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Radioactivity concentration variation with depth and assessment of workers' doses in selected mining sites

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ABSTRACT

Mining workers are exposed to radiation in the process of extracting minerals from the earth crust. In this research, activity concentration of the radionuclides in samples collected at different depths in Komu (0–220 ft) and Olode (0–30 ft) mining sites, Oyo State, Nigeria and the associated workers' radiological risks were assessed. Gemstones from these sites are mined for local and international markets. The radionuclide contents of the samples were determined using Gamma spectroscopy technique. At Komu, ^{238}U and ^{232}Th concentrations, with few exceptions, increased with depth while that of ^{40}K had no defined pattern. At Olode site, ^{238}U and ^{232}Th concentrations decreased with depth while that of ^{40}K was almost constant. Internal hazard indices at Komu in some cases indicated an unacceptable level of risk to workers. Workers' doses would have been underestimated by between 12 and 55% if the activity concentrations of samples in the pit were not included in the calculation.

1. Introduction

Naturally occurring radionuclides are the major sources of ionizing radiations in the environment. Human exposure to these ionizing radiations, if the level is enhanced beyond background, could lead to detrimental health effects. Enhancement of radiation level in the environment is usually due to human activities (Tubosun et al., 2013) such as mining and milling of mineral ores, nuclear fabrications, and handling of the fuel cycle tail end products (Saleh, 2011). Enhanced level of natural radioactivity through these activities may cause radiation doses to workers and/or the public in order of several mSv/yr (Jibiri & Temaugee, 2013; Stoulos, Manolopoulou, & Papastefanou, 2003). Part of the safety analysis recommended by the IAEA includes estimation of radiation doses likely to be received by workers during operation and estimation of doses and risks to the public (IAEA, 2002). Hence there is need for the assessment of radiation doses of workers in human activities that may enhance radiation levels to ensure that they do not exceed regulatory limits.

Presently there are scanty information from Africa on activity concentrations of soils and individual doses from

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mining activities which is the most prominent activity that could cause elevated radiation level in most developing countries where illegal mining is prominent. Previous reports on radioactivity measurements in mining locations around the world include the assessment of the radionuclide contents in minerals and soil samples from mining sites in America (USEPA, 2008), Australia (Cooper, 2005; Long, Sdraulig, Tate, & Martin, 2012; Senior & Chadderton, 2007) and Nigeria (Ibrahim, Akpa, & Daniel, 2013; Jibiri & Temaugee, 2013; Tubosun et al., 2013, 2014). Except for Senior and Chadderton (2007), none of these studies investigated the variation of activity concentration with depth, a knowledge which is important for a realistic assessment of the radiological risks to the miners. Furthermore, assessments of workers' doses in the studies were without reference to the fraction of time spent in the pits (Ibrahim et al., 2013; Tubosun et al., 2014). The calculations were done using only activity concentrations of samples collected on surface of mining locations. A more realistic dose calculation should however take into consideration the variation of activity with depth.

In this study, the radionuclide contents of samples collected at different variation of depths from two major mining sites located in Oyo State of Nigeria will be assessed. Tourmaline and Pegmatite, known to house radioactive minerals (Petta, Campos, Sindem, Nascimento, & Meyer, 2009) are mined in these sites. The occupational doses of the workers in the mining site will also be assessed taking into consideration the separate time spent by the workers in the pit and on the surface.

2. Materials and methods

2.1. Sample collection and preparations

Samples (soil + minerals) analyzed were collected at the surfaces and mining pits of different depths at Komu (0–220 ft) and Olode (0–30 ft) Mining Sites. Tourmaline, mica and pegmatite are the minerals of interest at Komu while it is aquamarine and pegmatite at Olode. The samples were sun dried and carefully placed in an oven for drying at a temperature of 150 °C to achieve a constant weight, then pulverized and sieved with a 2 mm aperture mesh sieve. About 650 g of each sample packed into a tightly closed Marinelli beaker and sealed with a PVC tape was stored for at least one month to ensure secular equilibrium between the parent radionuclides and their respective daughters.

2.2. Gamma analysis

The samples' radionuclide contents were analyzed by Gamma-ray spectrometric measurements using ORTEC high purity germanium detector (relative efficiency of 20%, energy resolution of 1.85 keV at 1332.5 keV) coupled to ORTEC Multi-Channel Analyzer (MCA). Maestro evaluation software was used for spectrum acquisition and processing. The energy calibration was made using different point sources in the energy range 59.54 keV–2505.74 keV while the efficiency calibration of the detector was made using a 650 g mixed CANBERRA soil standard containing ^{125}Sb, ^{155}Eu, ^{54}Mn, ^{65}Zn and ^{40}K. The absolute efficiency curve was fitted to a standard efficiency function of the form proposed by Gray and Ahmad (1985)

$$\varepsilon = \frac{1}{E}\left[\sum_{n=1}^{7} P_n [In\ E]^{n-1}\right] \tag{1}$$

where P_n are the parameters of the fitting function and ε is the efficiency at energy E.

2.3. Activity concentration

The specific activity concentration of each radionuclide in the samples was determined using Eq. (2)

$$A_i = \frac{NC_i}{\varepsilon \times y_i \times M \times T} \tag{2}$$

where A_i is the ith radionuclide concentration, NC_i = net count of the ith radionuclide, ε = detector efficiency at the energy of the ith radionuclide; y_i = the emission probability of the ith radionuclide, M = Mass of the soil sample in kg, T = counting time (10 h). The gamma lines of ^{228}Ac, ^{212}Bi, ^{212}Pb and ^{208}Tl were used to determine ^{232}Th while ^{214}Bi and ^{214}Pb were used for ^{238}U and 1460.8 keV for ^{40}K.

2.4. Dose rate

The absorbed dose rate in air at 1 m above the ground surface was estimated based on the provision by UNSCEAR (2000) as follows:

$$DR(nGy/h) = 0.462A_U + 0.604A_{Th} + 0.0417A_K \tag{3}$$

where DR is the absorbed dose rate in nGy/h and A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

The annual effective dose, E (in μSv yr^{-1}), to personnel from external exposure was calculated using the Eq. (4)

$$E_i = DR_i \times OF \times CF \tag{4}$$

where E_i is the annual effective dose due to ith radionuclide. CF is the conversion factor for absorbed dose in air to external effective dose in adults and is given as 0.7 Sv Gy^{-1} (UNSCEAR, 2008). DR_i is the absorbed dose rate at 1 m above the ground due to the ith radionuclide. OF is the occupancy factor.

When the workers are assigned to work in the pits, they usually spend about 3 h in the pit and 5 h on the surface. Hence, their effective dose E can be calculated as follows:

$$E_i = [DR_{i,depth} \times OF_{pit} \times CF] + [DR_{i,surface} \times OF_{surface} \times CF] \tag{5}$$

where $OF_{pit} = 3\text{hr}\ day^{-1} \times 5\text{days}\ week^{-1} \times 52\text{weeks}\ yr^{-1}$

$OF_{surface} = 5\text{hr}\ day^{-1} \times 5\text{days}\ week^{-1} \times 52\text{weeks}\ yr^{-1}$

2.5. Radiation hazard indices

In addition to the gemstone that is being mined at Komu and Olode site, there are evidences that sand and stones from the sites are also being used for building construction. In order to assess the radiological suitability of the sand and stones for use as building construction, the radium equivalent index,