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Radioactivity in Surface Soils around the Proposed Sites for Titanium Mining Project in Kenya

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ABSTRACT

Radioactivity measurements were carried out around Maumba and Nguluku villages, two of the proposed sites for titanium mining in the coastal area of Kenya. Samples of surface soils were analyzed using a HPGe gamma spectrometer. The average activity concentrations for ^{226}Ra, ^{232}Th *and* ^{40}K *are* 20.9 ± 7.6, 27.6 ± 9.1 *and* 69.5 ± 16.5 $Bqkg^{-1}$, *respectively. The absorbed dose rates in air, calculated on the basis of the measured activity concentrations, range from* 9.8 *to* 50.0 $nGyh^{-1}$, *with an average of* 29.2 $nGyh^{-1}$. *These values are below the global population-weighted mean, and they should be considered when planning appropriate monitoring and surveillance programmes during the mining operation, as well as the reclamation and restoration programmes after mining.*

Keywords: *Radioactivity Measurements*, *Titanium Mining*, *Absorbed Dose Rates*, *Natural Background Radiation*

1. Introduction

The ambient natural background radiation is usually of little or no radiological concern, and it varies from one location to another depending partly on the local geology. Mining and other industrial activities such as oil and gas exploration, extraction and purification of water, etc. can enhance the natural background radiation to levels that are not insignificant from radiation protection point of view [1,2]. Mining results in large volumes of materials containing natural radionuclides – the so called naturally occurring radioactive materials (NORM). This is not restricted to uranium and thorium ores, it is also true for other raw materials like heavy mineral sands, phosphate rocks, etc.

Tiomin Resources Inc., the Canadian mining company, discovered vast deposits of titanium in the coastal area Kenya [3]. Earlier appraisal of the areas' mineral potential [4] shows that most of the south coastal area of Kenya is underlain by the Duruma group consisting of the coarse-grained Taru and the fine-grained Maji-ya-Chumvi formations. Two of the deposits in Kwale district; the Central Dune at Maumba and South Dune at Nguluku constitute the Kwale titanium mining project, with a mineral reserve of 140.8 million tones (**Figure 1**). The average ore body composition is 3.48% heavy minerals, and the expected annual yield is 77,000 tonnes of rutile, 38,000 tonnes of zircon and 330,000 tonnes of ilmenite [3]. According to the mining company, the proposed operations will involve clearing the vegetation, removing and stockpiling the topsoil for further use in rehabilitation process, excavation of the dunes using bucket wheel excavators or scrapers and, transportation of the ore-bearing sand to the wet plant where the heavy minerals will be separated from sand. The final products will be transported from the mine sites to a ship-loading facility that will be constructed at Likoni, in Mombasa. It is estimated that mining activities in each of the two sites will take seven years.

The main source of surface water in the area is the Mukurumudzi river, a perennial river that flows from northwest to southeast and drains into the Indian ocean near Gazi Bay. Human population in these areas is estimated to be about 3,000 [5]. The project was put on hold because local residents and other stakeholders raised serious social, economic, environmental and radiological questions, which are still being addressed. Enhancement

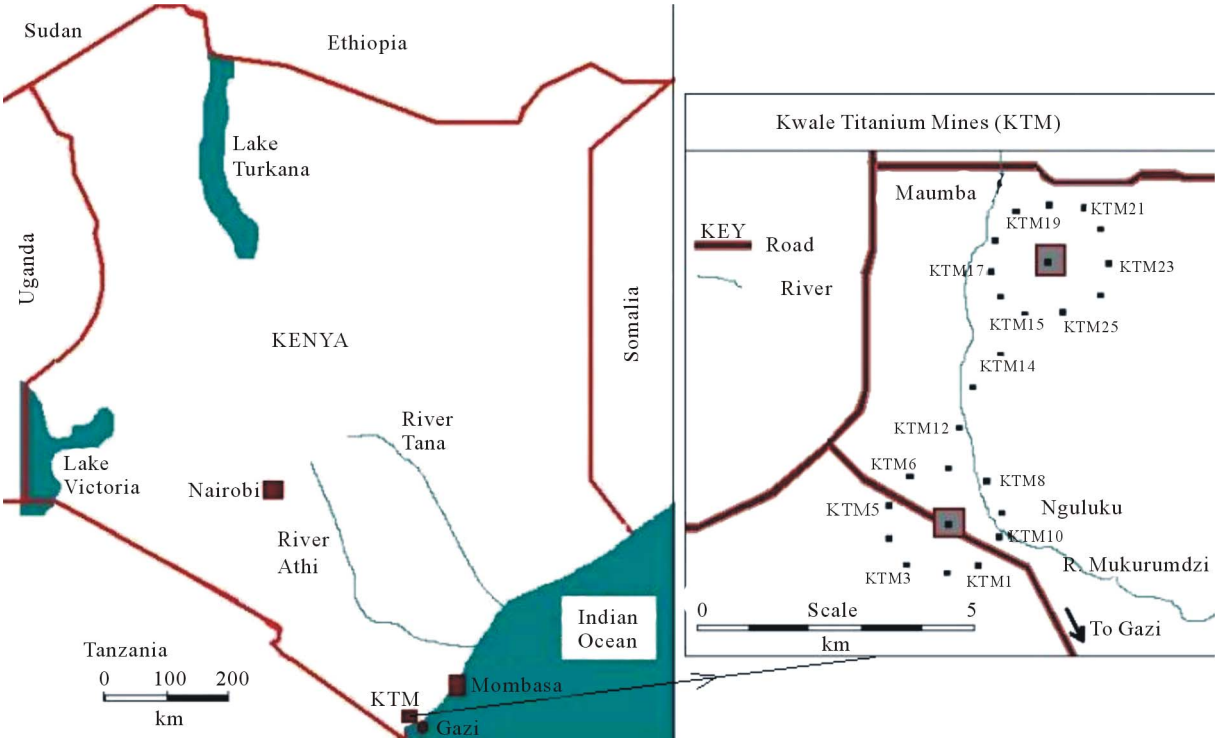

Figure 1. Location of Kwale Titanium Mines (KTM) and the sampling sites.

of the natural background radiation can arise from contamination of groundwater by liquid effluents and leaching radionuclides, contamination of land and agricultural produce by atmospheric releases, re-use of tailings, etc. The principal exposure pathways will be inhalation of airborne radionuclides, ingestions of radionuclides with food, water, etc., and external exposures to gamma radiation from tailings, surface deposition, and submersion in airborne radionuclides.

In order to assess the net radiological impact of the mining operations, it is necessary to establish baseline concentrations of the naturally occurring radionuclides in relevant environmental matrices prior to the commencement of the mining operation. Soil is the ultimate sink for various kinds of contaminants and it could be an important indicator of environmental pollution [6]. This is the report of an independent study carried out to establish the baseline concentrations of radionucides in the surface soil around the proposed mining sites.

2. Materials and Methods

2.1. Soil sampling and Preparations

Soil sampling was carried out in an area of about 20 km^2 and 10 km long surrounding the two mine sites (**Figure 1**). The area was divided into large grids around the two villages and along the adjoining path, but the sampling points within each grid were chosen randomly provided they are free from large stones or roots and relatively in the open. This is similar to the systemic/stratified random sampling technique described in the IAEA technical document [6]. The distance between neighbouring grid centers is about 500 m. At each sampling point, dirt and other extraneous (non-soil) materials were first removed to expose the soil. Soil was then collected with hand trowels down to 5 - 10 cm depth within a 30 × 30 cm^2 area. The soil was homogenized and three samples, each of about 1000 cm^3, were packed in clean polythene bags and labeled accordingly. Altogether 78 samples of sandy soil were collected from 26 sampling points. The sample preparation involve oven-drying at 110˚C, pulverizing to fine powder, and sealing aliquots in 450 ml bottles for a minimum of 4 weeks to establish secular equilibrium between ^{226}Ra and the short-lived decay products of ^{222}Rn before gamma-ray spectrometric analysis.

2.2. Gamma-Ray Spectrometric Analysis

The samples were analyzed using a high purity germanium (HPGe) detector of 30% efficiency relative to the standard 3" × 3" NaI(Tl) detector and energy resolution of 1.8 keV (FWHM) at the 1.33 MeV gamma line of ^{60}Co. Detailed description of the gamma-ray spectrometer setup as well as the detector calibration procedures using the IAEA reference materials (RGU-1, RGTh-1, and RGK-1) are presented in earlier reports [7-9].

3. Results and Discussions

3.1. Activity Concentrations of Radionuclides in Soil Samples

Figure 2 shows a typical gamma-ray spectrum of the soils. Concentrations of ^{226}Ra and ^{232}Th were derived from the gamma-lines of their respective decay products, namely: 238 keV of ^{212}Pb, 583 of ^{208}Tl, and 911 keV of ^{228}Ac for ^{232}Th; 295 keV and 352 keV of ^{214}Pb and 609 keV of ^{214}Bi for ^{226}Ra, while concentration of ^{40}K was derived from its 1460 keV gamma-line. There is no significant difference between the ranges of activity concentrations in the soils from Nguluku and those from Maumba (**Table 1**). A summary of the distributions of the concentrations is presented in **Figure 3**. They are lower than the global averages [10], and also lower than those reported by Mustapha et al [7] for soils in other parts of Kenya. Generally, soils derived from sedimentary rocks, such as in the areas where the present study was carried out, are expected to contain less radioactivity compared to those derived from igneous rocks. In particular, the surface soils from the mine sites appear depleted of ^{40}K - the highest concentration recorded (114 Bqkg^{-1}) is less than 30% of the global average (**Table 1**). These values are comparable to some of the lowest values so far reported, e.g. from Cyprus, Egypt, Iceland, etc. [10], and from Gazi [8] near the area being surveyed in the present study (**Figure 1**).

3.2. Absorbed Dose Rate in Air

Absorbed dose rate conversion factors: 0.047, 0.462, 0.604 nGyh^{-1} per Bq·kg^{-1} of ^{40}K, ^{226}Ra, and ^{232}Th, respectively [10], were used to convert the concentrations of radionuclides in the soils to absorbed dose rates, D(nGyh^{-1}), in air at 1m above the ground according to the relation:

$$D = 0.047A\left(^{40}\mathrm{K}\right) + 0.462A\left(^{226}\mathrm{Ra}\right) + 0.604A\left(^{232}\mathrm{Th}\right) \quad (1)$$

where A(^{40}K), A(^{226}Ra) and A(^{232}Th) are the specific activities (in Bq·kg^{-1}) of ^{40}K, ^{226}Ra, and ^{232}Th, respectively.

Table 2 shows the range and mean of the absorbed dose-rate in air around the miming sites. The mean value (29.2 nGyh^{-1}) is less than 50% of the global population-weighted average [10] and it is likely to be less than the country (Kenya) average, judging from results of similar surveys carried out in other parts of Kenya, e.g. Mustapha *et al.* [7]. According to the 2000 UNSCEAR report [10], the lowest cases of outdoor absorbed dose rates were reported in Cyprus (18 nGyh^{-1}), Iceland (28 nGyh^{-1}), Egypt (32 nGyh^{-1}), the Netherlands (32 nGyh^{-1}), Brunei (33 nGyh^{-1}) and UK (34 nGyh^{-1}). It therefore implies that prior to the commencement of mining operations in the proposed sites the external exposure rates due to the natural background radiation are among the world's lowest. It is therefore imperative that future assessment of radiological impact of the mining operations, as well as the effectiveness of the post-mining restoration programs should be based on the area-specific average as documented in this report, rather than on country or global averages. It is also recognized that distribution of radionuclides in surface soil alone will not provide complete assessment of the radiological impact of large-scale mining operations. The pre-operational survey should be extended to measurements of distribution of radionuclides in other relevant media, e.g. air, water, sediments and biota, etc. in the areas of interest. Finally, it is conceivable that mining operations and other NORM generating human activities will continue for the foreseeable future in different parts of Kenya. Therefore a well planned nationwide environmental radioactivity survey is desirable.

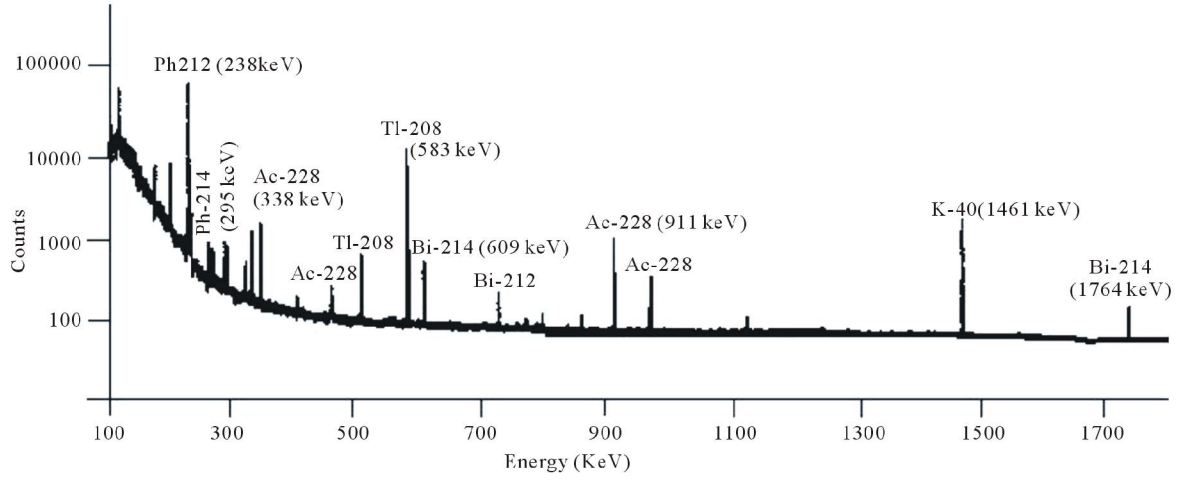

Figure 2. A typical gamma-ray spectrum of the soil samples.

Table 1. Comparison of mean activity concentrations of radionuclides in soils around the titanium mining sites to other areas.

Location	Activity concentration ($Bq \cdot kg^{-1}$)		
	^{40}K	^{226}Ra	^{232}Th
Nguluku	61.1 ± 13.0	21.2 ± 9.7	27.0 ± 11.8
Maumba	77.0 ± 15.0	20.6 ± 4.8	28.3 ± 5.8
Overall mean (and ranges)	69.5 ± 16.5 (31.9 - 114.1)	20.9 ± 7.6 (7.4 - 40.6)	27.6 ± 9.1 (8.4 - 43.6)
Kenya (different parts)[a]	255.7 ± 38.5	28.7 ± 3.6	73.3 ± 9.1
Gazi[b]	206.1 ± 26.7	11.9 ± 1.4	10.8 ± 1.0
Global average for soil[c]	420	33	45

[a][7], [b][8], [c][10]

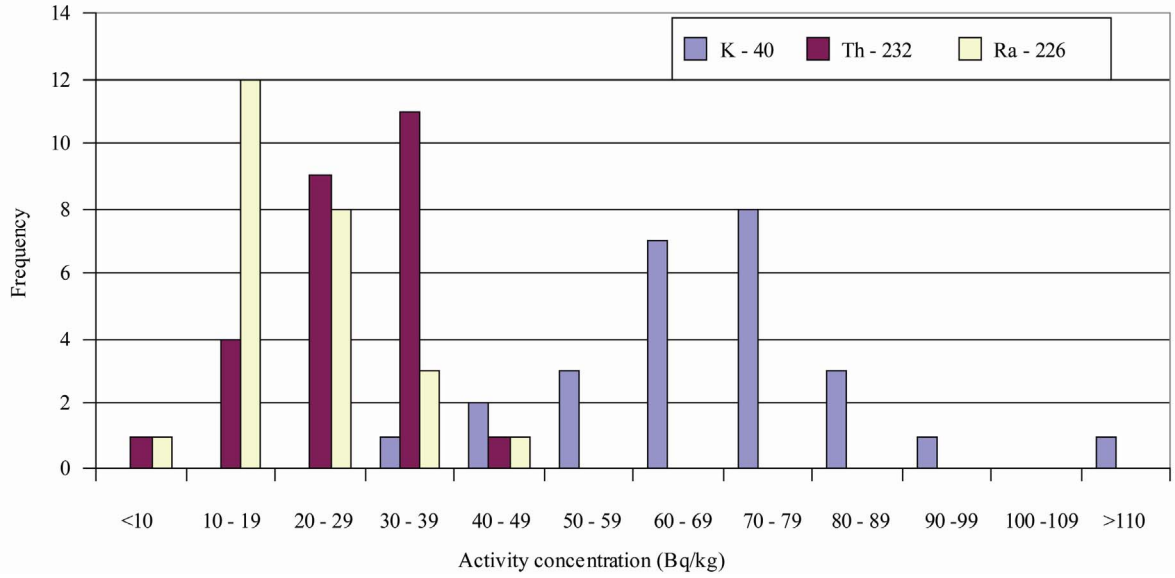

Figure 3. Distribution of activity concentrations of radionuclides in soil samples.

Table 2. Absorbed dose-rate in air estimated from activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in soil.

Location	Absorbed dose-rate in air ($nGyh^{-1}$)	
	Range	Mean
Proposed mining sites	9.8 - 50.0	29.2
Kenya (different parts)[a]	9.9 - 176.5	68.2
Global averages[b]	18 - 93	59

[a][7], [b][10].

4. Conclusions

Pre-operational environmental radioactivity measurements carried out around the proposed sites for Kwale titanium mining project in the coastal area of Kenya revealed that activity concentrations of naturally occurring radionuclides are low in the area's surface soils: means of 61.1, 21.2 and 27.0 (in $Bq \cdot kg^{-1}$) for ^{40}K, ^{226}Ra and ^{232}Th, respectively. The absorbed dose rates in air due to the observed radionucides concentrations in soils are also low, with a mean of 29.2 $nGyh^{-1}$. These values are the baseline on which the assessment of the impact of the mining operations should be based, instead of country or global averages. They will also be used in evaluating the effectiveness of the land restoration program.

5. Acknowledgements

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REFERENCES

[1] IAEA (International Atomic Energy Agency), "Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technological Options for Mitigation," Technical report series, No. 419, IAEA, Vienna, 2003.

[2] J. Van der Steen and A. W. Van Weers, "Radiation Protection," *NORM Industries* 11*th International Congress of the International Radiation Protection Association IRPA*11, Madrid, 23-28 May 2004.

[3] TRI (Tiomin Resources Inc.), Technical report on Kwale, 2004. Available at http://www.tiomin.com/s/NewsReleases.asp

[4] Austromineral, "Geological Survey of Mineral and Base Metal Prospecting in the Coastal Belt, South of Mombasa (Kwale District)," In A. Horkel Ed., *Kenya – Austria mineral exploration project: Report III*, Vienna, 1978.

[5] D, Ong'olo, "International Investment and Environmental Issues: The Case of Kenya's Kwale Mineral Sands Project," *Investment For Development (IFD) Project Launch meeting*, Jaipur, 13-14 December 2001.

[6] IAEA (International Atomic Energy Agency), "Soil sampling for environmental contaminants," IAEA-TECDOC-1415, IAEA, Vienna, 2004.

[7] A. O. Mustapha, J. P. Patel, and I. V. S. Rathore, "Assessment of Human Exposures to Natural Sources of Radiation in Kenya," *Radiation Protection Dosimetry*, Vol 82, No. 4, 1999, pp. 285-292.

[8] N. O. Hashim, I. V. S. Rathore, A. M. Kinyua and A. O. Mustapha, "Natural and Artificial Radioactivity Levels in Sediments Along the Kenyan Coast," *Radiation Physics and Chemistry*, Vol. 71, No. 3-4, 2004, pp. 805-806. doi:10.1016/j.radphyschem.2004.04.101

[9] A. O. Mustapha, P. Mbuzukongira and M. J. Mangala, "Occupational radiation exposures of artisans mining columbite- tantalite in the eastern Democratic Republic of Congo," *Journal of Radiological Protaction*, Vol. 2**7**, No.2, 2007, pp. 187-195. doi:10.1088/0952-4746/27/2/005

[10] UNSCEAR (United Nations Scientific Committee on Effects of Atomic Radiation), *Dose assessment methodologies UNSCEAR Report to the general assembly*, New York, 2000.

