of 123.6 to 422.76 mSv/yr. Around the Utah Mill area, field readings were between 24.75 and 129.6 Sv/hr, calculated at between 216.81 to 1135.3 mSv/yr, while in the Alheri area, they were 4.62 to 14.51 Sv/hr, equivalent to between 40.431 to 127.11 mSv/yr. From the non-mineral processing areas (Table 5), the results obtained vary from 0.14 to 0.66 Sv/hr, equivalent to 1.189 to 5.802 mSv/yr.

The data presented in Tables 1 to 5 were also used to plot a map of the distribution of gamma absorbed dose rates in Figure 6, as well as a radiation hazard map as shown in

Figure 7. The map indicates that 22.8% of the area studied lies in an area with high potential for radiological hazard based on a maximum permissible radiation absorbed dose rate of 4mSv/yr.

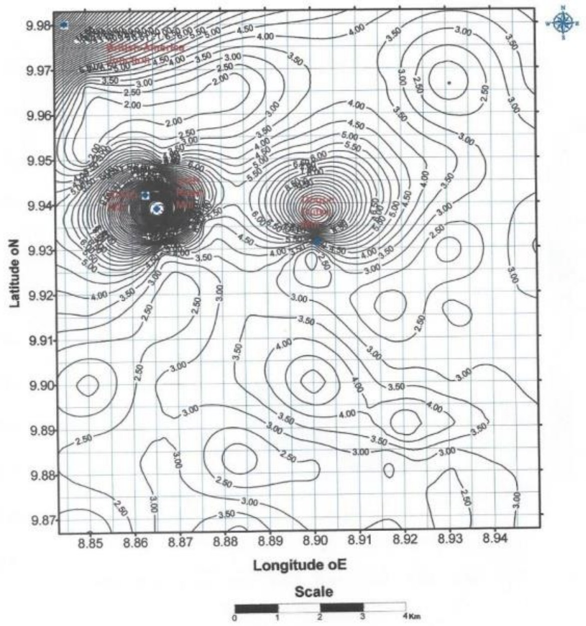

Figure 7: Distribution of Gamma Radiation Absorbed Dose Rates in the Study.

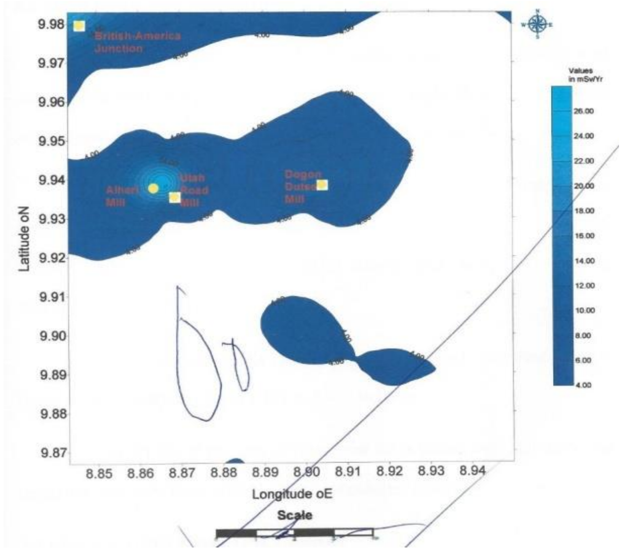

Figure 8: Map of the Distribution of Radiation Hazard in the Study Area.

This study investigated the levels of ionizing radiation and distribution of gamma dose rates in parts of Jos North LGA of Plateau State, resulting from mineral processing activities. It made the following findings:-

(i) Radiation absorbed dose rates from Dogon Dutse old mill range from 39.42 to 57.86 mSv/yr, British-America dump area, 123.6 to 422.76 mSv/yr, Utah Mill area, 216.81 to 1135.3 mSv/yr, and in the Alheri area, it is 40.431 to 127.11 mSv/yr.

(ii) Radiation levels from the non-mineral processing areas (background levels) vary from 1.189 to 5.802 mSv/yr.

(iii) About 22.8% of the area of study now lies in places with high radiation levels and, therefore, faces potential radiological hazards.

Considering the maximum permissible radiation levels set by various monitoring bodies such as the International Atomic Energy Agency (IAEA) as well as the World Health Organization (WHO), values obtained here, especially from the mineral processing areas and dumps, are high and well above the maximum permissible dose. This is likely to affect the inhabitants of the area over time.

The effects of radiation may be divided generally into four types. They include acute somatic effects, developmental effects, genetic effects, and late somatic effects (Noz and Maguire, 1979; UNSCEAR, 1972). Acute somatic effects occur in individuals within days or weeks of their exposure. These include injuries to the brain, damage to the eye lens resulting in cataracts, gastrointestinal tract injury resulting in nausea and vomiting, sterility if ovaries or testes are damaged, and damage to the bone marrow, which affects the body's ability to fight infection (United Nations Scientific Committee on the Effects of Atomic Radiation, 1977). Developmental effects normally occur in unborn children of mothers exposed to radiation. This usually leads to brain damage or mental disability, particularly if exposure occurs during gestation (Arena, 1971). Exposure to high levels of radiation may also cause genetic mutations in adults, which are carried through to children or later descendants. Late somatic effects are injuries produced in an individual many years after radiation exposure. The major late somatic effect is the development of various forms of cancer.

CONCLUSION AND RECOMMENDATIONS

The results obtained in this study are related to the levels of radiation in the area resulting from mineral processing activities. Radiation absorbed dose rates of more than the maximum permissible limits exist in about 22.8% of the area of study. These values were recorded around the mills and mine dumps. Mine wastes are still being dumped indiscriminately into the environment and in some places along streams where the minerals are washed before separation. The mine wastes here are also used for building construction, thereby increasing the inhabitants' exposure to further elevated levels of radiation.

From the results of the study, the following recommendations are hereby proposed:

(i) More works, including medical research, should be carried out in this area to fully assess the extent of the health and environmental problem resulting from mineral-related activities in the area.

(ii) The government should do more to raise the level of public awareness on the danger of indiscriminate disposal of mine waste into the environment.

(iii) The government should implement plans to safely relocate and properly bury waste materials to mitigate the hazards associated with these dumps.

(iv) The government should enact and enforce laws banning indiscriminate disposal of both liquid and solid wastes into the environment.

(vi) The government should encourage organizations and companies working on recycling waste.

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