ASSESSMENT OF NATURAL RADIOACTIVITY AND RADON EMANATION RATE FROM TIN MINE TAILINGS SITES AT JOS, NIGERIA

BY

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER DEGREE IN NUCLEAR PHYSICS

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MARCH, 2020

DECLARATION

I, Abdulwahab Muhammad Bashir, hereby declare that this dissertation titled **"**Assessment of Natural Radioactivity and Radon Emanation Rate From Tin Mine Tailings Sites at Jos, Nigeria " is my own work and has not been submitted in any other form for another degree or diploma to any other University or Institution. Information derived from published or unpublished work of other researchers has been fully acknowledged in the text.

_____ _____

Abdulwahab Muhammad Bashir Date

CERTIFICATION

This dissertation titled “ASSESSMENT OF NATURAL RADIOACTIVITY AND RADON EMANATION RATE FROM TIN MINE TAILINGS SITES AT JOS , NIGERIA” by ABDULWAHAB Muhammad Bashirmeets the regulations governing the award of the degree of Masters of Science (Nuclear Physics) atAhmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

_____ _____

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Head of Physics Department Date
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Dean, Post Graduate School Date
(Prof. S.A. Abdullahi)

DEDICATION

To my parent MrandMrsAbdulwahabUsman

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ABSTRACT

The tin mining activities in Jos result in a byproduct conventionally known as tailing(s). The release of this Radon gas into the atmosphere and the naturally occurring Radionuclide Materials associated with these tailings have radiological implications. In this research, assessment ofnaturally occurring Radionuclide Materials, radon emanation rate and relevant radiological hazard indices have been carried out in three tailing sites in Jos, Nigeria using Gamma ray spectroscopy and RAD7 detector. For Jos North LGA, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations are 64.21$\pm$10.33, 441.37$\pm$57.13 and 84.72$\pm$ 11.37respectively. For Barkinladi LGA, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations are 52.36$\pm$7.99, 863.77$\pm$120.97 and 80.56$\pm$14.00 respectively. Finally, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations for Jos south LGA are 30.32$\pm$4.03, 324.42$\pm$85.22 and 53.61$\pm$6.79 respectively. The activity concentration of K-40 exceeds that of Th-232 and Ra-226 in all the three tailing sites. The absorbed dose range from 92.49 – 119.47 nGyhr^{-1} with a mean value of 101.79 nGyhr^{-1}for Jos North LGA. For Barikinladi LGA, the value ranges from 86.48 – 132.72 with a mean value of 112.34 nGyhr^{-1}. Finally, for Jos South LGA, the absorbed dose range from 52.27 – 69.11 nGyhr^{-1} with a mean value of 62.33 nGyhr^{-1}. The equivalent dose however does not exceed the acceptable limit in any of the sampling area. Both the internal and external hazard index suggests that the radiological risk associated with the tailing site for Jos North and Barikinladi is too close to the acceptable limit of 1 mGyyr^{-1}. This implies that the radiological hazard potential in the areas is quite significant and thus radiation exposure mitigation steps need to be taken accordingly. Jos South tailing site is generally safe from radiation hazard point of view since there is no significant value recorded in all the radiological hazard indices.

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LIST OF SYMBOLS

A = Activity Concentration of Uranium in Bqkg-1

C_1 = Minimum radon concentration (Bq/m^3)

C_2 = Maximum radon concentration (Bq/m^3)

C_K = Activity concentration of potassium

C_{Ra} = Activity concentration of Radium

C_{Th} = Activity concentration of thorium [1]

D = Absorbed dose $nGyhr^{-1}$

ED = effective dose in $mSvyr^{-1}$

V = Volume of sample vessel (m^3)

$A = Activity$

$A =$ emanating surface area (m^2)

$C = activityconcentrationoftheradionuclidesinthesamplegiveninBqKg - 1$

$C = Interstitialconcentrationofradonisotopes\ (Bq.m - 3)$

$Cfk = Calibrationfactorofthedetectingsystem.$

$Cn = countrate(countspersecond)\boldsymbol{Countpersecond(cps)}$

$D = diffusioncoefficientofradonisotopes\ (m2\ s - 1\ )$

$E = parentradiumisotopesactivityconcentrationofthematerial\ (Bqkg - 1\ )$

$H = samplethickness\ (m)$

$L = diffusionlength\ (m)$

$N = Numberofradioactivenuclei$

$P = Bulkdensityofmaterial\ (kgm - 3\ )$

$\varepsilon = Porosityofthematerial$

$\lambda = Radioactivedecayconstant$

$\lambda = Radonisotopedisintegrationconstant\ (s - 1\ )$

λ =Decay constant of Radon-222 (s^{-1})

$\varkappa = Soil\ depth\ measured\ from\ the\ soil\ air\ interface\ (m)$

$I_{\propto}$ = Alpha index

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background to the study

Radon is tasteless, odorless, and colorless radioactive gas that is a product of decay of radium (Mark, 2016). It is an emitter of ionizing radiation and a second leading cause of lung cancer(Nisha *et al.,* 2016) .As a result of its relatively long half-life(3.82days), it can be transported from the earth's crust or from the walls and floors of buildings into both outdoor and indoor air(Mark,2016; Patitapaban,2013; Tso, M. W. and Li, C. (1987). In the case of indoor air, the risk of exposure to radon is higher, especially for buildings with poor ventilation systems, which may lead to a higher indoor concentration of radon(Patitapaban*et al.,*2013; OECD, 1979).

Radon emanation is defined as the ejection of radon gas from their source materials sometime after the radioactive decay of the parent radium isotope (Schumann 1994,). Radon emanates from a decay of radium, present in all soils and rocks, water, and building materials. Rn-222 spontaneously breaks down into its four relatively short-lived progenies (Po-218, Pb-214, Bi-214, and Po-214) which mix with room air, and subsequently inhaled into the human lung, where they emit alphaparticle, that irradiate sensitive cells in the bronchial tubes and increase the risk of lung cancer. The long-lived radon progeny including Pb- 210, Bi-210, and Po-210 however, contribute little to the radiation dose because they are eventually removed by the mucous and cilia in the gastrointestinal tract before they can decay (Schmann 1993). Radon gas is found in walls, floors and mine tailings or soil in the surrounding areas before being permeated into the cracks of buildings and emitted into closed spaces resulting in an increase in concentration in the air.

Many studies have shown that Exposure to Radon gas via inhalation has been associated with an increase in the risk of lung cancer (OECD 2009; Smith, 1988; Jacobi, 1988). Thus in developing a tin mine ventilation system, knowledge of the radon emanation rate is essential (Khan and Raghavayya, 1968). This will ensure that the Radon concentration in the tin mine environment is well below hazardous level.

One of the major hazards originating as a result of tin mining/ tailings is radon gas whose concentration depends on that of parent nuclide Radium-226 (Khan and Raghavayya, 1968). The release of radon atoms from the material grains to pore spaces is caused by processes such as recoil and diffusion (Hassan et al., 2011; Hosoda et al., 2008). Recoil is a process such that when a radium atom decays to radon, the energy generated is strong enough to send the radon atom to a distance of about 40 nanometers (Tanner, 1980). Radon gas formed from ^{226}Ra within the solid grains may not be directly released into the atmosphere due to their low diffusion coefficients in solids (Mark, 2016). However, when radon gas escapes into the interstitial space between grains, they may be released to the surface. The release of radon gas from the material to the atmosphere takes place by the following processes;

(a) **Emanation:-**The process of movement of radon gas from solid mineral grains to the interstitial space between the grains.
(b) **Transport:-**The process of diffusion and adventitious flow causing movement of the emanated radon gas through the material to the surface and
(c) **Exhalation:-**The process of movement of radon gas from the surface of the material to the atmosphere (Moed, et al, 1988).

The present study involves determination of radon emanation rate from Jos tin mines areas located in the northern part of Nigeria. Its lithological formations are basement complex, new basalt and biotite granite. Biotite granite is associated with tin and columbite which has contributed immensely to the national wealth and provides Nigeria with some social and

economic benefits. However, extensive mining operation can degrade the environment, thereby affecting the human population in the surrounding vicinity. Also large scale mining activities have the potential to enhance the background radiation levels prevailing in that region. Different types of environmental damage and hazards inevitably accompany the harnessing of these important minerals most especially the tailing of tin that is, the by-product from the mining and processing of tin such as monazite, thorite, zircon etc. This present study is important in that it will present radon related data which may be required in either designing or checking the radon-exposure-reduction efficiency of ventilation systems for on-site workers or establishing operational limits to mitigate chances of radiation exposure.

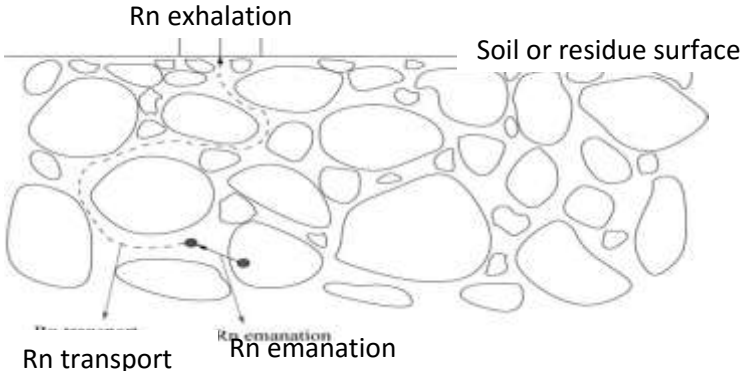


Figure 1.1 Possible path for the release of radon gasinto the atmosphere.

1.2 Research Problem

Tin Tailing is known to contain some amount of naturally occurring radioactive materials (NORMs) and a radioactive gas called radon which is a direct daughter product of ^{226}Ra. As a result of its relatively long half-life, it can be transported from the earth's crust, tailings into both outdoor and indoor air. In the case of indoor air, the risk of exposure to radon is higher, especially for buildings with poor ventilation systems, which lead to a higher indoor concentration of radon.

1.3 Aim and Objectives

The aim of this research is to assess the natural radioactivity and radon emanation rate of tailings in Jos, Plateau State, Nigeria.

The objectives of this research are to

(a) Measure the activity concentration of NORMs in Jos tin tailings;

(b) Measure the radon concentration and determine the radon emanation rate in Jos tin tailings

(c) To assess the radiological hazard arising from NORMs and radon concentration in Jos Tin tailings.

1.4 Justification

As miners spend a considerable amount of time in tailing sites and radon gas finds its way to homes of host communities, both miners and residents of minning communities are at risk associated with prolonged internal and external exposure situations. The internal and external exposure could be traced to their sources. The internal radiation exposure caused majorly by inhalation of ^{222}Rn gas and its short lived products which find their way into the air while the external radiation exposure is caused by the gamma emitting radionuclides, which in the

uranium series, mainly belonging to the decay chain segment starting with ^{226}Ra (Nisha et al,2016).

CHAPTER TWO

LITERATURE REVIEW

2.1 Previous Work

Muhammed *et al.,* (2016) carried out research on Radioactivity and Elemental Assessment of Some Vegetables Grown on Mine Tailings Ground, Jos plateau State, Nigeria. The soil of degraded tin minefield farm land in three LGA; Bokkos, Jos South and Barikinladi of extensive mining of tin on the Jos plateau state were analyzed for radioactivity and elemental concentrations. Cabbage, potatoes and carrot grown on the degraded mine field at dry season and grown away from the degraded minefield at raining season were also analyzed. The mean absorbed dose rate from the soil to the head (containing delicate organs) as farmers bow down to weed in degraded farm land (determined 67 and recommended 57Bq/Kg) from UNSCEAR (2000). The study also indicated a slight high effective radiation dose rate on the soil of the degraded mine field farmland than the recommended values (determined 82 and recommended 70Bq/Kg from UNSCEAR (2000) and the average annual committed effective dose , E_{ave} for cabbage and carrot of dry season are 0.25 and 0.26mSv/yr respectively which are within the recommended values of 0.3mSv/yr received per head worldwide (UNSCEAR,2000) where as that of potatoes for the dry season (0.18mSv/yr) was below the recommended values and as such there is no potential cancer risk to consume vegetables grown in both dry and raining season. It was also concluded that the elemental health risk of major element were above the save values. Tailings samples were considered in the present work in place of the grown potatoes, cabbage and carrot.

Recently, Patitapabanet al.,(2014) published an extensive literature review on the various sources of radon such as ore body, backfill mill tailings, broken ore and mine water in underground uranium mines. The review also comprehensively investigated the influence of

intrinsic factors such as ore grade, radon-226 content, water content, porosity and surface area of the materials and the extrinsic factors such as barometric pressure, temperature and ventilation on radon concentration in uranium mine. The review demonstrated that backfill mill tailings are the major source of radon in underground uranium mine. A comparison of radon exhalation rate of different rock types and backfill tailings also revealed that porosity had more pronounced effect on radon exhalation processes than the ore grade and ^{226}Ra content of the material. The radon exhalation rate from the moist materials is comparatively higher than the dry and saturated tailings. Reduction of barometric pressure in mine environments was observed to increase the radon exhalation rate from porous rock, backfill mill tailings and broken oil ore pills. The contribution of mine water on radon contamination of mine atmosphere mainly depends on the dissolved radon content and flow rate of water. In the present research generic study on various tailing types will not be carried out. Instead, a specific study on the radon emanation of Jos tin mine tailings will be the focal point of this research.

Radon emanation studies conducted in the laboratory as well as inside an operating underground uranium mine at Jaguda, India has been described in a previous research (Patitapaban*et al.*,2013). Some of the important parameter such as grade/^{226}Ra activities, moisture content, bulk density, and porosity and emanation fraction of ore, governing the migration of radon through the ore were determined. Emanation from the ore samples in terms of emanation rate and emanation fraction was measured in the laboratory under airtight condition glass jar. The in situ radon emanation rate inside the mine was measured from drill holes made in ore body. The in situ ^{222}Rn emanation rate from the mine walls was shown to vary in the range of 0.22-51.84x10^{-3}bqm^{-2}s^{-1}with the geometric means of 8.68x10^{-3}bqm^{-2}s^{-1}. A significant positive linear correlation ($r = 0.99$, $p<0.001$) between in situ ^{222}Rn emanation

rate and the ore grade was observed. The emanation fraction of the ore samples, which varied in the range of 0.004-0.089 with mean value of 0.025 ± 0.02, showed poor correlation with ore grade and porosity. Empirical relationship between radon emanation rate and ore grade/^{226}Ra were also established for quick prediction of radon emanation rate from the ore body.The previous research was centered on establishing a relationship between radon emanation and ore grade to see whether or not a linear correlation will emerge. The present research domesticated the previous research by shifting its attention to determining the radon emanation rate and radon concentration with their correlation and knows if the workers or populace are prompt to health related hazard from inhalation through the effective dose.

The quantitative assessment of radon emanation from the backfill tailings in jaguda mine using a cylindrical accumulator had been studied in India (Kumar et al 2011). Some of the important parameters such as ^{226}Ra activity concentration, bulk density, bulk porosity, moisture content and radon emanation factor of the tailings affecting radon emanation were determined in the laboratory. The study revealed that the radon emanation rate of the tailings varied in the range of 0.12-7.03Bqm^{-2}s^{-1} with geometric means of 1.10Bqm^{-2}s^{-1} and geometric standard deviation of 3.39. An increase in radon emanation rate was noticed up to a moisture saturation of 0.09 in the tailings after which the emanation rate gradually started declining with saturation due to low diffusion coefficient of radon in the saturated tailings. Radon emanation factors of tailings varied in the range of 0.08-0.23 with the main value of 0.21. The emanation factors of the tailings with the moisture saturation level over 0.09 were found to be about three times higher than that of the absolutely dry tailings. The empirical relationship obtained between ^{222}Rn emanation rate and ^{226}Ra activity concentration of the tailings indicated a significant positive linear correlation ($r = 0.95 < 0.001$). This researchwill

study the radon emanation rate of tailings inJos tin mine tailing sites, Nigeria and equally determine the correlation between the radon emanation rate and radium content.

Usikalu*et al.*,(2011) investigated the level of Radioactivity measurement of the Jos tin mine tailing in northern Nigeria measured using Hyper-pure statistical errors. Results showed the activities varied from one site to another. The activities of ^{226}Ra and^{232}Th were much higher than the recommended average limit given by UNSCEAR in the mining sites and even at 500 m away from the mining site. At 1 Km away from the mining site the activity measured was within the limit for normal background. The ratio of activity of Thorium to Radium was greater by factor of 5 in all the samples in the mining site and 500 m away which should be about unity. The mean absorbed doses (1828.66, 252.08 and 171.07 nGyh-1) for Site1, Site2 and 500m from mining site respectively in air were equally high compared with (51nGyh-1). Also, the estimated effective dose equivalents were much higher than the recommended limit except for 1 Km from the mining site. There is need to improve waste management practices in this industries in order not to expose those living and working in this environment to health hazards associated with these radionuclide.In the research performed by Usikalu's research group, the activity concentrations of only thorium and Radium were analyzed while the present research seeks to measure the emanation rate of Radon with the correlation and know if the effective dose of the populace within or above the recommended limit.

2.1.2 Statistical Nature of Radioactive Decay

The fact that radioactive decay follows the exponential law(see equation (2.6) implies that this phenomenon is statistical in nature. Every nucleus in a sample of radioactive material has a probability of decaying, but there is no way of knowing in advance which nuclei will actually decay in a particular time span. If the sample is large enough (that is, if many nuclei are present), the actual fraction of it that decays in a certain time span will be very close to

the probability for any individual nucleus to decay. The statement that a certain radioisotope has a half –life of 5hrs, then, implies that every nucleus of the isotope has a 50 percent chance of decaying in every 5hrs period (Knoll,2011). This does not mean a hundred percent probability of decaying in 10hrs. A nucleus does not have decay memory, and its decay probability per unit time is constant until it does actually decay. A half-life of 5hrs implies a 75 percent probability of decaying in 10hrs, which increases to 87.5 percent in 15hrs, to 93.75 percent in 20 hrs and so on, because in every 5hrs, interval, the probability is 50 percent.

2.1.3 Types of Radioactive Decay

i. **Alpha decay:** Is the emission of alpha particles (2 protons and 2 neutrons) from an unstable nucleolus. The daughter nuclide has an atomic number 2 less than the parent nuclide and a mass number of 4 less than the parent nuclide (DOE, 1993). When an element disintegrate with the emission of an alpha particle it turns into an element with chemical properties similar to those of an element two places in the periodic table.

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\propto \qquad 2.7 $$

ii. **Beta-negative decay:** Effectively converts a neutron to a proton and an electron, which is immediately ejected from the nucleus. The daughter nuclide has its atomic number increased by 1 and the same mass number compared to the parent (DOE, 1993)

$$ {}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + {}^{0}_{-1}\beta \qquad 2.8 $$

iii. **Beta-positive decay:** Effectively converts a proton to a neutron and a position, which is immediately ejected from the nucleus. The daughter nuclide has its atomic number decreased by 1 and the same mass number compared to the parents (DOE, 1993).

$$ {}^{A}_{Z}X \rightarrow {}_{Z-1}{}^{A}Y + {}_{+1}{}^{0}\beta \qquad 2.9 $$

iv. **Electron Capture:** The nucleus absorbs an electron from the innermost orbit. This electron combines with a proton to form a neutron and a neutrino (DOE, 1993).

v. **Internal conversion:** Occurs when a gamma ray, emitted by the nucleus as it goes from the excited stated to the ground state, interacts with one of the innermost electrons of the same atom. The electron is ejected from the atom parent (DOE, 1993).

vi. **X-rays:** If an orbital electron in an atom is distorted from their normal configuration by some excitation process, the atom exist in an excited state for a short time, the electrons then rearranges themselves to return the atom to its lowest energy level (ground state). The energy liberated in the transition from excited state to ground state takes the form of characteristics X-ray photon whose energy is given by the difference between the initial and final state of the electron parent (DOE, 1993).

vii. **Gamma ray:** Radioactive decay processes often leave product nuclide in an excited state which either falls directly or decrease in steps through the dissipation of energy as Gamma rays. Gamma rays interact with matter through different processes parent (DOE, 1993).

2.3 Radon 222 (^{222}RN)

Radon-222 is present in nature as the only gas found in the natural uranium-238 (^{238}U)radioactive decay series. It is the direct progeny of ^{226}Ra with half-life of 3.82days, it is

colorless, inert and the major radon isotope which is the heaviest gaseous element, ^{222}Rn is soluble in water at standard temperature and pressure and highly soluble in organic solvent (UNSCEAR, 1998). Two isotopes of radon exist and the^{232} Th and ^{235}U natural activity series, they are ^{220}Rn (Thoron) and ^{219}Rn (Actinon) respectively.The isotopes, especially ^{222}Rn as reported as contributes the largest component of human exposure to natural radiation, figure2.2 (UNSCEAR, 2000). Exposure through inhalation of radon isotopes and their progeny has been associated with an increase in the risk of lung cancer (Smith 1988; Jacobi 1998; Boice and Lubin 2015).The progeny of ^{222}Rn are electrically charged having been stripped of electrons during the decay process, a majority of them attach to the aerosols existing in the atmosphere.

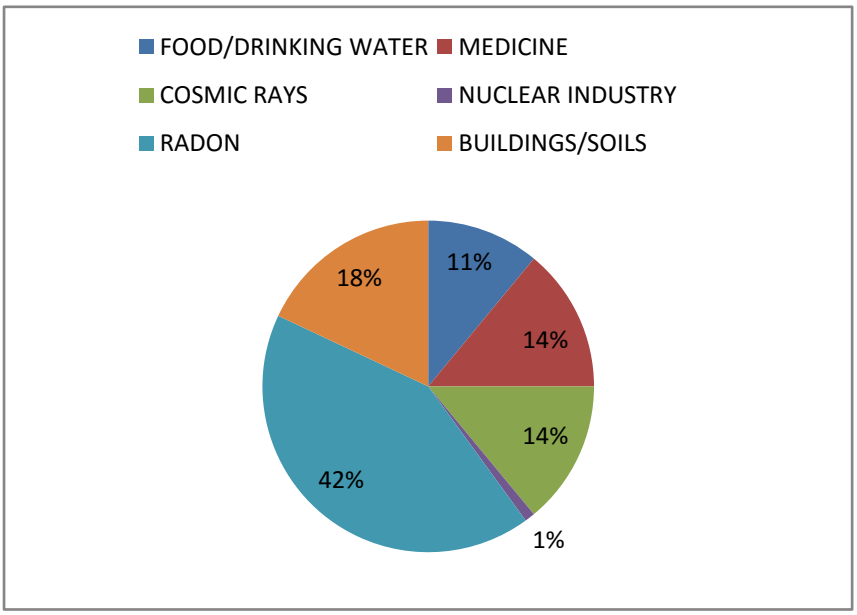


Figure 2.2 Radiation sources (source: World Nuclear Association)

2.3.1 Radon in Soil

Soil and rock have been identified as main sources of radon (Markanen and Arvela.1992) aswell as in building materials(Bossew P, 2003, Nielson *et al*.,1996). Tailings, as explained earlier are tones of processed waste product from the mineral processing plants. Once the rock containing the ore is crushed and treatedwith chemicals like cyanide to extract the minerals, the residue is dumped in huge constructed dams to hold and dry out the waste. These wastes may leave the natural occurring radioactive element uranium and other trace elements enhanced in activity concentrations. The waste also contain some of the other natural radioactive elements such as thorium (^{232}Th), potassium (^{40}K), uranium (^{238}U) and one of the uranium isotopes (^{235}U). These elements are radioactive and will decay to form their respective decay products and those will also be present in the soil. In the decay of ^{238}U, several decay products are formed, but the rather interesting one is ^{222}Rn which is a gas that may emanate from the host grain particle that the precursor of radon; ^{226}Ra, is contained in. There are three primary modes of decay whereby radioactive nuclei may transform to form other nuclei. These processes are α, β and γ decays. Unstable nuclei emit α and β particles to obtain a more stable arrangement. Gamma (γ) decay involves a nucleus in an excited state that decays to the ground state but does not change the nuclear species (Krane, 1988), whereas α and β decay alter the mass number of the nucleus. The energy released from γ-ray decay is usually in the form of a photon. The energies of the γ-rays range from thousands of electron volts (keV) to a few million electron volts (MeV). Different radioactive nuclei emit characteristic gamma radiation, and so these energies can be identified through γ-ray spectroscopy. Radon might escape the soil particle by recoil and then by the processes of diffusion and advection, could be transported to the surface of the mine dump. The properties that would influence these processes will be discussed

In the following sections as well as the processes whereby radioactive nucleitransform to form other species.

2.3.2 Radon Emanation

The fraction of radon atoms generated from radium decay that are released into a rock or soil pore space is defined as the radon emanationcoefficient (E), or emanating power, of the material. According to Schumann 1993, the emanation coefficient of rocks and soils typically variesbetween about 0.05 and 0.70, and an average value for soils is probably between 0.20 and 0.30. Geologic, pedologic, and climatic factors including radium content, grain size, consisting of radon parents within soil grains or on grain coatings, and soil moisture conditions, determine thesoil's emanating power and radon transport characteristics.

2.3.3 Radon Emanation and Radium Distribution

The distribution of radium in the soil grains are described as the key factors that affects radon emanation (Greeman and Rose 1995;Holdwarth and Akber, 2004). Thus pores will have a greater effect on the emanation coefficient for material with a homogeneous radium distribution compared with those with surface distribution. Original model of radon emanation assumed that radium distribution was homogeneous throughout the grain and that these grains were also spherical (Morawska and Phillips,1992). For material with homogeneous distribution of radium it is expected that the emanation coefficient would be low compared with surface distribution. While radon distribution is a key factor that affects radon emanation coefficient of materials like tailings other factors such as rock porosity, temperature and atmospheric pressure are all known to influence it (Greeman and Rose 1995).

2.3.4 Radon Emanation and Soil Moisture

After radon distribution the soil moisture content has been described as the next most important factor affecting the radon emanation coefficient. Water filling the pores grains and the interstitial space between grains shortens the range of radon atoms exciting the grains. This will stop radon atoms from embedding themselves into neighboring grains or crossing pores to embed in the same grain. Since radon is soluble, water may also aid in the release of radon trapped in pores on available in the gas phase and this will have a direct impact on the radon concentration and migration. There is a general agreement on the topic that it only require a small amount of moisture filling the interstitial space to increase emanation. The reduction in emanation coefficient seen with higher moisture content is attributed to reduction in the diffusion of radon trapped in water.

2.3.5 Radon Emanation and Rock Porosity

Both rock porosity and tailing sizeare known to affect radon emanation (Misdaq*et al*. 1998; Nazaroff and Nero 1988). Porosity is defined as the ratio of the empty space volume to solid material volume. It should be observed that tailing size and interstitial space are interrelated as tailing size increases so does interstitial space. Howeverthis does not necessarily increase the porosity as the increase may balance out. Smaller size tailing may also have larger than expected values of porosity especially if the tailingsare filled with pores providing more interstitial space, porosity also depend upon the amount of compaction of the material. An increase in interstitial space, hence porosity, means that radon has a greater chance of stopping in interstitial space after ejection from grain. It has been shown in a models and experiments that the radon emanation coefficient is directly proportional to porosity(Sun and Furbish 1995; Misdaq*et al*. 1998). While increasing the tailing size increase interstitial space,

proportionally less radon will escape from large grains due to smaller surface area to volume ratio. It has been shown that the radon emanation coefficient is inversely proportional to the tailings size (Morawska and Phillips 1992; Amin *et al*. 1995; Greeman and Rose 1995)

2.3.6 Radon Migration

Similar to radon emanation the most important factor affecting radon migration and exhalation is soil moisture. Numerous studies have examined the effects of soil moisture or precipitation on ^{222}Rn exhalation rates and soil gas concentration (Tanner 1980; Tidjani 1988; Thomas et al. 1992).Fick's law of diffusion of gases through porous media covers radon migration through unsaturated, undisturbed rock and soil (Nazaroff and Nero 1988). It shown in the equation below

$$\frac{d^2C}{dx^2} - \frac{\lambda C}{D} + \frac{E\lambda\rho R}{D\varepsilon} = 0 \qquad 2.10$$

Where;

C= interstitial concentration of radon isotopes (Bq.m^{-3})

$\varkappa$= Soil depth measured from the soil air interface (m)

λ= Radon isotope disintegration constant (s^{-1})

D=diffusion coefficient of radon isotopes (m^2 s^{-1})

E= parent radium isotopes activity concentration of the material (Bqkg^{-1})

P= Bulk density of material (kgm^{-3})

ε =Porosity of the material

The resultant radon exhalation rate of the soil air interface can be determined by

$$J = -D\varepsilon\left(\frac{dC}{dx}\right) \qquad 2.11$$

Where

$\frac{dC}{dx}$ = Is determined as a solution from equation 2.10

We can therefore write

$$J = E_{exp}\,\rho R\lambda L \times tanh\left(\frac{H}{L}\right) \qquad 2.12$$

Where;

H= sample thickness (m)

L= diffusion length (m)

With $L = \sqrt{\frac{D}{\lambda}}$ 2.13

2.5 Tailings

Tailings consist of ground rock and process effluents that are generated in a mine processing plant. Mechanical and chemical processes are used to extract the desired product from the run of the mine ore and produce a waste stream known as tailings. This process of product extraction is never 100% efficient, nor is it possible to reclaim all reusable and expended processing reagents and chemicals. The unrecoverable and uneconomic metals, minerals, chemicals, organics and process water are discharged, normally as slurry, to a final storage area commonly known as a Tailings Management Facility (TMF) or Tailings Storage Facility (TSF). Not surprisingly the physical and chemical characteristics of tailings and their methods of handling and storage are of great and growing concern.

Tailings are generally stored on the surface either within retaining structures or in the form of piles (dry stacks) but can also be stored underground in mined out voids by a process

commonly referred to as backfill. Backfilling can provide ground and wall support, improve ventilation, provide an alternative to surface tailings storage and prevent subsidence (EC 2004). The challenges associated with tailings storage are ever increasing. Advances in technology allow lower grade ores to be exploited, generating higher volumes of waste that require safe storage. Environmental regulations are also advancing, placing more stringent requirements on the mining industry, particularly with regard to tailings storage practices. This ultimately places added pressure on the operators of a tailings facility who carry out the day to day roles of tailings discharge and water management. The majority of historical tailings related incidents have been influenced by poor day to day management, which has resulted in the strengthening of regulations controlling tailings storage today. The particular design of these retaining structures is unique to a particular environment and mineral processing operation. When considering the design of a tailings storage facility there are many parameters which impact on the optimum site selected and the storage and tailings discharge methods used (Sokada *et al.*,2011). The environment and ground conditions are the most crucial parameters that control tailings storage methodology which ultimately affects the way a facility is designed, built, operated and closed. For this reason a range of alternate methods of tailings storage and discharge techniques need to be considered when designing a facility for a particular location. In industry, this is achieved by implementing a trade-off study, usually during the pre-feasibility stage of project development.

2.5.1 Nature of Tailings

The process of beneficiation of run of the mine ores and subsequent disposal to surface containment facilities exposes elements to accelerated weathering and can consequently increase their mobilization rates. The addition of reagents used in mineral processing may also change the chemical characteristics of the processed minerals and therefore the

properties of the tailings and waste rock (EC 2004). The processing of hard rock sulphidic bearing ores is just one example of accelerated weathering. In this case the sulphide minerals more readily oxidize in the tailings facility as a result of the size reduction from milling increasing the surface area and thus exposure of the tailings to air and water. Acid generation and metal mobilization occur that can find their way into the surrounding environment through runoff or seepage. This phenomenon is a well-known problem affecting the mining industry and is commonly known as Acid Mine Drainage (AMD) or Acid Rock Drainage (ARD) (Ferry et al., 2002; Sokada *et al.,* 2011). Depending on the mining project, alternative tailings storage techniques such as sub-aqueous disposal (below water deposition), and high density thickened tailings or dry stacking can be implemented to control oxidation of sulphides and the mobilization of metals.

2.5.2 Production of Tailings

The disposal of tailings is commonly identified as the single most important source of environmental impact for many mining operations (Ibeanu. 1999:Ferry *et al.,*2002).Over the last century the volumes of tailings being generated has grown dramatically as the demand for minerals and metals has increased and lower grades of ore are being mined through advances in extraction and processing technology. In the 1960's 10's of thousands of tons of tailings were produced each day and by 2000 this figure had increased to 100's of thousands (Kumar et al., 2011). Today there are individual mines producing in exces200,000tonesof tailings per day. Understanding the mineral processing techniques can help to determine how tailings are produced and the challenges associated with their storage.

2.5.3 Characteristics of Tailings

Tailings characteristics can vary greatly and are dependent on the ore mineralogy together with the physical and chemical processes used to extract the economic product. (Sodaka *et al.,*2011) reported that tailings of the same type may possess different mineralogy and therefore will have different physical and chemical characteristics. To help determine the design requirements of a tailings storage facility, the following characteristics of the tailings will need to be established (EC 2004): Chemical composition (including changes to chemistry through mineral processing) and its ability to oxidizes and mobilize metals Physical composition and stability (static and seismic loading)Behavior under pressure and consolidation rates.

Erosion stability (wind and water)Settling, drying time and densification behavior after deposition of Hard pan behavior (e.g. crust formation on top of the tailings).The engineering characteristics of tailings are in most instances influenced by the degree of thickening and the method of deposition. It is therefore essential that while investigating the properties of tailings that the physical characteristics and material parameters (e.g. beach slope Singles, particle size segregation, water recovery) that can occur as a result of varied deposition techniques be identified (Tripathi *et al.,* 2008). This is particularly true when considering high density tailings disposal and its associated transportation and deposition challengers**.**

2.6 Rad7 Solid-State Detector

The RAD7's internal sample cell is a 0.7 liter hemisphere, coated on the inside with an electrical conductor. The Rad7 comprises of a hemisphere chamber coated on the inside with a conducting material with silicon alpha detector implanted at the centre. A high voltage in the range of 2000-2500 V is applied to the conductor relative to the detector hence creating

an electric field throughout the volume of the cell (Durridge, 2000). The cell is equipped with a built-in pump with adjustable flow rate which draws in sample air through a hose. The hose is fitted with a filter which allows the gas to pass through while blocking the entry of the particulate progeny.

When the isotopes decay within the cell, the transformed nuclei are accelerated by the electric field towards the detector where they stick on the detector surface. Subsequent decays of the progeny lead to the emission of characteristic alpha radiation directly into the silicon detector (Durridge, 2000). Alpha particles are highly ionizing and interaction of the radiation with the silicon chip leads to the production of an electric current characteristic of the alpha radiation. This is then used to identify and quantify the isotope. The charged particles tend to accumulate on the detector surface with time and the detector must be purged every few hours by flushing dry isotope-free air.



Plate I: Electronic radon detector (RAD7)

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

The materials used in this research are stainless steel trowel, plastic container, Global positioning System device(GPS12 GARMAN), Radon Electronic Detector (DURRIGE RAD7), Sodium Iodide Detector,masking tape and candle wax.

3.2The Study Area

Jos is located on a granitic plateau about 1100 m above sea level in the North Central part of Nigeria at longitude 08°53′E and latitude 09°56′N as represented by Figure 3.1,The study area lies within the humid tropical zone whose climate ischaracterized by alternating periods of rainingseason and dry season. The raining season startsfrom March, with heavy rainfall in May-June-July and a dry break in August followed by heavy rainin September-October.

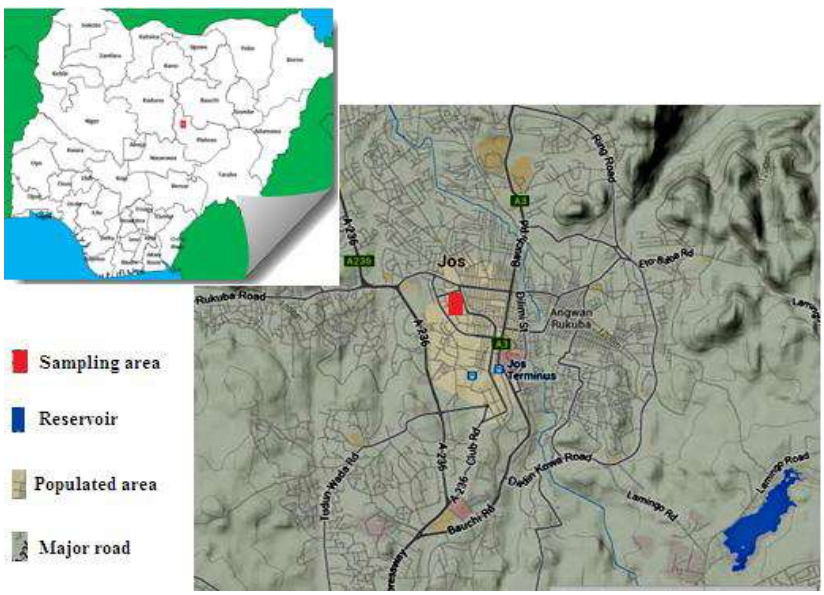


Figure 3.1: Location map of Jos Plateau area, inset is a map of Nigeria depicting this location (Google Earth)

The main geological formation of this area lends itself to the mining and milling of tin. The lithological formations are younger granite ring complexes and tertiary basaltic volcanic rocks of north central Nigeria Materials the Tin tailings used in this work were obtained from the Jos Tin mining field in Nigeria.Thetailingsare pumped into the mine in the form of aqueous slurry for backfilling, whichsettle and consolidate by its own weight to stabilize the excavations after drainingout of water.

3.3 Sample Collection

Twenty five tailing samples were collected from threelocal government areas corresponding to the tailing disposal area of the mining sites. A composite sampling technique (IAEA, 1989) was adopted to ensure that the samples are the actual representative of the sites from which they were taken the position of each sampling area was determined with the aid of Global Positioning System (GPS device). The samples were well labeled to avoid mixed up and stored in a plastic container. The sample collection sites were indicated in Figure 3.2.

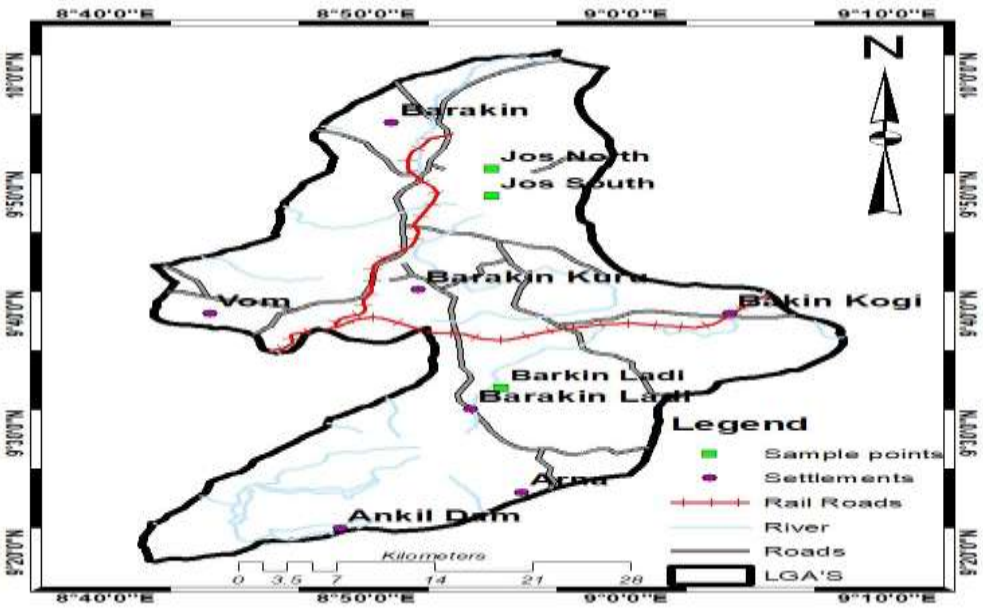


Figure 3.2Map of Jos showing the sampling locations

3.4 Sample Preparation

Each of the tailing samples collected wasairdried(ambient temperature) and crushed to fine powder with the use of pulverizer. Packaging of the samples into radon-impermeable cylindrical plastic containers to prevent radon-222 escaping, the packaging in each case was triple sealed.

The sealing process included smearing of the inner rim of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container, and tight-sealing lid-container with masking adhesive tape. Radon and its short-lived progenies were allowed to reach secular radioactive equilibrium by storing the samples for 30 days prior to measurements.

3.5 Radon Concentration measurement

Radon concentration measurements in the tailing samples was conductedat Centre for Energy Research and Training in Ahmadu Bello University Zaria, Nigeria by using Radon Electronic Detector,(RAD 7) which uses a solid state alpha detector to convert alpha radiation to electrical signals and has the ability to electrically determine the energy of each alpha particle. Radon was quantified based on the ^{218}Po and ^{214}Po peaks at alpha energies 6.00MeV and 7.69MeV respectively and thoron from the ^{216}Po peak at alpha energy 6.78MeV.

Before radon measurement begins, It was ensured that there is desiccant(to strips off moisture in air coming from the sample) and the inlet filter were place between the sample and RAD7.The schematic diagram of the experimental arrangement is shown in Figure 3.3. The detector was then set in SNIFF mode due to it fast response to change in concentration and rapid recovery from high concentration.The counting procedure is preceded by running the pump for five minutes in order to flush the measurement chamber. The actual measurement

of radon concentration was carried out for a complete cycle lasting for five minutes for a total of 24cycles.

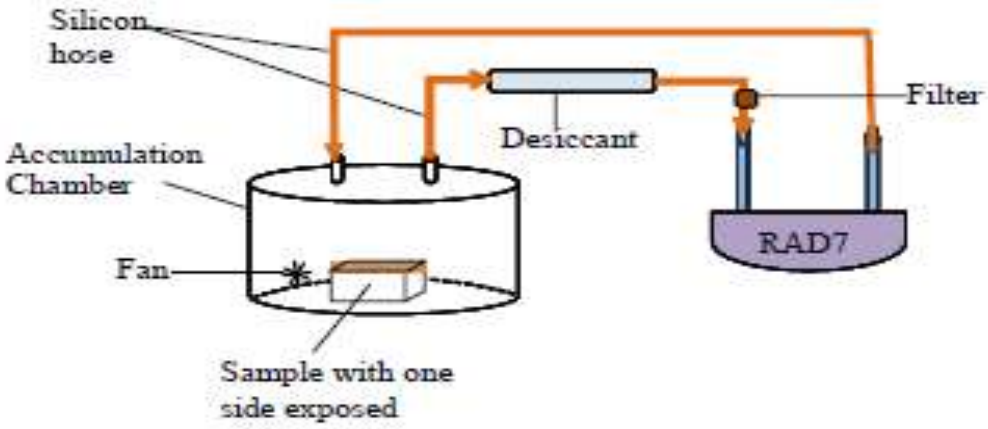


Fig 3.3: Experimental Setup for Radon Concentration Measurement

Table 3.1 Radon concentration for Jos North LGA Mining site

Sample code	^{222}Rn conc. C_1 (Bqm^{-3})	^{222}Rn conc. C_2 (Bqm^{-3})	Mean ^{222}Rn conc. (Bqm^{-3})
JSN 1	282	1440	720
JSN 2	301	1320	670
JSN 3	196	1520	800
JSN 4	299	1330	673
JSN 5	205	1221	638
JSN 6	321	1450	715
JSN 7	125	1051	626
JSN 8	204	1322	712
JSN 9	132	1008	570
JSN 10	246	1455	745

Table 3.2 Radon concentration for Barkinladi LGA Mining site

Sample code	^{222}Rn conc. C_1 (Bqm^{-3})	^{222}Rn conc. C_2 (Bqm^{-3})	Mean ^{222}Rn conc. (Bqm^{-3})
BKL 1	538	1510	645
BKL 2	482	1420	790
BKL 3	584	1770	739
BKL 4	304	1624	796
BKL 5	542	1355	575
BKL 6	332	1224	610
BKL 7	826	1781	645
BKL 8	542	1922	820
BKL 9	822	2043	670
BKL 10	724	1987	775

Table 3.3 Radon concentration for Jos South LGA Mining Site

Sample code	^{222}Rn conc. C_1 (Bqm^{-3})	^{222}Rn conc. C_2 (Bqm^{-3})	Mean ^{222}Rn conc. (Bqm^{-3})
JSS 1	36	393	370
JSS 2	84	494	420
JSS 3	95	295	340
JSS 4	106	521	411
JSS 5	76	804	530

3.6 Measurement of Natural Radionuclide

The measurement was madeat Centre for Energy Research and Training in Ahmadu Bello University Zaria, Nigeria using a 76x76mm **NaI(Tl)** detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1kilovolt external source. The detector is enclosed in a 6cm lead shield with cadmium and copper sheets. This arrangement is aimed at minimizing the effects of background and scattered radiation.Sodium Iodide is a type of detector within a class known as scintillation detectors. Gamma rays penetrate through the detector housing and into the NaI crystal where they may experience interactions with the atoms inside the crystal these interactions can cause photons of visible light to be released from the atom and travel short distances within the crystal.Visible light is created inside the NaI crystal due to incoming gamma rays. This visible light is converted to an electrical signal by the photocathode. This electrical signal is amplified by the Photomultiplier Tube (PMT) and then processed into a spectrum by the Multichannel Analyser (MCA). The data acquisition software is **Maestro** by Canberra

Nuclear Products. The samples were measured for a period of 29000 seconds, for each sample.

3.7 Radon Emanation Rate

Radon emanation rate of the tailings samples used in this study was calculated using the relation (IAEA, 2013; Thompkin and Cheng, 1969);

$$J = \frac{K\left(C_2 - C_1 e^{-\lambda t}\right)}{3600} \times \frac{V}{A} \quad 3.1$$

Where;

$$K = \frac{\lambda}{\left(1 - e^{-\lambda t}\right)} = depletion factor \quad 3.2$$

C_1= Minimumradonconcentration (Bq/m^3)

C_2= Maximumradonconcentration (Bq/m^3)

V = Volume of sample vessel in m^3 (7x $10^{-3}m^3$)

λ =Decay constant of Radon-222 in s^{-1}(3.30x $10^{-6}s^{-1}$)

A = emanating surface area inm^2(4.02 x $10^{-2}m^2$

3.8 Equivalent Dose

$$ED = DR\ (nGyh^{-1}) \times 0.7\ SvGy^{-1}(conversion\ factor) \times 0.8\ (occupancy\ factor) \times 8766h \times 10^{-6} \quad 3.3$$

Where;

ED = Equivalent dose in $mSvyr^{-1}$

DR = Absorbed dose rate

The absorbed dose rate was calculated using equation (3.4) (UNSCEAR 2000):

$$DR = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \leq 80nGyh^{-1} \quad 3.4$$

Where;

C_{Ra} = Activity concentration of Radium

C_{Th} = Activity concentration of thorium [1]

C_K = Activity concentration of potassium

3.9 External hazard index

In order to ensure that the external radiation exposure due to NORMs does not exceed a maximum permissible limit of 1 mSv·y^{-1}, the External Hazard Index (H_{ex}) was introduced by the International Commission of Radiological Protection (ICRP). The value of the H_{ex} is obtained using equation (3.5) (Beretka& Mathew, 1985; OECD, 1979):

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4180} < 1\text{mGyy_1.} \quad 3.5$$

3.10 Internal hazard index

Since radon and its short-lived products constitute internal exposure to radiation through inhalation by human beings, an Internal Hazard Index H_{in} was also defined in order to quantify this type of exposure. The value for H_{in} is obtained using Equation (3.6) (Beretka& Mathew, 1985; OECD, 1979). Similar to the requirement for $H_{ex,}$ H_{in}should not exceed a value of 1 mSv·y^{-}

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4180} < 1\text{mGyy_1}. \quad 3.6$$

3.11 Alpha index

Radon is an alpha emitter. This implies that high radon inhalation can lead to the elevated alpha radiation in the internal organs of the body. Alpha index, defined in equation(3.7) (Leipeng, &Gelian, 2006), accounts for alpha radiation due to radon inhalation.

$$I_{\propto} = \frac{C_{Ra}}{200} \quad 3.7$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 ActivityConcentrations of ^{226}Ra, ^{232}Th and ^{40}K

Table 4.7 to 4.9 shows the results of radioactivity measurements of mine tailings collected from selected locations (i.e. Jos North, Barkinladi and Jos South LGAs) of Jos tin mining area. For Jos North LGA, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations are 64.21±10.33, 441.37±57.13 and 84.72± 11.37respectively. For Barkinladi LGA, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations are 52.36 ± 7.99, 863.77 ±120.97 and 80.56±14.00 respectively. Finally, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations for Jos south LGA are 30.32±4.03, 324.42±85.22 and 53.61±6.79 respectively. The specific activity concentrations of ^{40}K were generally higher than that of ^{226}Ra and ^{232}Th for all three LGAs.

Table 4.1 Radioactivity concentration of radionuclide in Jos North mine tailings (Bqkg^{-1})

Sample Code	K – 40 (Bqkg^{-1})	Ra 226 (Bqkg^{-1})	Th-232 (Bqkg^{-1})
JSN 1	409.23 ± 2.31	73.28 ± 1.36	96.25 ± 3.62
JSN 2	391.14 ± 2.10	67.46 ± 1.69	84.63 ± 2.30
JSN 3	431.36 ± 1.98	58.55 ± 3.21	79.34 ± 4.21
JSN 4	411.48 ± 1.77	74.86 ± 1.42	98.12 ± 3.61
JSN 5	501.89 ± 3.14	70.38 ± 2.01	92.38 ± 5.20

JSN 6	399.85 ± 1.95	62.87 ± 1.55	74.62 ± 3.01
JSN 7	548.38 ± 4.01	49.26 ± 3.42	62.83 ± 5.42
JSN 8	388.42 ± 2.11	50.32 ± 1.32	78.21 ± 3.21
JSN 9	421.38 ± 1.88	56.52 ± 2.11	84.25 ± 3.51
JSN 10	510.56 ± 2.22	78.59 ± 1.89	96.57 ± 2.80
MEAN	441.37± 57.13	64.21± 10.33	84.72± 11.37

Table 4.2 Radioactivity concentration of radionuclide in Barkinladi mine tailings

Sample Code	^{40}**K**(Bqkg^{-1})	^{226}**Ra** (Bqkg^{-1})	^{232}**Th** (Bqkg^{-1})
BKD 1	946.59 ± 7.88	56.98 ± 1.68	88.86 ±1.93
BKD 2	946.89 ± 15.03	50.45 ± 17.37	71.86 ± 16.64
BKD 3	635.89 ± 6.13	40.45 ± 7.37	63.69 ± 7.81
BKD 4	840.04 ± 12.49	37.84 ± 7.83	55.45 ± 8.50
BKD 5	894.23 ± 5.65	55.24 ± 2.10	76.86 ± 4.59
BKD 6	901.46 ± 8.21	49.68 ± 1.98	98.22 ± 2.55
BKD 7	666.76 ± 6.95	57.85 ± 2.40	77.47 ± 8.21
BKD 8	891.21 ± 6.34	54.52 ± 6.23	92.45 ± 7.26

BKD 9	902.43 ± 7.15	57.18 ± 1.96	86.24 ± 3.17
BKD 10	1012.23±10.34	63.45±5.56	94.57±6.33
MEAN	863.77±120.97	52.36±7.99	80.56±14.00

Table 4.3 Radioactivity concentration of radionuclide in Jos mine tailings ($Bqkg^{-1}$)

Sample Code	**K – 40 ($Bqkg^{-1}$)**	**Ra-226 ($Bqkg^{-1}$)**	**Th-232 ($Bqkg^{-1}$)**
JSS 1	204.52 ± 1.42	33.54 ± 1.22	52.54 ± 1.30
JSS 2	306.52 ± 5.1	24.68 ± 2.20	43.26 ± 3.20
JSS 3	299.89 ± 5.44	29.58 ± 1.99	58.76 ± 2.24
JSS 4	422.58 ± 8.24	34.85 ± 1.72	52.86 ± 1.92
JSS 5	388.58 ± 7.23	28.95 ± 2.43	60.62 ± 3.42
MEAN	324.42±85.22	30.32±4.03	53.61±6.79

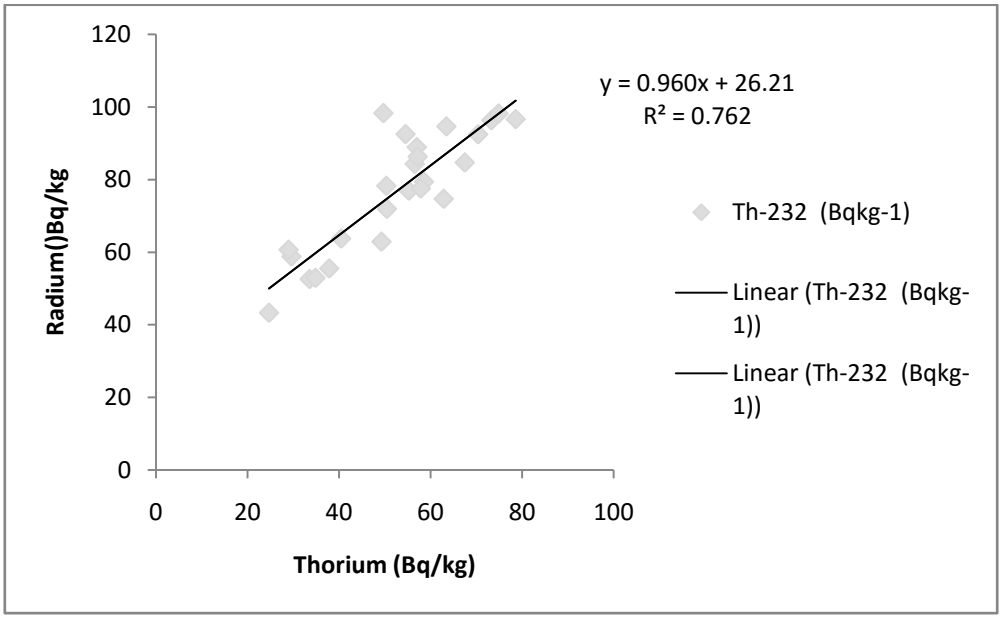


Figure 4.1- Correlation between ^{226}Ra and ^{232}Th activity concentrations in tailing samples.

Ra and K

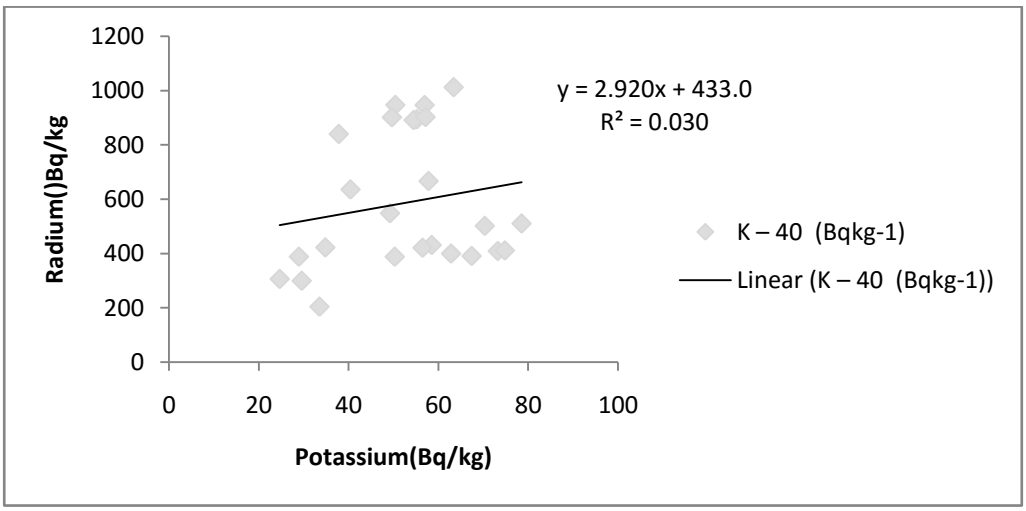


Figure 4.2- Correlation between ^{226}Ra and ^{40}K activity concentrations in tailing samples.

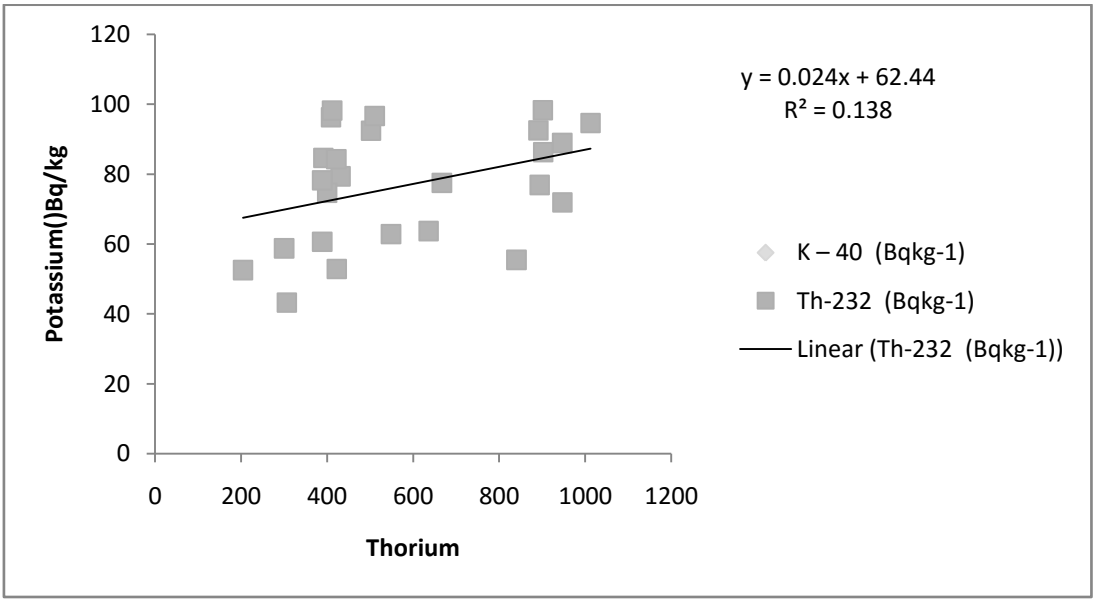


Figure 4.3- Correlation between ^{40}Kand ^{232}Thactivity concentrations in tailing samples.

Fig.4.1 shows a fairly strong correlation between ^{226}Ra and ^{232}Th activity concentration. This suggests that between the activity concentrations of Radium gives an idea of the activity concentration of Thorium 232. Fig.4.2 and Fig. 4.3 shows a very poor correlation between ^{226}Ra and ^{40}K and ^{40}Kand ^{232}Th activity concentrations respectively. Since the activity concentration of Potassium far exceeds that of Radium and Thorium in all the sampling sites as shown in Table 4.1 4.2 and4.3 this suggests that potassium is the major contributor to background radiation in the areas.

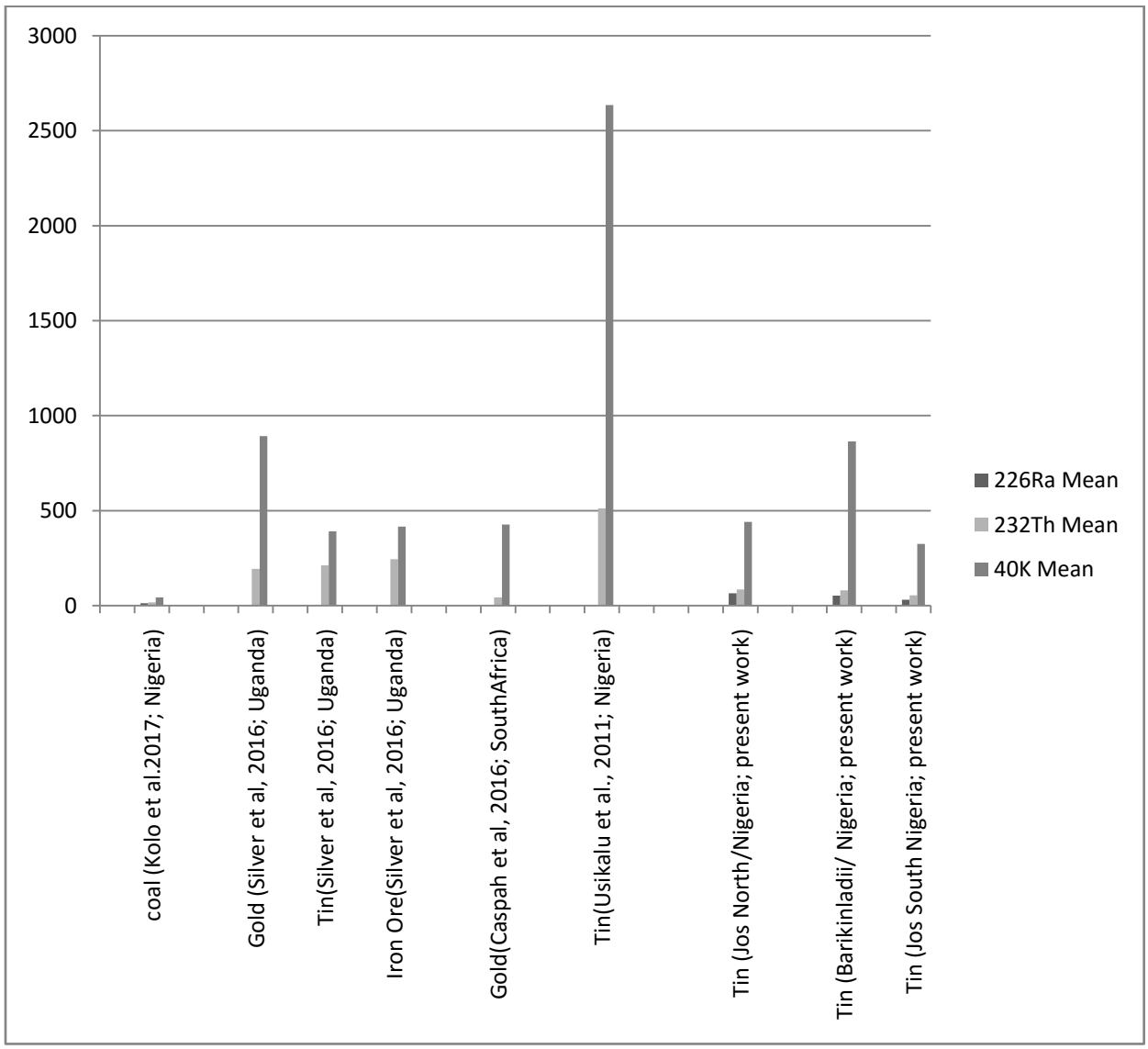


Fig 4.4 Comparison of specific activities of ^{226}Ra, ^{232}Th and ^{40}K in tailings in Jos, Nigeria and other mineral tailings in other cities around the world

Table 4.4 Radiological hazard indices of tailings in Jos North LGA

SAMNPLE ID	H_{ex} **(**nGyhr^{-1}	H_{in} **(**nGyhr$^{-1)}$	I_{α}**(**Bqm$^{-3)}$
JSN 1	0.667±0.020	0.859±0.022	0.366±0.007
JSN 2	0.603±0.021	0.786±0.022	0.337±0.009
JSN 3	0.567±0.030	0.725±0.033	0.293±0.016
JSN 4	0.670±0.064	0.878±0.088	0.374±0.007
JSN 5	0.667±0.028	0.857±0.038	0.352±0.010
JSN 6	0.554±0.021	0.724±0.021	0.315±0.008
JSN 7	0.506±0.031	0.639±0.032	0.211±0.017
JSN 8	0.700±0.020	0.834±0.021	0.251±0.006
JSN 9	0.763±0.019	0.910±0.025	0.283±0.011
JSN 10	0.930±0.021	1.143±0.023	0.393±0.009

Table 4.5 Radiological hazard indices of tailings in Barikinladi LGA

SAMNPLE ID	H_{ex} (nGyhr^{-1}	H_{in} (nGyhr^{-1}	$I_{\propto}$ (Bqm$^{-3)}$
BKL1	0.723±0.033	0.877±0.052	0.285±0.008
BKL 2	0.640±0.014	0.777±0.016	0.252±0.087
BKL3	0.370±0.014	0.481±0.017	0.202±0.004
BKL4	0.517±0.060	0.620±0.082	0.189±0.004
BKL5	0.659±0.031	0.809±0.031	0.276±0.011
BKL6	0.729±0.022	0.865±0.023	0.248±0.009
BKLL7	0.614±0.041	0.770±0.047	0.289±0.012
BKL8	0.717±0.021	0.865±0.025	0.273±0.031
BKL9	0.702±0.020	0.856±0.025	0.286±0.009
BKL10	0.778±0.033	0.950±0.037	0.317±0.028

Table 4.6 Radiological hazard indices of tailings in Jos south LGA

SAMNPLE ID	H_{ex} **(**nGyhr$^{-1)}$	H_{in} (nGyhr$^{-1)}$	$I_{\propto}$**(**Bqm$^{-3)}$
JSS1	0.342±0.014	0.432±0.017	0.168±0.006
JSS 2	0.307±0.029	0.373±0.036	0.123±0.011
JSS3	0.370±0.020	0.449±0.021	0.148±0.009
JSS4	0.398±0.014	0.492±0.019	0.174±0.0208
JSS5	0.338±0.022	0.416±0.028	0.145±0.017

4.2 Radon Concentration

The result of the mean radon concentrations of tailings samples from Jos North LGA, Barkinladi LGA and Jos South LGA of the mining site are presented in table 4.8, 4.9 and 4.10 respectively.

Results of measurements as presented in Table 4.8 - 4.10 indicate that, for Jos North LGA sampling site, radon concentration ranges from 421±16.2 Bqm^{-3} to 880±29.5 Bqm^{-3}, for Barkinladi sampling site, the variation is from 754±21.4 Bqm^{-3} - 1041±51.2 Bqm^{-3}. Finally for Jos South LGA sampling site radon activity concentration ranges from 158±9.61 Bqm^{-3} - 341±13.1 Bqm^{-3} The results further indicate that in the entire sampling area, the highest radon concentration was found in the sample BKLD 9 with mean radon concentration value of 1041±51.2 Bq.m^{-3}, and lowest is found in the tailing sample JSS3 with mean concentration value of 158±9.61 Bqm^{-3}.

Table 4.7 Radon concentration variation for Jos North LGA Mining site

Sample code	Mean ^{222}Rn conc. (Bqm^{-3})
JSN1	720
JSN2	670
JSN3	800
JSN4	673
JSN5	638
JSN6	715
JSN7	626
JSN8	712
JSN9	570
JSN10	745

Table 4.8 Radon concentration variation for Barkinladi LGA Mining site

Sample code	Mean ^{222}Rn conc. (Bqm^{-3})
BKL1	645
BKL 2	790
BKL3	739
BKL4	796
BKL5	575
BKL6	610
BKLL7	645
BKL8	820
BKL9	670
BKL10	775

Table 4.9 Radon concentration variation for Jos South LGA Mining Site

Sample code	Mean ^{222}Rn conc. (Bqm^{-3})
JSS1	370
JSS2	420
JSS3	340
JSS4	411
JSS5	530

As a result of recognition of radon as a carcinogen, reference levels within the range of 100-140 Bqm^{-3} had been recommended (US EPA, WHO). Measurement data beyond this range will require radon mitigation measures. Most of the sampling site selected for the present study registered radon concentration well above the above the upper limit of 148 Bqm^{-3}. In terms of radiation protection therefore, radon appears to be a major source of indoor radioactivity in the sampling sites.

4.3 Radon emanation rate

As uranium decays into radium, and radium also undergoes decay, radon is formed and is released into small air or water containing pores between soil and rock particles. The exhalation of radon from soil is affected by many factors most importantly the radium content of the bedrock or soil (Patitapaban, 2013). Each sample of mine tailing will have different values of radon emanation. Table 4.4-4.6 shows the result of radon emanation rate for the

different tailing samples. It is readily observed that a strong correlation (R^2> 0.9) exist between radon emanation rates and the radium concentrations in all the sampling sites i.e Jos North, Barikinladi and Jos south LGA in the various sampling sites as shown in fig.4.4-4.6. The strong correlation between radon emanation rate and radium concentration suggests that the higher the radium concentration, the higher the radon emanation rate. Since radon gas is a direct daughter of radium decay, the radon concentration gives an idea of the radium activity concentration in the areas. Since the average radium activity concentration is lesser the average potassium activity concentration, it suggests that radium may not be the major contributor to background radiation in the area. But with the high radon concentration for all the samples; 148 Bq/m3 and 100 Bq/m3 is the acceptable limit according to US EPA and WHO respectively, it can be inferred that the health risk associated with exposure to radon arises from the inhalation of the short-lived decay products and the consequent alpha particle irradiation of the bronchial airways.

Table 4.10Radon Emanation Rate for Jos North LGA Mining site

Sample code	**Radon Emanation J ($Bqm^{-2}s^{-1}$) x 10^{-3}**
JSN1	4.59
JSN2	4.04
JSN3	5.25
JSN4	4.09
JSN5	4.03
JSN6	4.48
JSN7	3.67
JSN8	4.53
JSN9	3.19
JSN10	4.79

Table 4.11Radon Emanation Rate for Barkinladi LGA Mining site

Sample code	Radon Emanation J ($Bqm^{-2}s^{-1}$) x 10^{-3}
BKL1	3.80
BKL 2	5.10
BKL3	4.70
BKL4	5.20
BKL5	3.22
BKL6	3.54
BKLL7	3.79
BKL8	5.47
BKL9	4.84
BKL10	5.01

Table 4.12Radon Emanation Rate for Jos South LGA Mining site

Sample code	Radon Emanation J ($Bqm^{-2}s^{-1}$) x 10^{-3}
JSS1	1.4
JSS2	1.8
JSS3	1.1
JSS4	1.7
JSS5	2.8

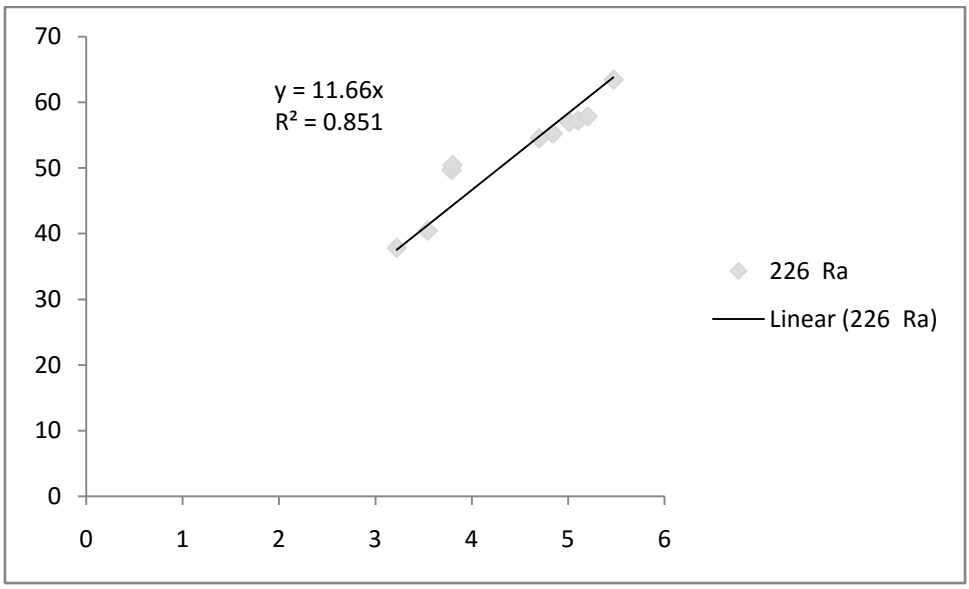


Figure4.4 Radon concentrations against Radon Emanation Rate for Jos North LGA Mining site

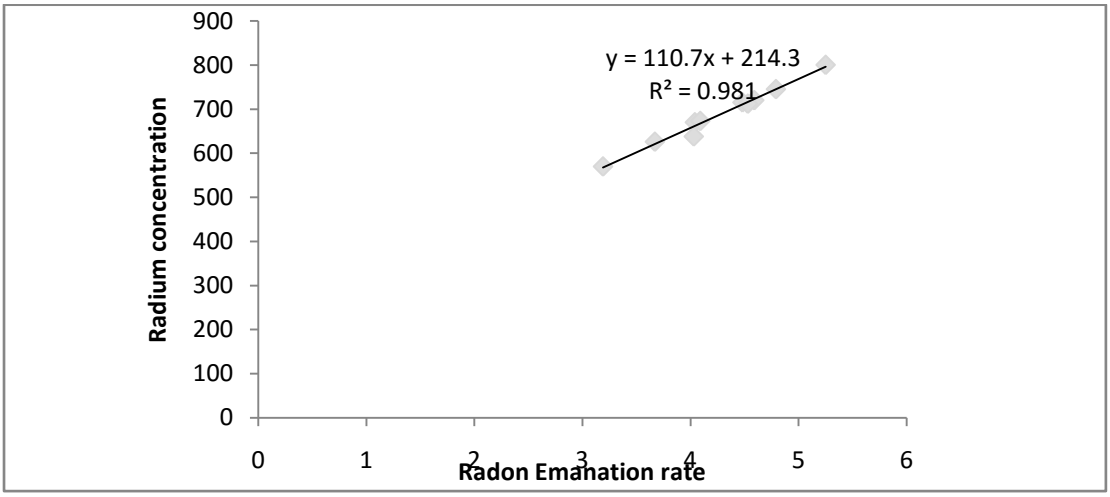


Figure4.5 Radon concentrations against Radon Emanation Rate for Barkinladi LGA Mining site

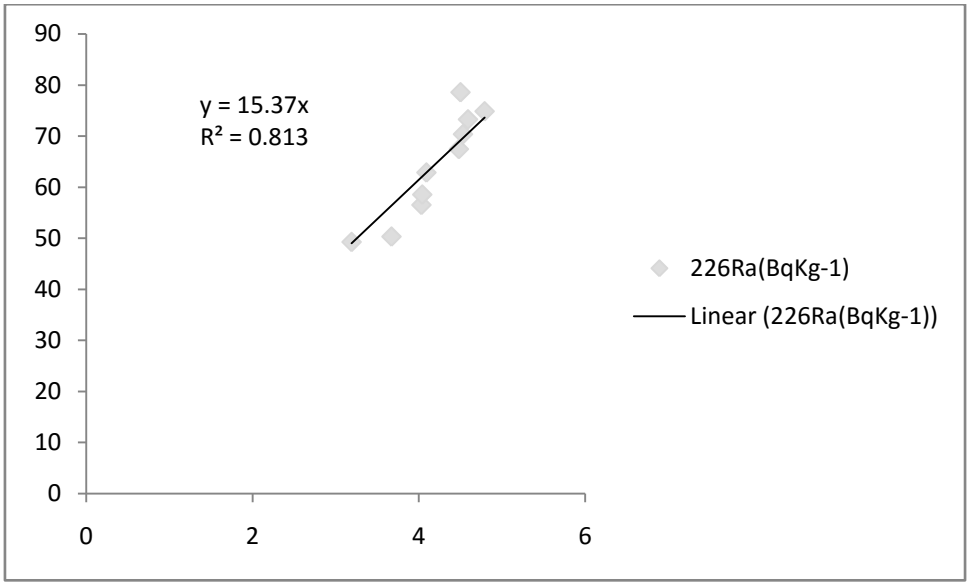


Figure 4.6 Radium concentration against Radon Emanation Rate for Jos South LGA Mining site

4.4 Radiation Hazard Assessment

The activity concentrations of NORMs in the tailing sample are non-uniform. So, in order to quantify the radiological risks associated with the NORMs, absorbed dose, equivalent dose, external hazard index, internal hazard index and Alpha index was defined by UNSCEAR.

As shown in Table 4.14 the absorbed dose range from 92.49 – 119.47 $nGyhr^{-1}$ with a mean value of 101.79 $nGyhr^{-1}$ for Jos North LGA. As for Barikinladi LGA, the value ranges from 86.48 – 132.72 with a mean value of 112.34 $nGyhr^{-1}$. Finally, for Jos South LGA, the absorbed dose range from 52.27 – 69.11 $nGyhr^{-1}$ with a mean value of 62.33 $nGyhr^{-1}$. The mean value for the absorbed dose of all three LGAs shows that the absorbed dose rate for Jos North and Barikinladi LGAs exceeds the 59 $nGyhr^{-1}$ acceptable limit by UNSCEAR (2000). Although mean value for the absorbed dose of all three LGAs shows that the absorbed dose rate for Jos North and Barikinladi LGAs exceeds the 59 $nGyhr^{-1}$ acceptable limit by UNSCEAR, none of the sampling sites exceeded the acceptable limit of 1 $mSvy^{-1}$ as can be seen in table 4.14. It can be seen from table 4.5 – 4.7 that no value for external hazard index exceeded the 1 $mGyy^{-1}$ accepted limit. Only one sample t JSN 10 exceeded the 1 $mGyy^{-1}$ accepted limit for internal hazard index. There should however be concern most of the values for the internal hazard index for Barikinladi and Jos North LGAs are quite close to the acceptable limit of 1 $mGyy^{-1}$.

Table 4.13Radiation hazard assessments for the tailing sites.

Local Government	**Sample Code**	**Absorbed dose ($nGyhr^{-1}$)**	**Equivalent dose ($mSvyr^{-1}$)**
	BKL1	123.38	0.757
	BKL2	109.27	0.670
	BKL3	86.48	0.530
BarakinLadi	BKL4	88.44	0.542
	BKL5	112.44	0.689
	BKL6	123.99	0.760
	BKL7	104.42	0.640
	BKL8	122.39	0.751
	BKL9	119.87	0.735
	BKL10	132.72	0.814
	JSN1	112.72	0.691
	JSN2	101.73	0.624
	JSN3	95.59	0.586
	JSN4	114.16	0.700
Jos North	JSN5	112.79	0.692

	JSN6	93.46	0.573
	JSN7	86.01	0.523
	JSN8	89.99	0.552
	JSN9	92.49	0.567
	JSN10	119.47	0.733
	JSS1	57.97	0.355
	JSS2	52.27	0.321
Jos South	JSS3	64.42	0.395
	JSS4	67.90	0.416
	JSS5	69.11	0.424

CHAPTER FIVE

SUMMARY CONCLUSION AND RECOMMENDATION

5.1 Summary

Mining activities in Jos result in a byproduct conventionally known as tailing. Radon gas has also been pointed out to be particularly associated with Jos tin tailing. This research assessed the NORMS, radon emanation rate and radon concentrationand radiological hazard from tailings in Jos tin mine. The NORMs concentration were determined using gamma spectroscopy technique. The radonConcentration of the tailing samples were determined using laboratory measurementstechniques via the electronic radon detector known as RAD7 specially designed for this particular kind of purpose. The Equivalent dose, external hazard index, internal hazard index, and Alpha index were assessed. The absorbed dose for Barakinladi and Jos North tailing site exceeds the acceptable limit of 59 $nGyhr^{-1}$. The equivalent dose however does not exceed the acceptable limit in any of the sampling area. Both the internal and external hazard index suggests that the radiological risk associated with the tailing site for Jos North and Barikinladi is too close to the acceptable limit of 1 $mGyyr^{-1}$. This implies that the radiological hazard potential in the areas is quite significant and thus radiation exposure mitigation steps need to be taken accordingly. Jos South tailing site is generally safe from radiation hazard point of view since there is no significant value recorded in all the radiological hazard indices.

5.2 Conclusion

Assessment of NORMs, radon concentration and emanation rate and radiological hazard indices have been carried out for three tailing sits in Jos, Nigeria. For Jos North LGA, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations are 64.21 ± 10.33, 441.37 ± 7.13 and

84.72± 11.37respectively. For Barkinladi LGA, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations are 52.36±7.99, 863.77±12.97 and 80.56±14.00 respectively. Finally, the mean ^{226}Ra, ^{232}Th and ^{40}K activity concentrations for Jos south LGA are 30.32±4.03, 324.42±8.22 and 53.61±6.79 respectively. The specific activity concentrations of ^{40}K were generally higher than that of ^{226}Ra and ^{232}Th for all three LGAs which implies that it is the major contributor to background radiation.

The absorbed dose for Barakinladi and Jos North tailing site exceeds the acceptable limit as recommended by UNSCEAR (2000). The equivalent dose however does not exceed the acceptable limit. Both the internal and external hazard index suggests that the radiological risk associated with the tailing site for Jos North and Barikinladi is too close to the acceptable limit. Jos South tailing site is generally safe from radiation hazard point of view.

The radon emanation rate for Jos North LGA ranges from (3.16 - 5.26)x 10^{-3}

Bqm^{-2}s^{-1} while that of BarikinLadi ranges from (3.22 - 5.47 26)x 10^{-3}

Bqm^{-2}s^{-1}. The radon emanation rate for Jos North ranged from(1.10 – 2.80 26)x 10^{-3}.

Bqm^{-2}s^{-1}.

The absorbed dose range from 92.49 – 119.47 nGyhr^{-1} with a mean value of 101.79 nGyhr^{-1}for Jos North LGA. For Barikinladi LGA, the value ranges from 86.48 –132.72 with a mean value of 112.34 nGyhr^{-1}. Finally, for Jos South LGA, the absorbed dose range from 52.27 – 69.11 nGyhr^{-1} with a mean value of 62.33 nGyhr^{-1}. The mean value for the absorbed dose of all three LGAs shows that the absorbed dose rate for Jos North and Barikinladi LGAs exceeds the 59 nGyhr^{-1} acceptable limit by UNSCEAR (2000).

The mean value of external hazard index is 0.663 for Jos North LGGA while the mean value is 0.644 for Barikinladi. . For Jos South LGA, the external hazard index has a mean value of 0.351. None of the mean values for external hazard index exceeded the 1 $mGyy^{-1}$ accepted limit. This implies that the risk of radiation hazard from gamma emitting radionuclide is well below accepted limit. One sample, JSN 10 exceeded the 1 $mGyy^{-1}$ accepted limit for internal hazard index. Except for Jos South LGA, all other samples in Jos North and Barikinladi LGA recorded an internal hazard index quite close to the acceptable limit of 1 $mGyy^{-1}$. On the average it can be inferred that all three sampling sites do not exceed the internal hazard index limit of 1 $mGyy^{-1}$. There should however be concern and radiation mitigation exposure steps should be undertaken for Jos North and Barikinladi LGAs since most of the values for their internal hazard index are quite close to the acceptable limit of 1 $mGyy^{-1}$.

5.3 Recommendation

Using our research as a baseline,wemake the following recommendation

1. The mining site should maintain a better ventilation system so that they may be free from related illness from emanation of radon gas.
2. For further research purposes the three ways of which radon gas is released (emanation exhalation and transportation) to atmosphere should be considered in relation to radon content.
3. For further research purpose the same assessment should be carried out in order tailing sites of various states.

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