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Public Exposure to Natural Radioactivity Near Uranium Deposits in Manyoni Area, Central Tanzania

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ABSTRACT

Assessment of public exposure to background radiation was performed in Manyoni, Tanzania to address public concerns following the discovery of uranium deposits in their neighborhoods. Results show that the highest concentrations of radionuclides are 112, 95 and 463 Bq.kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The highest annual effective dose to the public is 2.91 mSv.y^{-1} with a mean value of 1.29 mSv.y^{-1}. Authorities may use these results to address public concerns as well as the baseline information. Further investigations on public exposures in Manyoni are recommended.

Keywords: **Natural radioactivity, public exposure, Manyoni, Tanzania.**

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1. INTRODUCTION

Exposure to radiation from natural sources is an inescapable feature of everyday life in both working and domestic environments [1]. This is because detectable amounts of radioactive materials are present naturally in the soil, rocks, water, building materials, air, and vegetation which are inhaled and or ingested into the body [2]. In addition, humans receive external exposure from gamma radiation and cosmic radiation from space, making 2.4 $mSv.y^{-1}$ the world average dose from internal and external exposure due to the natural radiation background [3,4]. The primordial radionuclides responsible for both indoor and outdoor gamma radiation are ^{238}U, ^{235}U, and ^{232}Th series and ^{40}K [5]. Gamma radiation from the ^{238}U, ^{235}U and ^{232}Th series isotopes, as well as ^{40}K cause external exposure, while the inhalation of radon (^{222}Rn), thoron (^{220}Rn) and their short-lived progenies cause internal exposure leading to health risks to the population [6 – 8]. Chronic exposure to large amounts of these radionuclides can lead to negative health effects such as damage to the cells and genetic materials (i.e., deoxyribonucleic acid, or DNA), cancer, and the degeneration of tissues [9]. For public health protection therefore, the determination of radiological hazard indices (e.g., radium equivalent concentration) and external absorbed dose rates in outdoor and indoor air is indispensable [10].

Even though these radionuclides are naturally widely distributed in our environment, their concentrations are influenced by local geological conditions which differ from one location to the next [3,11]. For instance, areas with unusually high background radiation have been reported in Yangjiang, China; Kerala, India; Guarapari, Brazil; Ramsar, Iran and Minjingu, Tanzania; among others [12,13]. The discovery of uranium deposits in Manyoni area, central Tanzania in recent years [14] raises concern about public exposure to natural radiation at Manyoni before, during and after the uranium mining and milling operations. Manyoni being one of the potential uranium deposits in Tanzania, the need for comprehensive radiological characterization studies in this area, especially in residential zones arises. Residential zones are of primary concern because houses in this region are mostly built from traditional materials like soil, stones, bricks and sand found within neighborhoods. The presence of uranium deposits suggests that the ground on which the buildings

are erected, and the building materials used may contain high concentrations of primordial radionuclides and their decay products that can enhance outdoor and indoor radiation levels [15].

This study aims at assessing public exposure to radiation from natural sources in the Manyoni area. The results could help in addressing public concerns regarding radiation levels in their residential areas. The study will generate baseline data that can be used to assess changes in natural background radiation levels as a result of human activities, mainly uranium mining in these areas.

2. MATERIALS AND METHODS

2.1. Description of Study Area

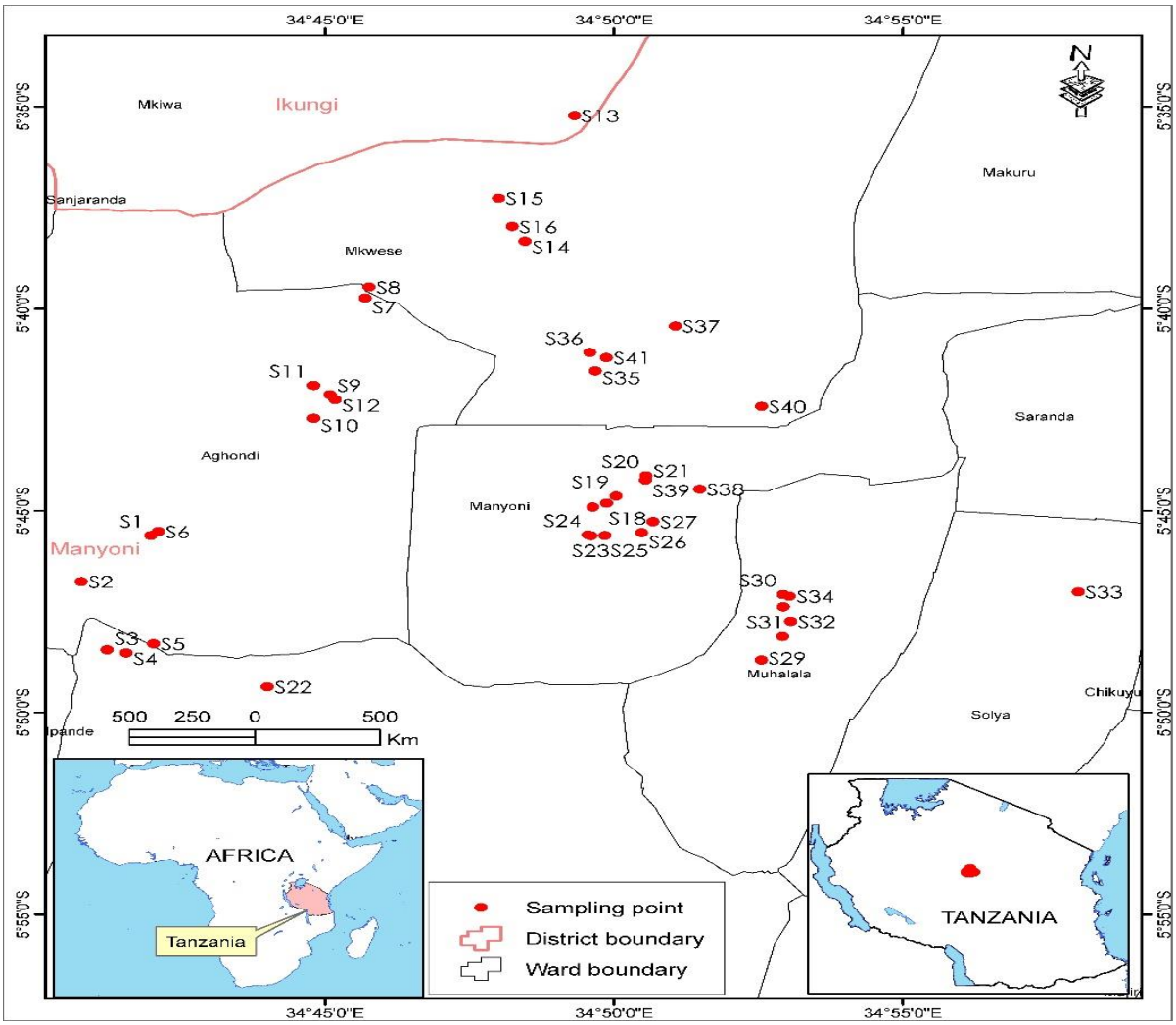
Manyoni District is located in Singida region which is in the central part of Tanzania (Figure 1). Its geographical coordinates lie between Latitudes 5° 30' 0" and 7° 34' 0" South of the Equator and Longitudes 33° 27' 0" and 35° 26' 0" East of Greenwich. It has an area of 28,620 km^2 with a population of 296,763 people [16]. The discovered uranium deposit is situated in the Northern section of the Bahi province about 10 km from the town of Manyoni, which is 120 km North-West (NW) of Dodoma, the capital of Tanzania. The region combines an extensive locked draining system developed over weathered uranium rich granites [14].

2.2. Collection and preparations of soil samples

Soil samples were collected from residential areas near the uranium deposits. Samples were collected from the surface to a depth of 15 cm using shovels and spoons. The number of samples was highly dependent on the size of the residential area (village or town). Some samples were collected from outside the buildings in locations where residents spend most of their day time for recreation purposes. Other samples were collected in the cultivated land where residents spend a substantial amount of time harvesting or using hand hoes for weeding. In total, three hundred samples were collected. Collected soil samples were transported to the laboratory and dried at room temperature followed by drying in an oven at 55–60 ^{0}C until constant weight was achieved indicating complete dryness. Dried soil samples were grounded or segregated using paste and mortar. The resulting powder was sieved and then placed in plastic zip bags or desiccators to

prevent the absorption of moisture [17,18]. Samples were highly homogenized before they were packed in air-tight steel canisters where they were stored for at least 21 days to allow ^{226}Ra and ^{232}Th to attain secular equilibrium with their daughters before counting [19].

Figure 1: *Map of Tanzania showing the study area and sampling points S1 – S41.*



2.3. Determination of natural radioactivity in soils

Determination of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) concentrations in soil samples was carried out using a low-background gamma ray spectrometry system with a Hyper Pure Germanium

(HPGe) detector according to the method described in [19,20]. The output of the detector was connected to a Digital Spectrum Analyzer (DSA LX from Canberra Industries) through an amplifier. The detector was surrounded by 1 mm, 1 mm and 100 mm thick low background shielding of cadmium, copper and lead respectively to reduce the background response of the detector. Energy calibration was performed using ^{60}Co and ^{137}Cs point sources. The efficiency calibration of the detector was performed using Laboratory Source-less Calibration Software (LABSOCS) from Canberra Industries. The IAEA – 375 certified reference material [21] was used to validate the measurements. The acquisition time for each sample spectra using Genie 2000 (gamma acquisition and analysis) software was twenty-two hours. The activity concentration (Ai) of each radionuclide was determined using Eq. 1 [19,22].

$$A_i = \frac{N}{t \times \eta_i \times P_i \times m} \quad (1)$$

Where N is the net peak area at energy E_i; "t" is the sample counting time; ηi is the photo peak efficiency at energy E_i; P_i is the gamma line emission probability for radionuclide ''i' 'and "m" is the dry weight (kg) of the sample counted.

2.4. Determination of Radium Equivalent Activity (Ra_{eq})

An index used to represent the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K by a single quantity is known as Radium equivalent activity. This index takes into account the radiation hazards associated with ^{226}Ra, ^{232}Th, and ^{40}K. This index is estimated using Eq.2 [4].

$$Ra_{eq}(Bqkg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

Where A_{Ra}, A_{Th} and A_K is the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The value of Ra_{eq} must not exceed 370 Bq.kg^{-1} for the annual effective dose to the public to be less than 1 mSv.y^{-1} [23].

2.5. Determination of absorbed dose rate in air

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soils collected from residential areas were used to calculate the absorbed dose rate (D) in the air at 1 m from the ground. D was calculated using Eqn. 3 [24 – 26].

$$D\ (nGy.h^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_{K} \quad (3)$$

Where A_{Ra}, A_{Th} and A_{K} is the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1}, respectively.

2.6. Direct measurement of indoor gamma dose rates

Measurements of indoor gamma dose rates were carried out using a calibrated digital survey meter (Graetz X5C plus). The survey meter is capable of measuring gamma radiation dose rates in the range 1μSv.h^{-1}, ≤H*(10) ≤20 mSv.h^{-1} and has energy response in the range 40 keV ≤ E ≤ to 1.3 MeV. Prior to dose rate measurements, the survey meter was calibrated against ^{137}Cs (662 keV gamma energy) at the Tanzania National calibration laboratory for ionizing radiation which is traceable to the International Measurement System through the International Atomic Energy Agency (IAEA). For the indoor dose rate, measurements were performed at one meter above the floor and at the room centre [25, 27]. The readings were integrated for a minimum of five (5) hours at each measurement location and then the arithmetic mean values were estimated.

2.7. Determination of annual effective dose equivalent

The effective dose is the basic quantity used to describe public exposure and is therefore used for radiation protection purposes. Since doses to members of the public cannot be measured directly, they can be assessed based on the environmental assessments [28]. Therefore, values of the dose rate calculated or measured are used to estimate the annual effective dose equivalent for the member of the public by using Eq.4 [4, 29,30].

$$E_D = R \times T \times T_C \times F \times 10^{-6} \quad (4)$$

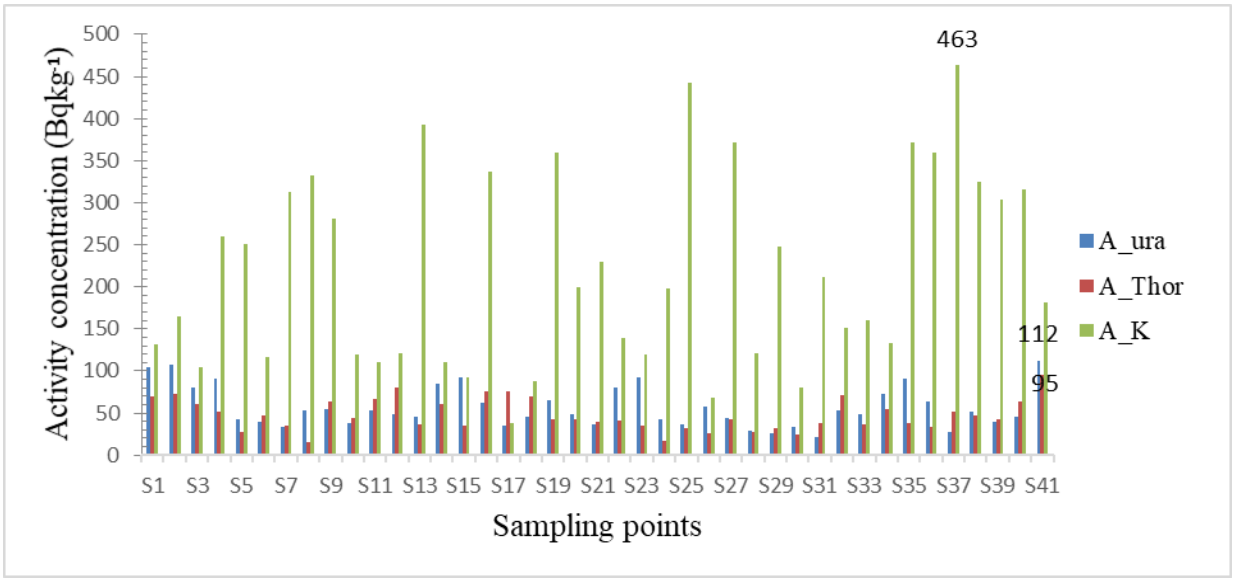
Where, E_D is the annual effective dose rate in $mSv.y^{-1}$, R is the average absorbed dose rate in indoor or outdoor environments in $nGy.h^{-1}$ or $nSv.h^{-1}$, T is the annual exposure time in hours (i.e. 8760 hours), T_C is the occupancy factor equal to 0.2 and 0.8 for outdoor and indoor environments, respectively. F is the dose conversion factor equal to 0.7 $Sv.Gy^{-1}$ or unity for dose rates reported in $nGy.h^{-1}$ and $nSv.h^{-1}$, respectively [4, 31].

3. RESULTS AND DISCUSSION

3.1 Natural radioactivity in soils

Results of natural radioactivity (^{226}Ra, ^{232}Th and ^{40}K) in soils are shown in Figure 2. These results show that radioactivity levels ranged from 21 – 112, 16 – 95 and 38 – 463 $Bq.kg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The estimated arithmetic mean was 50, 46 and 218 $Bq.kg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The highest values of ^{226}Ra and ^{232}Th were recorded in location S41while the highest value of ^{40}K was observed in location S37. The lowest values of ^{226}Ra and ^{232}Th were recorded at locations S31 and S8, respectively while the lowest value of ^{40}K was observed at location S18. On average, the reported concentrations are below the screening levels. In this context, the screening level is a radiation-protection tool in existing exposure situations aiding in the decision-making processes in a similar way that exemption level in planned exposure situations [31]. According to the IAEA [31], for bulk amounts of materials with radionuclides of natural origin, a value of 1 $Bq.g^{-1}$ for each radionuclide in the uranium decay chain or the thorium decay chain and 10 $Bq.g^{-1}$ for ^{40}K can be used for screening purposes. In comparison, a study in Manyoni [32] found out the concentrations of radionuclides ranged from 23.2 to 835, 12.3 to 49.1 and 47.2 to 151 $Bq.kg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K, respectively. It can be noted that the maximum value of ^{226}Ra measured in this study is lower than the maximum value reported by Nkuba and Nyanda [32]. On the contrary, the maximum values of ^{232}Th and ^{40}K measured in this study were higher than those reported by Nkuba and Nyanda [32]. The observed differences may be explained by the fact that sampling locations within Manyoni were different and therefore existing geological differences may be responsible.

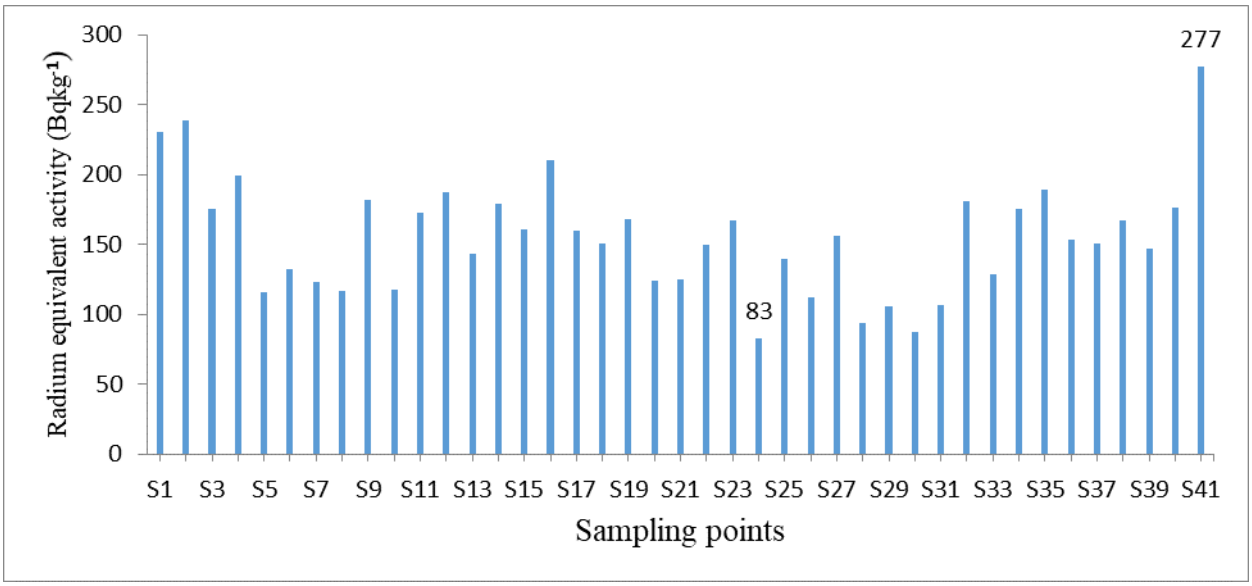
Figure 2 : *Activity concentrations of radium (A_ura), thorium (A_Thor) and potassium (A_K) per sampling location.*



3.2 Radium Equivalent Activity

One of the radioactive parameters applied widely in radiation health hazards is the radium equivalent content (Ra_{eq}). Values of radium equivalent concentrations (Ra_{eq}) obtained during this study are presented in Figure 3. Results showed that Ra_{eq} concentrations ranged from 83 to 277 $Bq.kg^{-1}$ with a mean value of 155 $Bq.kg^{-1}$. These values are below 370 $Bq.kg^{-1}$ which is recommended if the annual effective dose to the public is to be less than 1 $mSv.y^{-1}$[23]. In comparison, Nkuba and Nyanda [34] reported Ra_{eq} concentrations ranging from 57.09 to 882.08 $Bq.kg^{-1}$. Unlike the findings of this study where the maximum value of Ra_{eq} was less than 370 $Bq.kg^{-1}$, the maximum value reported by [32] is approximately twice the maximum value of 370 $Bq.kg^{-1}$.

Figure 3 : *Radium equivalent activity per sampling point*

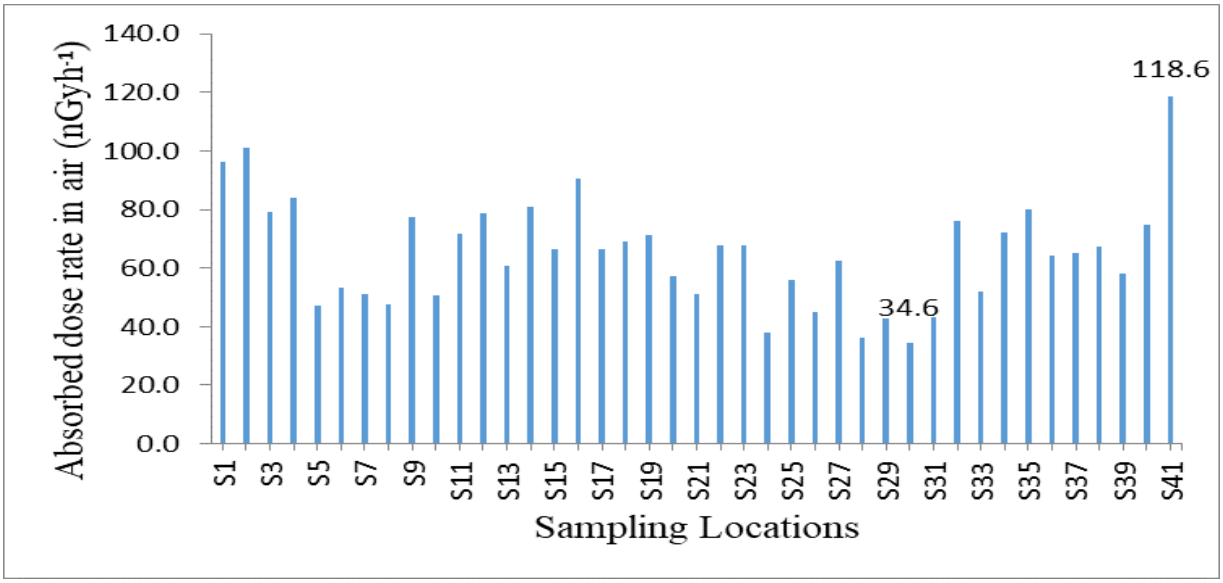


3.3 Absorbed dose rate in air as calculated from soils radioactivity

The absorbed dose rates in air estimated using Eq. (1) are presented in Fig. 4. These results show that the absorbed dose rates ranged from 34.6 – 118.6 nGy.h^{-1} with a mean value of 73 nGy.h^{-1}. The highest value of the absorbed dose rate was recorded in location S41 while the lowest was recorded at location S24. The reported mean and maximum values are above the world average value of 59 nGy.h^{-1} [4]. In comparison, Nkuba and Nyanda [32] found out that the absorbed dose rate in air (in Manyoni) ranged from 25.36 to 385 nGy.h^{-1}. It is clear that the maximum value reported by Nkuba and Nyanda [32] was three times higher than the value reported for this study and seven times higher than the world average. A study of background radiation dose rate in Manyoni by Elisadiki and Makundi [33] using thermoluminescent dosimeters (TLD-200) found out that the mean dose rate ranged from 16.68 to 507.00 nGy.h^{-1} with a mean value of 74.86 nGy.h^{-1}. The mean value reported by this author is in agreement with the one established during this study. However, the maximum mean dose rate of 507 nGy.h^{-1} reported by Elisadiki and Makundi [33] was about 9 times higher than the world average value cited above and 4 times higher than the maximum value reported in this study. A common finding in Nkuba and Nyanda [32], Elisadiki and Makundi [33] and this study is that the background radiation dose rate in Manyoni area is higher

than the world average. The differences in values reported in these studies may be explained by geological differences since sampling or measurements were not done at the same points.

Figure 4: *Absorbed dose rates in air*



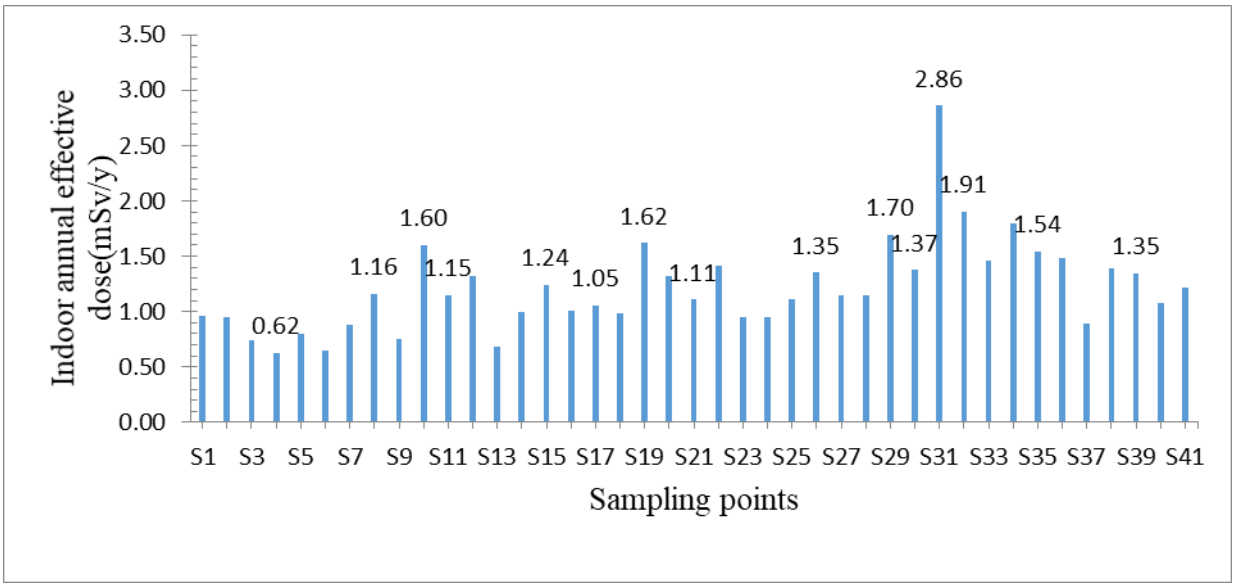
3.4 Indoor gamma dose rates from direct measurements

The highest indoor gamma dose rate was measured at location S31 and the lowest was measured at location S4 with values of 408 nSv.h^{-1} and 89 nSv.h^{-1}, respectively. The overall mean value was 173 nSv.h^{-1}. Measured indoor gamma dose rates were converted into annual effective doses using Eq. (4) and are presented in Figure 5. From Figure 5, the highest and lowest indoor annual effective dose rates were 2.86 mSv.y^{-1} and 0.62 mSv.y^{-1} for stations S31 and S4, respectively. Generally, a variation of indoor gamma radiation has been observed in the assessed houses. The reasons may be the differences in concentrations of radionuclides in the building sites and in the building materials. Dose rate differences between houses built with the same materials were also observed. This may imply that the materials used for the construction of these buildings have different origins and consequently differ in radioactivity concentrations.

Since data for indoor gamma dose rates in Tanzania are scarce or missing, the findings of this study were compared with the indoor gamma dose rates for different countries. For example, indoor doses of 0.23 mSv.y^{-1} in Greece [34], 0.50 mSv.y^{-1} in Slovenia [35], 1.04 mSv.y^{-1} in Malaysia [36], 1.97 mSv.y^{-1} and 1.77 mSv.y^{-1} in Iran [37]. It is evident that the maximum annual

effective dose obtained during this study (2.86 $mSv.y^{-1}$) is higher than those reported in the sampled studies. Also, the mean value for this study (1.21 $mSv.y^{-1}$) is higher than the values reported for Greece, Slovenia and Malaysia. However, the mean value obtained during this study is lower than the values reported for Iran.

Figure 5 : *Annual Effective dose in the indoor environment*

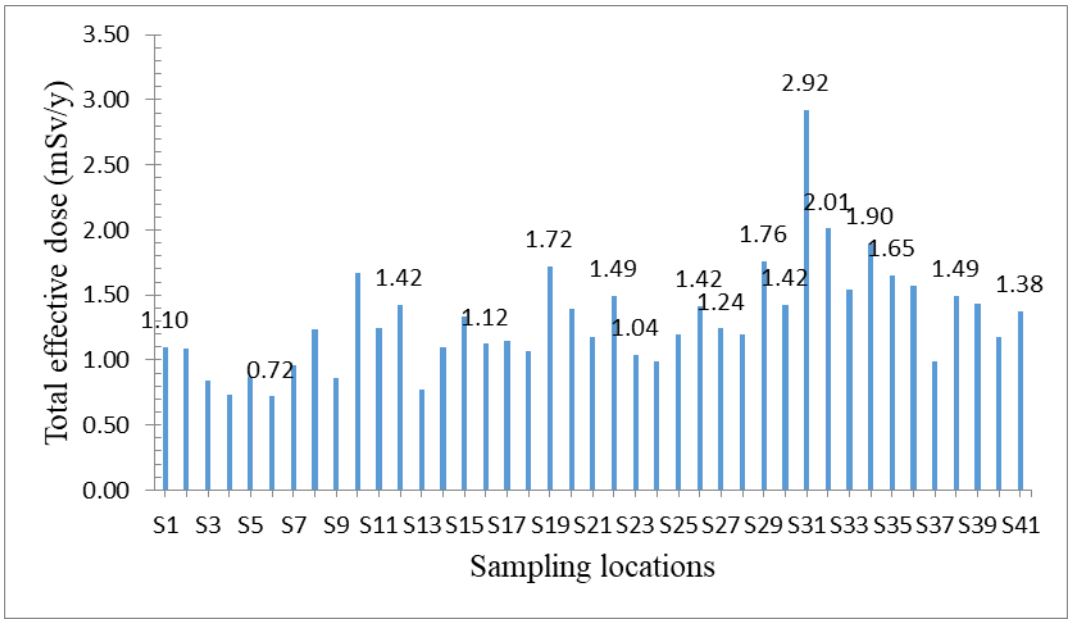


3.5 Total annual effective dose resulting from indoor and outdoor exposures

The estimated total dose rates for members of the public at each sampling point are presented in Figure 6. Total doses were obtained by combining annual effective doses resulting from indoor exposure (from direct measurements) and annual effective dose rates derived from natural radioactivity in soil, with occupancy factors considered. Although these are different approaches in dose estimation, studies have shown that results do not differ significantly. For example, a study by Inoue et al. [38] revealed that the average ratio of the dose from direct measurement to the absorbed dose rate in air derived from soil concentration was 0.9 $mSv.y^{-1}$. Ignoring this slight difference therefore, the total annual effective doses ranged from 0.72 $mSv.y^{-1}$ to 2.92 $mSv.y^{-1}$ with a mean value of 1.29 $mSv.y^{-1}$. The minimum and maximum values were recorded for locations S6 and S31, respectively. The highest contributor to the annual effective dose at S31 was the indoor dose rates

presumably due to high activity concentrations in building materials which were not analyzed during this study.

Figure 6 : *Annual effective dose resulting from indoor and outdoor exposure (mSv.y^{-1})*



4. CONCLUSIONS

In conclusion, radioactivity levels in residential areas in the vicinity of the uranium deposits in Manyoni, central Tanzania were investigated with the aim of assessing public exposure. Reported parameters include: radioactivity in soil, absorbed gamma dose rates in air, radium equivalent activity and annual effective gamma dose rates. Results indicate that radioactivity in soils are below the screening values of 1 Bq.g^{-1} for each radionuclide in the uranium decay chain or the thorium decay chain and 10 Bq.g^{-1} for ^{40}K as specified in the IAEA Safety Guide.

The estimated Raeq concentrations were below the recommended limit of 370 Bq.kg^{-1} signifying that the resulting dose will be below 1 mSv.y^{-1}. This was in good agreement with the annual effective doses derived from soil radioactivity. However, total annual effective doses resulting from combined indoor and outdoor exposures in the study area exceeded 1 mSv.y^{-1} in

most of the assessed locations. This study aimed to obtain preliminary results in response to the public concerns over the discovered uranium deposits and possible uranium mining operations in Manyoni area. These results can serve as baseline data to assess changes in the natural background radiation levels in this area during and after uranium mining and milling operations. This implies that any future increment from these values will perhaps be linked to uranium mining and milling operations which may take place in the nearby uranium deposits. The study area coverage was limited by the resources that were made available during this study. Therefore, future research covering wider areas of Manyoni District is highly recommended.

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CONFLICT OF INTEREST

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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