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Rapid *in-situ* radiometric assessment of the Mrima-Kiruku high background radiation anomaly complex of Kenya

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ABSTRACT

This paper presents the radiometric survey results of the Mrima-Kiruku high background radiation (HBR) anomaly complex of south coastal Kenya. Utilizing a portable γ-ray spectrometer consisting of a 2.0 *l* NaI(Tl) backpack detector integrated with GPS to perform the relevant *in-situ* radiometric measurements, a novel geospatial gating method was devised to represent the measurements. The goal of this study was to assess radiation exposure and associated natural radioactivity levels in the complex and to compare the results obtained with those from previous preliminary related studies. Absorbed dose-rates in air were found to range < 60–2368 nGy h^{-1}. These rates were observed to correspond with the spatial variability of the underlying geology and terrain, increasing toward the summits of both Mrima and Kiruku Hills which implies that the complex is a geogenic HBR anomaly. The activity concentrations of ^{232}Th in the study area are generally higher than those of ^{40}K and ^{238}U: The means of ^{40}K, ^{238}U and ^{232}Th ranged 235±19–603±28 Bq kg^{-1}, 68±6–326±24 Bq kg^{-1} and 386±12–1817±51 Bq kg^{-1} respectively. It was concluded that the high air absorbed dose-rate values that were measured (> 600 nGy h^{-1}) are due to elevated activity concentrations of ^{232}Th. Therefore there is significant (> 1 mSv/y) radiological hazard to the inhabitants of the area particularly those who reside at the foothills of both Mrima and Kiruku Hills.

1. Introduction

The Mrima-Kiruku complex of south coastal Kenya is highly heterogeneous in terms of the underlying geology, mineralogy and topography. It is characterized by a number of rock formations namely alkaline, igneous, and sedimentary of the Duruma sandstone series lying at altitudes between 30 and 323 m ASL, and is naturally rich in Fe, Mn, Nb and many rare earth elements, which are closely associated with U and Th bearing minerals such as monazite and pyrochlore. Detailed description of the soil and rocks of the complex is given by Baker (1953) and JICA (JICA, 1993). Although several mineral prospecting activities have been initiated in the complex, commercial mining has not been actualized mainly due to the in-homogeneity of the mineral ores as a result of alteration caused by weathering and mineralization (JICA, 1993; Loupekine, 1968). Nonetheless, laterite from Mrima Hill has been used locally as building material for dwellings (Chege et al., 2015) and for paving roads (Kaniu, 2017). There are also a number of human activities such as land cultivation, hand dug wells and settlement at the foothills of both Mrima and Kiruku Hills that are local occupations for which radiation exposure risk needs to be assessed.

Preliminary estimation of absorbed dose-rates in Mrima Hill using a conventional radiation survey meter and sample collection strategies found 200 - 14,000 nGy h^{-1} (Kebwaro et al., 2011; Patel, 1991), which is approximately more than 3–233 times compared to the global population weighted average value of 60 nGy h^{-1} (UNSCEAR, 2000) and higher than background values reported in related studies (Hashim et al., 2004; Maina, 2008; Osoro et al., 2011) within the region. However, no extensive and systematic survey for the accurate delineation of radiometric anomalies and source apportionment employing geophysical survey and geospatial mapping techniques, has been carried out so far in Mrima Hill and the adjoining environs.

*In-situ*γ-ray spectrometry offers a low-cost, rapid and spatially representative radiometric method for rapid assessment of radiation exposure and environmental radioactivity in contrast to laboratory based techniques. Conventional application of the method has relied upon the deployment of static measuring stations in a manner similar to traditional sampling strategies (Anspaugh, 1976; Beck et al., 1972; Macdonald et al., 1996; Tyler and Copplestone, 2007). While these detectors were portable, the logistical deployment of measurement teams still carried a large overhead from the cost of the equipment and

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Abbreviations

Annual effective dose estimate (AEDE)
Above sea level (ASL)
High background radiation (HBR)
High background radiation areas (HBRA)
Median absolute deviation (MAD)
Minimum detectable activity (MDA)
Naturally occuring radioactive materials (NORM)
Standard deviation (SD)

personnel time coupled to the length of measurements, typically 30–60 mins per measurement point due to the efficiency of the available detectors. The advent of mobile computing resources has enabled a range of GPS equipped detectors to become readily available and combined with large volume detectors, an efficient continuous γ-ray measurement system is readily deployable for airborne and ground-based radiometric surveys.

Airborne systems although expensive are cost effective for large area surveys and mapping (Beamish, 2016; Dickson, 1990; Wilford et al., 1997) but provide limited spatial resolution. Carborne systems are relatively cheaper and are thus alternatively used for contamination mapping of road networks and areas with off-road access (Aage et al., 2006; Bezuidenhout, 2015; Cesar and Moreira, 1991; Karlsson et al., 2000; Kobayashi et al., 2015; Sanderson et al., 2002), radioactive source search and recovery (Aage and Korsbech, 2003; Hjerpe et al., 2001), and radioactive mineral prospecting (Grasty and Cox, 1997). Mobile backpack systems are used to provide detailed radiometric mapping especially in areas with limited vehicular access and provide high spatial resolution of up to a few meters, depending on the density of measurements (Cresswell and Sanderson, 2009; Kock and Samuelsson, 2011; Nilsson et al., 2014).

The present study was aimed at assessing radiation exposure and natural radioactivity levels of the Mrima-Kiruku complex employing *in-situ* (carborne and mobile backpack) γ-ray spectrometry, and comparing the results obtained with related studies in the Mrima area. The rigorous application of portable GPS equipped γ-ray detectors and mapping techniques in typical large and rugged environments with limited manpower to provide rapid radiometric measurements and detailed high resolution maps, is emphasized. In addition, a novel geospatial gating approach of representing *in-situ* radiometric measurements is presented.

2. Materials and methods

2.1. The study area

The Mrima-Kiruku complex (Fig. 1) located in Kwale County of Kenya is bound by latitudes of 4° 27′ and 4° 30′ S and longitudes of 39° 14′ and 39° 17′ E. Small scale farming is a major activity in the area and the human population is dense in the highlands which could be indication of high land productivity. Mrima Hill is the carbonatite portion of the complex; it is a broad dome-shaped hill and approximately 3.8 km^2 in area, covered by undergrowth and dense tropical forest. Kiruku Hill is a carbonitized-agglomerate intrusion lying about 5 km north-east of Mrima Hill; it is a conical-shaped hill and approximately 0.3 km^2 in area, covered by thick vegetation.

2.2. In-situ radiometric measurements

The radiometric survey of the complex was conducted over 2.5 days (13–15 June 2014) covering approximately 28 km^2 using a portable PGIS-2 *in-situ* γ-ray spectrometer from Pico Envirotec Inc., consisting of a 2.0 *l* NaI(Tl) detector integrated with GPS, and a data logger unit controlled by an Android based Tablet computer via wireless bluetooth connection (PEI, 2013). The dimensions and weight of the PGIS-2 system are 46 cm × 22 cm ×16 cm and 12 kg, respectively. Carborne measurements (see Fig. 1) were taken at 1 s interval while transiting the study area at speeds not exceeding 60 km h^{-1}, with the detector laid horizontally on the vehicle floor, behind the gear compartment such that its sensitive volume was approximately 0.5 m above ground level.

Ground-based continuous measurements (see Fig. 1) also taken at 1 s interval entailed systematic transverses over accessible parts of selected sites on foot with the detector mounted on a tightly strapped backpack casing, as illustrated in Fig. 2. In this configuration, the

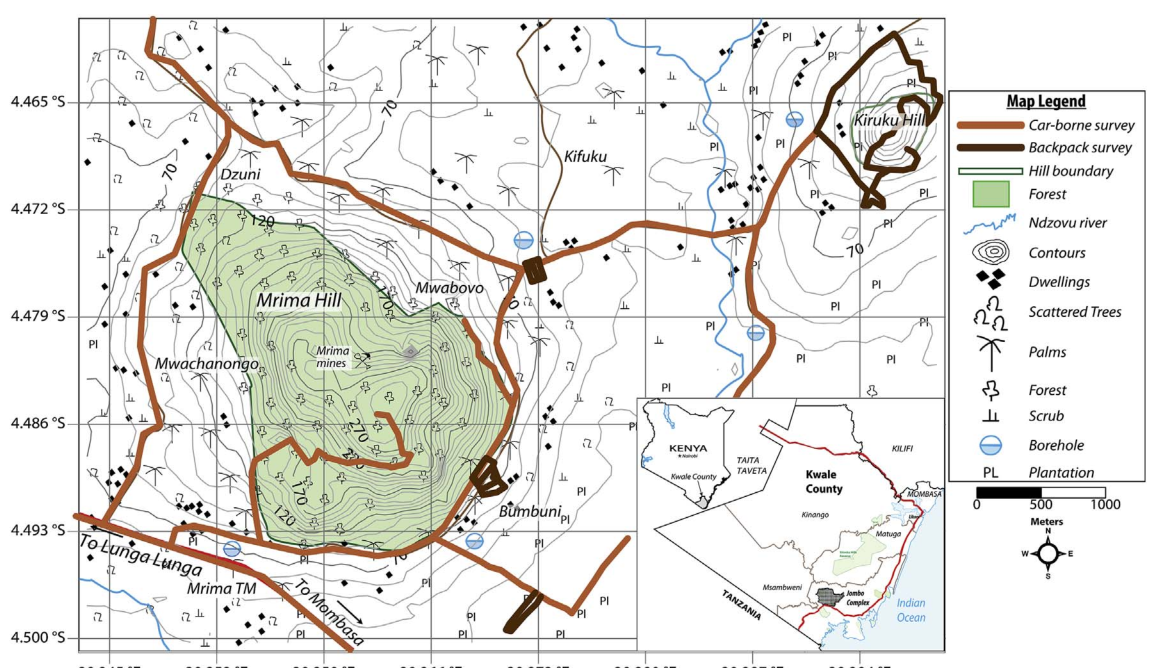

Fig. 1. Map indicating the topography of the Mrima-Kiruku complex in south coastal Kenya (contour heights are ASL). Also indicated are areas surveyed using both the carborne and mobile backpack γ-ray spectrometry geometries.