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Measurement of Radiation Exposure Due to Natural Radionuclides in Gemstone Mining Area in Olode, Ibadan South Western Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author IAT designed the study with FOB and GAO conducted the field work and sampling. Sample preparation and Gamma counting were performed by authors FOB and LAO. Authors PT and CAA carried out the statistical data analysis and evaluation, while the first draft was written by authors IAT and PT. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: To determine the level of radioactivity due to naturally occurring radioactive materials (NORM) and also assess the radiological hazards to both workers and the public.
Place and Duration of Study: Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria between January and April 2012.
Methodology: Fifteen samples comprising rocks, soils, water and mine wastes were obtained from three (3) mining sites in Olode, Ibadan and a topsoil sample two kilometers away from the site that served as control were investigated for their natural radioactivity contents using a well-calibrated HPGe gamma-ray spectrometer.
Results: For both rock and soil samples, the activity concentrations of the radionuclides range between 86.42-2200.71Bq/kg; 3.00-13.11Bq/kg and 6.09-11.95Bq/kg for ^{40}K, ^{238}U

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and ^{232}Th respectively, while the Absorbed Dose Rate and the Dose Equivalent were in the range of 10.58–96.71nGy/h and 0.07–0.6mSv/yr. In water, the activity concentration was in the order of 10^{-2} Bq/L and the Annual Effective Dose was between 0.08–0.12; 3.47–3.78 and 20.65–24.18μSv/yr for ^{40}K, ^{238}U and ^{232}Th respectively.
Conclusion: The gemstone-bearing pegmatite rock from mine 1 has the highest dose equivalent value of 0.60mSv/yr which is lower than the threshold limit of 1mSv/yr set by the International Commission on Radiation Protection (ICRP) for the general public. The results obtained thus indicate that the mining activities do not pose any significant radiation hazard so far. However, caution must be exercised in case of prolonged exposure in the mine environment to avoid other unnecessary health hazards.

Keywords: Radioactivity; gemstone; health Impacts; Nigeria.

1. INTRODUCTION

Many materials found in the earth's crust contain small but measurable amounts of naturally occurring radioactive materials (NORM) which are sources of man's exposure to ionizing radiation. This contribution could be higher in areas where there has been enhancement due to industrial activities such as mining of ores which contain this at levels much higher than those present in the crust. Among the operations which may lead to significant increase in exposure to natural radiation sources are mining of ore, extraction of rare earth elements (REEs), production of Nb etc. This has the potential to increase the radiation dose received by workers and the general public. Pegmatites, which are coarse grained igneous or metamorphic rocks and generally of granitic composition, are characterized by a wide range of accessory minerals containing REEs. They are a common feature throughout the Nigerian Basement Complex. Pegmatites may be simple or complex; the complex ones in particular often have associated with them economic elements such as Tin, Tantalite, Columbite etc. The Sn-Nb-Ta bearing pegmatites, first described by Jacobson and Webb [1] and further elaborated by Wright [2] were known mainly from a broad ENE-WSW trending belt about 600km x 125km and are significantly mineralized [3]. The belt was an important tin producer for many years and Nigeria's tin fields were among the important ones globally.

In recent times, there has been a resurgence of interest in Nigeria's pegmatite occurrences because of their associated metal and gemstone mineralization. Apart from the known Nigerian pegmatite belt, the metallogeny of the rare metal pegmatites has been further elaborated [4].This has led to increased activities by artisanal miners and discovery of new rare metal pegmatite fields beyond the known belt [4,5]. They are now more widely distributed than previously known and are found to be important sources of precious and semi-precious stones such as beryl, aquamarine, tourmaline etc. These new Solid Minerals have played a significant role in the economic and social development of the country.

The Gbayo mines around Olode which is the focus of this work belongs to one of these fields: The Ibadan–Oshogbo field of rare metal pegmatites. As a result of the presence of these NORMS in mineral products and wastes, workers particularly miners engaged in such operation face the risk of such exposure, the knowledge of which is important for assessing the dose received or making reliable estimates of doses to workers.

The investigated mines are located at Olode, Ibadan South Western Nigeria. The pegmatites which serve as the main hosts for these minerals intrude older lithologic units (schists) of the Basement Complex [4]. The pegmatite mineralogy is simple and comprises quartz,

microcline and albite feldspar, muscovite and biotite. At Olode, the pegmatite is mined for beryl which is found embedded in the hard rock. Mining is by crude open cut, sometimes mechanically assisted, method. Hand drilling is usually employed followed by blasting. The blasted rock is hand-cobbed to recover the valuable minerals and the waste rock is discarded. Exploitation has been going on for some years and wherever the water table is reached, diesel pumps are employed to evacuate the water.

In the course of the exploitation, enormous quantities of mine wastes have been generated leaving behind heaps / mounds of mine residues and a highly devastated landscape. Except for the area around the Jos Tin-Columbite fields and mills in North Central Nigeria which has been investigated for NORM risks and associated radiological risks [6,7], there is little or no published NORM-related work on the implications of the exploitation of the rare metal pegmatites in the southwestern part of the country.

In this work, we report the results of investigation on the natural radioactivity due to NORM and the potential radiological implications/occupational radiation risks of the mining operations on the mine workers and the surrounding environment. Solid minerals have played a significant role in the economic and social development of the country. Nigeria has a long but discontinuous history of mining and the country is a prominent exporter of about 34 mineral commodities including tantalite and columbite among others. The country has initiated deep and wide ranging reforms to promote the development of the mining sector leading to more discoveries and massive widespread mining activities with attendant negative effects not only on the workers and general public, but also on the environment over the years. Not only that, the area is within Ibadan metropolis, one of the largest and most populated cities in tropical Africa attracting more people in search of means of livelihood from mining.

2. MATERIALS AND METHODS

2.1 Sampling and Sample Preparation

The study area is situated in Gbayo, west of Olode village in south eastern part of Ibadan in the Oluyole Local Government area of the city. Olode village lies between latitudes N7°10′ and N7º13′ and longitudes E3°55′ and E3°58′. Accessibility to the area is by untarred roads and foot paths which start from the village entrance into the forest in which the mine is situated. It is located in the humid tropical region, which experiences two main seasons annually namely rainy and dry seasons, with a temperature ranging between 20º and 32ºC. Olode village lies in the tropical rain forest which is characterized by tall evergreen trees of about 8-10 meters in height, some thick shrubs as well as cash crops are present. Shrubs are the most dominant vegetation cover present at the mine sites and they are present at the fringe of the mines. Most of them have been destroyed as a result of the ongoing mining activities. The relief of Oyo State is in two categories, hills occurring as dome shaped inselbergs and the undulating low land terrain. The Olode area belongs to the latter type of terrain. The main river in the area is river Omi which with the other rivers form a dendritic drainage pattern around the area.

A total of 32 samples were collected from three contiguous mine sites. They include pegmatite ore, the host rock, tailings, overburden, mine/ fissure water and a control soil sample as detailed in Table 1. Solid samples were oven-dried at 105°C for the removal of moisture followed by crushing, sieving through a 2mm sieve so as to obtain a dry weight of

about 250g and above for each, whereas 1 liter of water that was acidified at the rate of 10ml/l of HCl (11M) to prevent adsorption of radionuclides unto the wall of the container. Each sample was put into a cylindrical plastic container named Marinelli beaker that was previously washed and rinsed with dilute H_2SO_4 and sealed firmly for at least 28 days prior to analysis for the attainment of secular equilibrium [8].

2.2 Instrumentation

The gamma ray spectrometry analysis system located at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Nigeria was carried out using a Canberra vertical HPGe detector having a length of 10cm and diameter 10cm with a relative efficiency of 20.2%, enclosed in a lead shield of 10 cm thickness with complete electronic instrumentation connected to a PC-based MCA card for gamma spectrum evaluation. The Full Width at Half Maximum (FWHM) at 1,332.50keV of ^{60}Co and 122.10keV of ^{57}Co were respectively 1.76keV and 0.826keV, hence the resolution which was in the order of 10^{-3} made it possible to identify a large number of γ-rays in the samples. Both the energy and efficiency calibration were done using a well mixed soil standard [9]. The ratio energy to channel ($E\gamma$/Ch) was about 0.50 in average. Each sample was counted for a period of 25,200 seconds (7hours) and the gamma spectra analysis was carefully studied using a Canberra software Genie 2000 which matched each photopeak to a particular radionuclide. The activity concentration of ^{226}Ra(^{238}U series) and ^{228}Ra(^{232}Th series) were obtained indirectly from the γ-rays emitted by their respective progenies namely ^{214}Bi (609.31 keV and 1120.30 keV) for ^{238}U, ^{212}Pb (238.63 keV) and ^{228}Ac(583.19 keV) for ^{232}Th while that of the non-series ^{40}K was directly from its photopeak at 1460.75 keV.

3. RESULTS AND DISCUSSION

3.1 Radioactivity Contents

The activity concentrations in various samples analyzed are presented in Table 1 and Fig. 1. The results show that the radionuclides observed belong to the decay series of naturally occurring radionuclides of ^{238}U and ^{232}Th as well as the non-series ^{40}K, which accounts for the largest contribution of the radionuclide present. ^{226}Ra is the precursor of all the gamma-emitting radionuclides identified in the ^{238}U series, while ^{232}Th could be considered as the source of the radionuclides from the thorium series. In both soil and rock, the activity concentrations for ^{238}U and ^{232}Th and ^{40}K vary from 3.00±2.05 to 13.11±5.81Bq/kg; 6.09±1.12 to 11.95±1.97Bq/kg and 86.42±6.67 to 2200.71±92.04Bq/kg respectively. The high abundance of ^{40}K in the gemstone-bearing rock is mainly due to the geochemical characteristics of rare metal pegmatites, as also observed in the findings of Okedeji et al. [10]. They noted that the activity of ^{40}K in rock samples is dictated by minerals such as K-feldspar, mica and other clay minerals present in them. This high abundance of ^{40}K found in the gemstone bearing rocks especially that from Pit 1 can also be attributed to the presence of K-feldspar which has been described as micro perthite and also mica probably (muscovite) in rare metal [4]. The activity of ^{40}K is quite similar in all the three mines, but the striking difference is that the activity of ^{40}K in the gemstone-bearing rock from Pit 1 is about 10 times higher than that from Pit 3. This difference in activity concentrations of ^{40}K can be attributed to local geological variations in the pegmatites of the study area. In water, the activity level from the three mines is quite low ranging in value from 0.0436±0.0038 to 0.0526±0.0052Bq/L as observed by (Tchokossa et al. [11]).

Table 1. Sample description, location and activity concentration in various samples analyzed

Sample Code	Sample Description	Latitude (N)	Longitude (E)	Activity concentration		
				^{40}K	^{226}Ra (^{238}U)	^{228}Ra (^{232}Th)
Soil (Bq/kg)						
S11	slurry (soil) sample from active mining in Main Mine 1	N7°11.436′	E3°55.642′	230.68±12.85	8.23±4.07	8.22±1.41
S21	Dark colored soil from the overburden from Main Mine 1	N7°11.430′	E3°55.656′	195.20±10.61	7.71±3.87	6.13±1.57
S12	Sample of the Overburden from Mine 2	N7°11.475′	E3°55.684′	158.47±9.40	7.64 ±3.84	9.43±1.48
S22	Reddish-brown sample of the Overburden from Mine 2	N7°11.473′	E3°55.676′	140.98±9.05	13.11 ± 5.81	6.09 ±1.12
S32	Sample of the Overburden from Mine 2	N7°11.453′	E3°55.697′	206.31±10.82	3.10±1.85	6.14±1.05
S42	Sample of the overburden from Mine 2	N7°11.456′	E3°55.687′	214.21±11.92	4.24±2.79	6.30 ±1.83
S13	Slurry (soil) sample from recently exploited area in Mine 3	N7°11.453′	E3°55.705′	102.4 ± 7.12	5.74± 2.80	6.72±1.09
S23	Slurry (soil) sample from recently exploited area in mine 3	N7°11.452′	E3°55.702′	86.42±6.67	4.85±2.41	7.47±1.19
S33	Slurry (soil) sample from active mining activity in Mine 3	N7°11.433′	E3°55.705′	195.22±10.78	6.43±3.13	7.48±1.21
S_c (Control)	Dark colored top soil	N7º11.840′	E3°56.059′	211.61±12.81	3.00±2.05	11.95±1.97
Rock (Bq/kg)						
PM11	Gemstone bearing rock from Main Mine 1	N7°11.434′	E3°55.635′	2200.7±92.04	ND	6.43 ±1.24
PM21	Biotite Schist sample from Main Mine 1(Tailing)	N7°11.427′	E3°55.649′	486.95±14.05	9.71±4.25	10.93±1.73
PM13	Gemstone bearing rock sample from Mine 3	N7°11.422′	E3°55.701′	227.2±13.58	9.38±4.67	11.01±1.24
Water(Bq/L)						
W11	Water issuing out from the biotite schist-pegmatite rock interface (fissure water)	N7°11.432′	E3°55.639′	0.0436±0.0038	0.0322±0.0018	0.0667±0.012
W12	Water sample from a pit in Mine 2	N7°11.470′	E3°55.672′	0.0460±0.0039	0.0341±0.0019	0.0959±0.015
W13	Water sample from a pit in Mine 3	N7°11.428′	E3°55.709′	0.0526±0.0052	0.0373±0.0021	0.0820±0.013

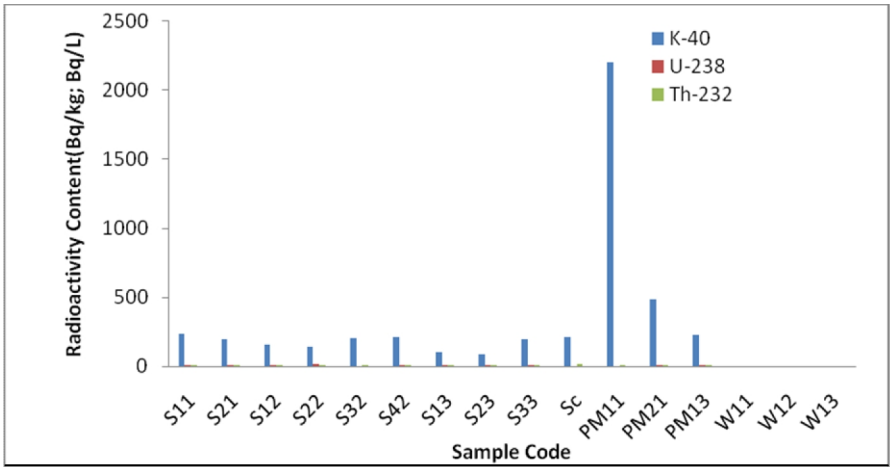

Fig. 1. Bar chart showing the activity concentration in the samples

The value recorded for ^{40}K in the rare metal pegmatite (from the Gbayo mines) of the Ibadan Oshogbo field, falls slightly below the range observed for some countries with high ^{40}K activity such as Pakistan, India, Norway and Brazil. ^{238}U makes the least contribution to the total activity in the area, contributing 1.86% of the total activity concentration. The results also show that the activity concentrations of ^{232}Th in the slurry (soil) samples are slightly higher than those of ^{238}U, but the values are generally low. It has been observed that the ^{232}Th content of the water samples are slightly higher than their ^{238}U content. Both gemstone bearing rocks from Mine 1 and Mine 3 also have a low ^{238}U: ^{232}Th ratio. ^{232}Th makes the second highest contribution to the total activity in the area and constitutes about 2.25% of the total activity in the area. The gemstone bearing rock from Mine 3 has the highest ^{232}Th activity value of 11.01±2.56Bq/kg when compared with other samples. The control sample has a slightly higher value of ^{232}Th than others with an activity concentration of 11.95 ± 2.79 Bq/kg. This may be due to the presence of a thorium bearing mineral in the control area. The fact that the activity concentrations of ^{232}Th is higher in the gemstone bearing rocks than in the slurry (soils) from the mine points may be attributed to contamination of the soil from where the control sample was obtained. In fact, ^{238}U is more soluble than ^{232}Th and its mobility is much higher than that of ^{232}Th even if they occur at the same concentration in the "source rock" which probably is the pegmatite [12,13]. This consistency in mobility is also reflected in the activity concentrations of ^{232}Th and ^{238}U derived from both the soil and rock samples. The higher abundance of ^{232}Th than ^{238}U in all the water samples further lends credence to the fact that Uranium is more mobile than Thorium; hence due to this difference in mobility, Thorium is readily more retained in water than Uranium. The activity concentrations of both ^{238}U and ^{232}Th measured in all the samples are generally lower than the 35Bq/kg and 30Bq/kg average values reported by UNSCEAR [14]. Due to the relatively high concentration of radionuclides in most minerals, the National Radiation Protection Department (NRPD) as the competent authority has established national limits of 900Bq/kg for ^{232}Th, 1800Bq/kg for ^{226}Ra and 11000Bq/kg for ^{40}K; but the overall general limits for all nuclide elements is 25Bq/kg as the maximum permissible activity concentrations. Following the NRPD maximum permissible limits, it can be seen that the concentration of ^{232}Th is the lowest followed by ^{226}Ra.

Judging by the activity concentrations of these samples, ^{40}K which is probably from the feldspars and mica can be said to be the major source of radiation in the Gbayo mines,

followed by thorium and then the least contributor of radiation is ^{226}Ra from ^{238}U. The mean activity concentration values of each radionuclide in the samples from the Gbayo mines (Table 1) are compared with the mean value of these radionuclides obtained from the processed mine tailings site located in the Jos tin fields of Plateau State, Nigeria as shown in Table 2 where it can be observed that the concentration of ^{232}Th ranges between 5055.5-27930Bq/kq with an average value of 16494.55Bq/kg while that of ^{238}U ranges between 364.9-1302.8Bq/kg with an average value of 785.5Bq/kg. These values are much higher than the values obtained for the Gbayo mines at Ibadan and the 25Bq/kg which is regarded as the maximum permissible activity concentration limit for all nuclide elements.

Table 2. Concentrations of ^{40}K, ^{226}Ra and ^{232}Th in tailing samples from the Jos processing site area [16]

Samples	Type of sample	Activity in Bq/kg		
		^{40}K	^{226}Ra	^{232}Th
A1	Tailings	6095.1	ND	16470.4
A2	Tailings	5061.4	ND	15437.8
A3	Tailings	5809.8	1004.8	17523.6
B1	Tailings	4772.5	661.4	14793.4
B2	Tailings	4299.4	1302.8	14954.4
B3	Tailings	6037.0	681.1	16040.9
C1	Tailings	6986.1	ND	20509.0
C2	Tailings	4821.9	ND	14097.5
C3	Tailings	5244.2	674.2	14898.3
D1	Tailings	6415.7	609.8	5055.5
D2	Tailings	5226.5	ND	20222.7
D3	Tailings	5535.1	364.7	27930.0

ND = Not detected

Tailings characteristics can vary greatly and depend on the ore mineralogy together with the physical and chemical processes used to extract the economic product, even of the same type. Typically, the tailings from mining activities in the Jos area consist of heavy accessory minerals that include Zircon, Monazite, Xenotime, Ilmenite. Magnetite, some columbite and cassiterite [15]. These tailings that contain radioactive elements remain active for a very long period of time and will continue to be potentially dangerous. Over the last century, the volumes of tailings being generated has grown drastically as the demand for minerals and metals has increased and lower grades of ore are being mined.

Monazite and zircon are found to be more hazardous than the rest of the minerals that are frequently associated with cassiterite (garnet, pyrite, rutile, etc) [7]. As such, all these minerals are radioactive and constitute a major source of external radiation hazard to workers who handle them in the mines and mills as well as the general public living around the area.

From the ongoing discussion, it can be observed that minerals such as Monazite, Zircon, Ilmenite and Xenotime are the principal sources of radioactivity in the Jos mining district and these minerals contain appreciable quantities of Uranium and Thorium. These minerals were not found in the mineralized pegmatites of the Gbayo mines, hence this could be the reason why low values of activity of ^{238}U and ^{232}Th were obtained at the mine site. From the values of the activities of these samples, the radioactivity level at the mine at Gbayo is not as hazardous as that of the mine at Jos. Hence, it can be concluded that it is safe for the miners to handle the mineral/gemstone bearing rocks. Also, in the long term, prolonged exposure of the miners could possibly pose health hazards.

3.2 Radiological Hazards

The absorbed dose itself does not give a direct indication of the possible biological effects caused by radiation, hence the degree of biological risk caused by different types of radiation can be calculated by multiplying the absorbed dose rate by a weighting factor which are 1 and 20 for gamma and alpha radiation respectively [17]. The resultant quantity is the equivalent dose rate measured in sieverts per year (Sv/yr).

The absorbed dose rates were obtained by the following expression [18]:

$$D = 0.042\ Ac\ (K) + 0.428\ Ac\ (U) + 0.666\ Ac\ (Th) \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where D = Absorbed dose rate in (nGy/hr – nanogray per hour)

Ac (K), Ac (U) and Ac (Th) are activity concentrations of Potassium, Uranium and Thorium (Bq/kg) respectively.

From Table 3, the absorbed dose rate values range from 10.58 to 96.71nGy/yr. The calculated mean absorbed dose rate for the thirteen solid samples was found to be 23. 12nGy/yr, which represents about 38% the international limit of 60nGy/yr [14].

Effective doses resulting from intake of ^{40}K, ^{238}U and ^{232}Th may be determined directly from all water types since some of them are ingested indirectly by man. Assuming the volume of drinking water from adult males to be 1L/d [19], the annual effective dose was calculated using the intake of individual radionuclide and coefficient ingestion doses (Sv/Bq) reported by the International Commission on Radiological Protection [17]. The equation for calculating the annual effective dose per person is given by:

$$\text{The Annual Effective Dose (AED)} = 365\sum_{i} I_i D_i$$

Where I_i is the daily intake of radionuclide i (Bq/d)

D_i is the ingestion dose coefficient (Sv/Bq).

The results obtained are presented in Table 4. The derived AED received by the population as a result of the ingestion of ^{238}U in water is estimated to have a range of 3.27–3.78μSv/yr with an average of 3.51μSv/yr, while that of ^{232}Th varies between 16.87 and 24.18μSv/yr with an average of 20.57±4.92μSv/yr and lastly for ^{40}K it varies between 0.01 and –0.12μSv/yr with an average of 0.08±0.02μSv/yr. The ^{40}K contribution to the AED was very low when compared with that of ^{238}U and ^{232}Th. According to ICRP recommendations [17], the limit for public exposure should be expressed as an effective dose of 1mSv/yr. The doses estimated from our investigation are below the limit for water samples from all the pits. Although, the water sample with the dose close to that limit is not used for any direct domestic purpose, it can get into the soil and find its way into foods through plant roots. It is therefore vital to manage it through proper disposal.

The dose equivalent rate ranges from 0.07 to 0.60mSv/yr in the soils and rocks. The highest value of 0.60mSv/yr came from the gemstone-bearing pegmatite rock (PM1) from Mine 1, while the least of 0.07mSv/yr resulted from slurry soil from Mine 3. All the values were below the threshold value limit of 1mSv/yr set for the general public [17]. Nevertheless regular monitoring is necessary to avoid cumulative effects on the general public.

Table 3. Absorbed dose rates and corresponding dose equivalents

Sample	Sample type	Absorbed dose rate (D) in (nGy/hr)	Dose equivalent rate (mSv/yr)
S11	Slurry (soil) sample from active mining in Main Mine 1	18.68	0.1
S21	Dark coloured soil from the overburden from Main Mine 1	15.58	0.09
PM11	Gemstone-bearing rock from Main Mine 1	96.71	0.60
PM21	Biotite Schist sample from Main Mine 1(Tailing)	31.89	0.20
S12	Sample of the Overburden from Mine 2	16.21	0.10
S22	Reddish-brown sample of the Overburden from Mine 2	15.59	0.09
S32	Sample of the Overburden from Mine 2	14.08	0.08
S42	Sample of the overburden from Mine 2	15.01	0.09
S13	Slurry (soil) sample from recently exploited area in Mine 3	11.23	0.07
S23	Slurry (soil) sample from recently exploited area in Mine 3	10.58	0.07
PM13	Gemstone-bearing rock sample from Mine 3	20.89	0.10
S33	Slurry (soil) sample from active mining activity in Mine 3	15.93	0.09
Sc	(Background) Dark coloured sample containing top soil	18.13	0.10

Table 4. Estimated Annual Effective Doses from water in the three pits

Water	Origin	Intake per person (Bq d^{-1})			Annual Effective Dose (μSv/yr)		
					Ingestion dose coefficient (Sv Bq^{-1}) [17]		
					6.2 x10^{-9} Sv Bq^{-1} for K-40	2.8 x 10^{-7} Sv Bq^{-1} for U-238	6.9 x10^{-7} Sv Bq^{-1} for Th-232
		K-40	U-238	Th-232	K-40	U-238	Th-232
W11	Water issuing out from the biotite schist-pegmatite rock interface (fissure water)	0.044±0.004	0.032±0.002	0.06 ±0.001	0.01± 0.00	3.2±0.23	16.87±3.12
W12	Water sample from a pit in Mine 2	0.046±0.004	0.034±0.002	0.096±0.002	0.10± 0.01	3.47± 0.82	24.18±6.21
W13	Water sample from a pit in Mine 3	0.052±0.005	0.037±0.002	0.082±0.001	0.12± 0.03	3.78±1.01	20.65±5.43
Mean		0.047± 0.041	0.034± 0.002	0.082±0.001	0.08± 0.02	3.51± 0.69	20.57±4.92

4. CONCLUSION

A well calibrated high purity Germanium detector(HPGe) has been used to determine the activity contents as well as the derived absorbed dose and the dose equivalent rates in the rocks (gemstone-bearing pegmatites), slurry soils (Mine wastes) and water samples of the Gbayo mine site in Olode, Ibadan south western Nigeria. The radionuclides identified with regularity belong to the naturally occurring decay series headed by ^{238}U and ^{232}Th as well as the non series ^{40}K.

The results obtained were very low while comparing these with similar work from the Jos processing site which was several magnitude greater. This is due to the presence of radioactive minerals such as Monazite and Xenotime present in the Younger Granites where metals such as Tin and Columbite are extracted. This study has also shown that the principal source of radioactivity in the area is actually the pegmatites and not the Biotite Gneiss.

Although the results are well below the international threshold limits, prolonged exposure could lead to some severe health hazards not only to the workers, but also to the general public either directly or indirectly. Also, physical disturbance and instability of the land surface will promote erosional activities and flooding of the area, thereby rendering land employed for agricultural activities unsuitable for such purpose. Hence, there is a need for land reclamation in the area. It is also vital that similar works be carried out on other mines within the Ibadan-Oshogbo rare metal pegmatite field and the country as a whole.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

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