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Lifetime cancer risk due to gamma radioactivity in soils from Tudor Shaft mine environs, South Africa

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ABSTRACT

This study is aimed to evaluate the soil radionuclides' activity concentrations and environmental outdoor gamma dose rates in Tudor Shaft mine environs, South Africa. The excess lifetime cancer risks are also calculated. Outdoor gamma dose rates were determined in 45 soil samples taken from 9 locations. The maximum and minimum average outdoor gamma dose rate taken 1 m above ground was 202.74 ± 14.18 and 131.09 ± 5.43 nGy/h, respectively. Also, the maximum and minimum mean annual effective gamma dose of Tudor Shaft mine environs was 2.49×10^{-1} and 1.61×10^{-1} mSv/y, respectively and the excess lifetime cancer risk from the average values of the outdoor gamma dose from nine areas of 1.03×10^{-3} was observed. Soil samples were analysed by gamma spectroscopy and the average ^{238}U, ^{232}Th, and ^{40}K activities were 271.96 ± 3.59 Bq/kg, 47.65 ± 3.69 Bq/kg and 87.17 ± 5.19 Bq/kg, respectively. The average soil radionuclides' concentrations of Tudor Shaft mine environs were above the worldwide range and some extreme values had been determined. Annual effective gamma doses and the excess lifetime risks of cancer were higher than the world's average.

1. Introduction

Tudor Shaft informal settlement is in Krugersdorp, west of Johannesburg and is highly affected by gold mine shaft and tailings dam which contains radionuclides. The community are affected by this mine's bequest. The community of Tudor Shaft built their shacks on the tailings soil, grow their vegetables and the children play on the soils. The area is polluted by acid mine drainage (AMD) and other heavy metals due to the mining of gold in the past (Norgate & Haque, 2012). Environmentalists have tried to warn the residents about the radioactive dangers from the tailings dump, but it's been a difficult task. Even today, the residents grow pumpkins and corn in small gardens on the dump. There is no fence to prevent children from playing around the slimes.

In 2012, acting on advice from the National Nuclear Regulator (NNR), the local government, the mining company began removing the Tudor Shaft waste dump. About half of the soil was removed, but environmentalists were alarmed that it was being done without risk-assessment studies or consultations. It was observed that some families were living on top of the waste dump.

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Study finds extreme uranium and heavy metal contamination in cattle grazing near the slimes in Tudor shaft. It was found that the internal organs of cattle kept in the area have been contaminated with uranium and cobalt. It was also observed that the analysed animals' kidneys were found uranium levels 4350 times higher than those in a control group.

In addition, people are exposed to background radiation that stems both from natural and man-made sources (Abbady, El-Arabi, Abbady, & Taha, 2008; Aborisade, Olomo, & Tchokossa, 2003; Akhtar, Tufail, & Ashraf, 2005). Natural background radiation, which is equal to 2.4 mSv per person, makes up approximately 80% of the total radiation dose a person is exposed in a year (IAEA, 1989, 1996). Soil radionuclide activity concentration is one of the main determinants of the natural background radiation (Ahmed & El-Arabi, 2005). Rocks that are rich in phosphate, granite and salt contain natural radionuclides like uranium-238, thorium-232 and potassium-40 and when they are disintegrated through natural processes, radionuclides are carried to soil by rain and flows (NCRP, 2010). In addition to the natural sources, soil radioactivity is also affected from man-made activities.

Radioisotopes present in soil significantly affect terrestrial gamma radiation levels. Several studies have been carried out to assess the average outdoor terrestrial gamma dose rate in air at 1 m from the ground and revealed that the effective gamma radiation levels were generally in the range of 10–200 $nGyh^{-1}$ with a mean of 60 $nGyh^{-1}$ (UNSCEAR, 2000).

It is critical to evaluate soil radioactivity in order to understand background radiation concentrations. Measuring terrestrial gamma dose rates is also essential since gamma radiation provides information concerning excess lifetime cancer risks. However, in South Africa, studies have been carried out to evaluate soil radioactivity (DME, 2005) and terrestrial gamma dose rates but limited in estimating lifetime cancer risk especially in mining environs. Hence the objective of this study is to evaluate soil radionuclides' radioactivity concentrations as well as environmental outdoor gamma dose rates in Tudor shaft which is an informal settlement located in Kagiso, West Rand Municipality, Gauteng province of South Africa. This area is influenced by abandoned gold mined tailing dams (slimes). Until now, there hasn't been a comprehensive study evaluating background radiation levels and relating it to excess lifetime cancer risk, hence, the equilibrium dose rates and lifetime cancer risks are also calculated to provide useful information on gamma radioactivity in soil around Tudor Shaft mine environs.

2. Materials and methods

2.1. Study area

Tudor Shaft is an informal settlement in Krugersdorp, west of Johannesburg and highly affected by gold mine shaft and tailing dams. It is a suburb of West Rand, Gauteng province which is about 30 km south of Johannesburg. Tudor Shaft was created in 1996 when the local government relocated hundreds of people to this site. An example of some informal shacks scattered all over the environs is captured in Fig. 1.

Fig. 1 – Informal settlement in Tudor Shaft environs.

2.2. Outdoor gamma dose rate determination

In order to determine the outdoor gamma dose rates, Tudor Shaft environs was divided to nine geographic areas (Table 1). From each geographic area five sampling locations were randomly selected. For each sampling locations, measurements were taken and the mean of the measurements for each geographical area was calculated and appointed as the outdoor gamma dose rate.

The Eberline smart portable device (ESP-2) connected with an SPA-6 model plastic scintillation detector was used for the outdoor gamma dose rates measurements, taken in air for 2 min at 1 m above the ground. The gamma dose rates were recorded as mRh^{-1} and then converted to $nGyh^{-1}$. The gamma absorbed doses in $nGyh^{-1}$ were also converted to annual effective dose in $mSvy^{-1}$ as proposed by UNSCEAR (UNSCEAR, 2000).

The annual effective dose equivalent (AEDE) was calculated by using the following equation:

$$AEDE = ADRA \times DCF \times F_O \times T \quad (1)$$

where ADRA = absorbed dose rate in air ($nGyh^{-1}$), F_O = the outdoor occupancy factors of 0.2, DCF = dose conversion factor (0.7 $SvGy^{-1}$) and T = time (8760 hyr^{-1}).

Excess lifetime cancer risk (ELCR) was calculated by using the Equation (2):

$$ELCR = AEDE \times E_{LD} \times C_{RF} \quad (2)$$

where E_{LD} = Expected lifetime duration (70 yrs) and C_{RF} = fatal cancer risk factor (for stochastic effects, ICRP, 1990 uses a value of 0.05 for the general public).

2.3. Determination of soil radioactivity and terrestrial gamma dose rates

In order to determine soil radionuclides' activity concentration, the 45 soil samples from the nine geographical locations, were selected. Soil samples were obtained as described in Table 1.

Open, flat and undisturbed geographical locations which had good water permeability were selected as the sampling points. The first 10 cm of topsoil was taken, foreign bodies were removed and the remaining soil was placed in clean, sealed and labelled bags. The samples were dried at 60 °C for