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ASSESSMENT OF INDOOR RADON-222 CONCENTRATIONS IN THE VICINITY OF MANYONI URANIUM DEPOSIT, SINGIDA

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ABSTRACT

This study aimed to assess indoor radon concentrations in the vicinity of the Manyoni Uranium Deposit in Singida. The concentrations were measured for two months in 32 houses in the vicinity of Manyoni Uranium Deposit and 9 houses at Manyoni town using a portable radon gas monitor (Alpha –GUARD™). The radon concentrations ranged from 27±3 to 518±28 Bq/m^{3}with the overall mean of 166±12 Bq/m^3 which is above recommended values of 100 Bq/m^3 and 148 Bq/m^3 set by WHO (World Health Organization) and EPA (Environmental Protection Agency's), respectively. The overall mean of indoor radon concentrations from each village were Kipondoda (169±13 Bq/m^3), Muhalala (177±16 Bq/m^3), Mwanzi, (287±13 Bq/m^3), Mitoo (325±21 Bq/m^3) and Majengo (377±23 Bq/m^3) which exceed the limit set by WHO (World Health Organization) and EPA (Environmental Protection Agency). The value of 325±21 Bq/m^3 and 377±23 Bq/m^3 from Mitoo and Majengo respectively, exceed the limit of 300 Bq/m^3 recommended by ICRP (International Commission on Radiation Protection). Thus there is a non-negligible probability of incurring stochastic effects for people living in the vicinity of Manyoni Uranium mine. It is recommended that human activities should be controlled near the uranium deposits and dwelings should be well ventilated.

Keywords: Indoor radon, Concentrations, Cancer, Manyoni uranium deposit, Alpha –GUARD.

INRODUCTION

The Radon radioisotope ^{222}Rn, produced from the decay of ^{238}U, is the main source (approximately 69%) of internal radiation exposure to human (ICR 1993, Mishra et al. 2004, Al-Saleh 2007). The radioisotope, ^{222}Rn is important because of its long half-life of 3.83 days compared to ^{220}Rn and ^{219}Rn with short half-lives of 56s and 3.96s respectively (Al-Saleh 2007).

Exposure to high levels of radon daughters through breathing air indoors increases the risk of lung cancer proportionally to the concentration and the period of exposure (Akortia et al. 2010).

Radon daughters have been found to be mainly responsible for lung cancer not only among the uranium miners but also among the general public (Khan et al. 1990). Radon is the second largest cause of lung cancer after smoking in most countries (Bochicchio et al. 1995, Chen 2005, WHO 2009, Abu-Haija et al. 2010, EL-Araby and EL-Sayed, 2012. In addition to the serious health hazards related to radon, it can also be used to predict the arrival of an earthquake, to locate uranium deposits, oil and geothermal energy sources (Khan et al. 1990).

The major indoor radon sources, in order of importance are: soil, building materials (sand, rocks, and cement,), outside air, water and natural energy sources used for cooking like (gas, coal, etc.) which contain traces of ^{238}U (Somlai et al. 2006, Nsiah-Akoto et al. 2011). Uranium (^{238}U) is particularly abundant in uranium deposit, rock phosphate deposit, power plant, industrial radiation, etc. (Akortia et al. 2010, Zubair et al. 2011). Uranium is present to some extent in all soils and rocks (UNSCEAR 2000; Somlai et al. 2006). Thus, small amounts are dispersed throughout the earth's crust. This means radon may be found everywhere (Akortia et al. 2010). Radon being an inert gas seeps through cracks in the bedrock and soil before it finally escapes into the atmosphere in harmless levels. ^{222}Rn gas from the soil can enter buildings through faults and cracks in foundations, walls, hollow concrete blocks and sump-pump openings (Anastasiou et al. 2003, Akortia et al. 2010). The soil composition under and around a house affects ^{222}Rn levels and the ease with which ^{222}Rn migrates into a house (Anastasiou et al. 2003). Due to different sources of radon in houses many people are at high risk of cancer (Chen 2005).

Indoor radon concentration depends in a complex way on the building structure and design, ventilation condition, topography of the area, soil characteristics, wind direction, atmospheric pressure, soil gas radon concentration and the life style of people (Anastasiou et al. 2003, Somlai et al. 2006, Kumar et al. 2010, Nsiah-Akoto et al. 2011). Normal pressure differences between the house and the soil can create a slight under–pressure in the house that can draw ^{222}Rn gas from the soil into the building (Anastasiou et al. 2003). Radon concentration is dependent on the distance from the source (Mishra et al. 2004, Zubair et al. 2011). It is also dependent on the ventilation rate because its decay constant (64 h^{-1}) is much higher than normal ventilation rate (1 h^{-1}) (Zubair et al. 2011). Once in a building, ^{222}Rn can accumulate to high levels in poor ventilated houses, so that precautions must be taken (DOE 2002, Ngachin et al. 2007, Akortia et al. 2010, Quashie et al. 2011, Zubair et al. 2011).

Recently uranium deposits have been discovered at Manyoni and Bahi in Central Tanzania and Mkuju uranium deposit (Namtumbo, Ruvuma) (URANEX, 2010). Manyoni uranium deposits are surrounded by many villages. The common building materials are stones, soil and sand from the surroundings. Many houses are constructed by mud walls, thatched iron/grass roofs and others with stones, bricks and blocks. In the vicinity of a uranium deposit, the release rates of radon and related activities in air can be elevated over natural background, depending on local conditions and/or mine operations (Mudd 2008).

Due to low awareness about the concentrations and effects of radon, many people have continued to work and live in places (e.g. above, near and around the uranium deposits, phosphate mines, coal mines) unaware of the dangers posed to their lives. Since there is no study which has been done to determine indoor radon concentrations in Tanzania, this study will be the first one to produce scientific statistical data of concentrations of indoor radon. Therefore the data obtained may provide information about the indoor radon concentrations which will make people to be aware of potential radiological risk on their health. Also the data obtained may be used by the authorities and other stakeholders to set relevant regulations and to conduct similar studies in other different places with elevated uranium levels such as Bahi and Mkuju uranium deposits, Kiwira coal mine and Minjingu phosphate mine.

Sawe, (2010) determined radon gas in the working environments of Kiwira coal mine and found highest mean radon concentration was 305±29 Bq/m^3, Kahuluda and Makundi (2014) determined the concentrations of radon gas in the underground Merelani Tanzanite mines and obtained a geometric mean of 118.4 Bq/m^3whch is below the ICRP workplace guidance level of 500-1500 Bq/m^3. Since there is no national database of radon concentration in houses, there is a need to study the indoor radon concentrations in the vicinity of Manyoni uranium deposit.

MATERIALS AND METHODS

Radon concentrations measurements were carried out in dry season for two months (September, 2012 to November, 2012) in 41 houses (32 houses in the vicinity of Manyoni Uranium Deposit and 9 houses at Manyoni town) using, a portable radon gas monitor (AlphaGUARD). Measurements were recorded for five consecutive hours for good average results for each location in single measurement or double measurements (day and night). Eight (8) villages which are located close to the uranium mineralized zone were selected including Manyoni town for the measurements of indoor radon concentrations. The villages are Agondi, Mkwese, Muhalala, Mitoo, Mwanzi, Kamenyanga, Kipondoda and Majengo. At certain houses the permission was granted to take measurement but no power supply or the power supply was available but no permission to use it, in that situations the generator was used. Night readings were major limited to accessibility of homes at night. The geographical position of each house numbered 1 to 41 was determined by a Global Positioning System (GPS). The locations were selected by taking into consideration the coverage of almost all the villages surrounding the uranium deposit area. 8 Outdoor measurements were taken at the same place at height of 1 m from the ground used as control.

Manyoni District is located in the central part of Tanzania. Its geographical coordinates are 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 and population of 205,423 people (URT 2002).

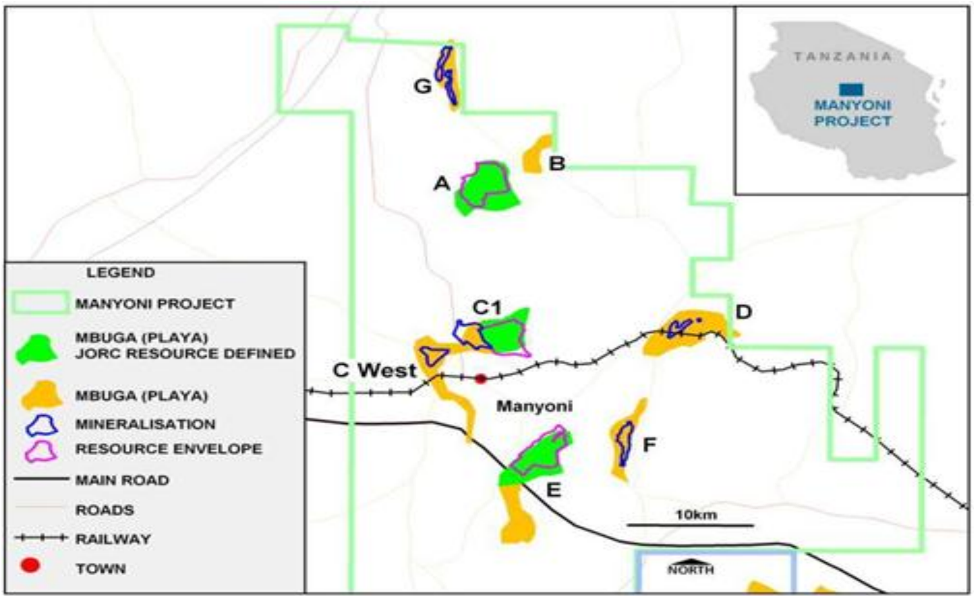

Figure 1: Location of Manyoni Uranium Deposit with Playa Lakes/Mbuga A, B, C, D, E & F (URANEX 2010)

Manyoni uranium deposit is situated in the northern section of the Bahi regional uranium province near the town of Manyoni, which is 120 km North West of Dodoma. The region incorporates an extensive closed draining system developed over weathered uranium rich granites. This drainage captures dissolved uranium leached from underlying rocks and transports it to suitable precipitation trap sites (Mbuga/playa lakes A, B, C, D, E, F) along the drainages. The uranium targets in the area are described as calcrete-hosted uranium mineralization near to the surface and sandstone-hosted deposits within buried fluvial channel systems (URANEX 2010).

A portable radon monitor (Alpha-GUARD), which is an active radon sampling sensor, was used to measure radon concentrations. It has an ionization chamber and detects radon concentration using an alpha spectroscopy, it has optimal sensitivity: Alpha spectrometric detector with 5 cpm at 100 Bq/m³ and linear response from (2– 2M) Bq/m³. This instrument has high detection efficiency, a wide measurement range, fast response and permanent, maintenance-free operation with long-term stable calibration (AlphaGUARD User Manual 1998). In this study AlphaGUARD instrument was operated under factory Calibration. The calibration factor was set at 1 so the measured values of radon concentrations were reported directly without use of any equation. As the long-term stability of the system is expected to be excellent, normally the calibration factors will not require frequent changes. Once the AlphaGUARD instrument is suited with correct calibration factors it keeps its stability over many years (guaranteed 5 years). Based on the in-built quality assurance system the user can have full confidence in the calibration of the unit as long as there is no indication of malfunction (AlphaGUARD User Manual 2007).

AlphaGUARD monitor in diffusion mode was set to measure the radon concentration readings in every ten minutes cycles for five hours. In the diffusion mode, only ^{222} Rn gas passes through the glass fiber filter which is a part of Alpha Guard Ionization Chamber (Retention coefficient >99.9%) into the chamber while the filter retains the radon progeny products (Sumesh et al. 2011). The reading for every ten minutes, hourly and overall mean indoor radon concentration was recorded. The measured radon concentrations were obtained in Bq/m³ units. In addition to determination of radon concentration in air, AlphaGUARD's integrated sensors measure and record ambient temperature, relative humidity and atmospheric pressure.

RESULTS AND DISCUSSIONS

The mean radon concentrations in Becquerel per cubic metre (Bq/m^3) from this study are presented together with statistical errors recorded in consecutive 5 hours from 41 houses.

Variation of Indoor Radon Gas Concentrations with Time

Figure 2 and Figure 3 shows the radon concentrations observed to vary with time and the variation were higher than the statistical error indicated. Radon concentrations can vary between adjacent homes, and can vary within a home from day-to-day and from hour-to-hour. Short time changes of the radon concentration can be associated with influences such as temperature, relative Humidity (rH) and pressure. Because of these fluctuations, estimating the annual mean concentrations of indoor radon requires measurements of mean radon concentrations for at least three months (WHO 2009). Radon concentrations fluctuate seasonally, but are usually higher in winter than in summer, and are usually higher at night than during the day. This is because the sealing of buildings (to conserve energy) and the closing of doors and windows (at bedtime), reduce the intake of outdoor air and allow the build-up of radon (WHO 2005, EPA 2013).

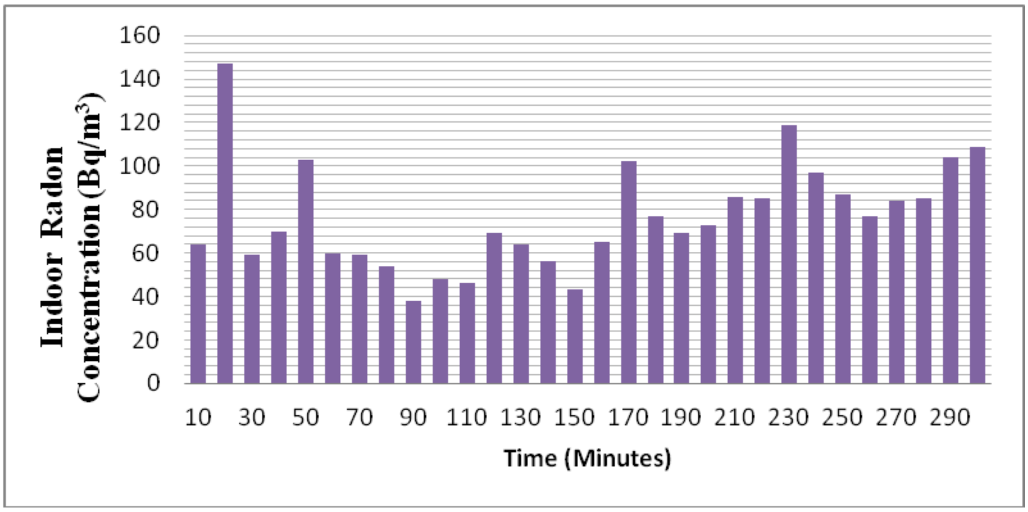

Figure 2: Variation of Indoor Radon Gas Concentrations with Time from Agondi Village (H1). Mean Indoor Radon = 74±6 Bq/m^3

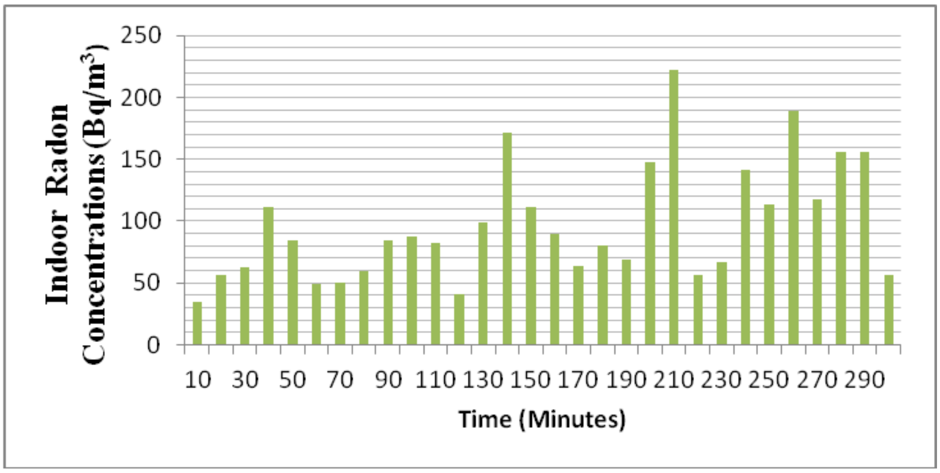

Figure 3: Variation of Indoor Radon Gas Concentrations with Time from Kamenyanga Village (H6). Mean Indoor Radon= 96±8 Bq/m^3

Mean Indoor Radon Concentrations

The mean Indoor radon concentrations and environmental parameters recorded in the vicinity of Manyoni uranium deposit are presented in Tables 1a, 1b and 1c. The comparison of mean Indoor radon concentrations recorded during day and night are presented in Table 2. The mean Indoor radon concentrations as a function of distance from the known deposits are presented in Tables 3a, 3b and 3c. The overall mean outdoor radon concentrations in the vicinity of Manyoni uranium deposit used as control are presented in Table 4. The comparison of overall mean Indoor and Outdoor radon concentrations recorded from eight areas are presented in Table 5.

Tables 1a, 1b and 1c present summary of the mean Indoor radon concentrations in the entire representative in 32 houses from eight villages in the vicinity of Manyoni Uranium Deposit. The highest radon indoor concentration of 518±28 Bq/m^3 was recorded at Mwanzi village in H8 while the lowest indoor radon concentration of 27±3Bq/m^{3}was recorded at Agondi village in H4. The second highest indoor radon concentrations of 512±29 Bq/m^3 appears at Majengo in H30. The indoor radon concentrations is in range of (27±3-518±28) Bq/m^3 with the overall mean of 166±12 Bq/m^3 which is above recommended values of 100 Bq/m^3 and 148 Bq/m^3 set by WHO and EPA, respectively. Others measurements were taken in 9 houses at Manyoni town. The overall mean indoor radon concentrations is 66±5 Bq/m^3 with the lowest and highest values of 19±3 Bq/m^3 and 164±10 Bq/m^3, respectively.

Table 1a: Summary of Overall Mean Indoor Radon Concentrations, Location, Temperature and Relative Humidity

Areas	House code	House Location	Radon conc. (Bq/m^3)	Temperature	rH (%)
Agondi Village	H1	S05^{0}45`36.9`` E034$^0$41`59.3``	74 ±6	26 - 29	49 - 60
	H2	S05^{0}46`45.2`` E034$^0$40`47.1``	66±6	24 - 30	45 - 57
	H3	S05^{0}46`26.5`` E034$^0$41`13.9``	37±9	26 - 32	39 - 54
	H4	S05^{0}48`31.3`` E034$^0$41`33.7``	27±3	31 - 32	27 - 33
	H5	S05^{0}48`17.6`` E034$^0$42`02.0``	59±5	26 - 32	35 - 54
Kamenyanga Village	H6	S05^{0}39`44.1`` E034$^0$45`41.8``	96±8	28 - 30	42 - 44
	H7	S05^{0}39`27.7`` E034$^0$45`45.9``	55±6	23 - 29	43 - 56
	H8	S05^{0}42`07.6`` E034$^0$45`05.4``	31±3 54±4*	31 - 33	35 - 44
	H9	S05^{0}42`42.7`` E034$^0$44`48.6``	74±6	25 - 30	45 - 57
	H10	S05^{0}41`53.8`` E034$^0$44`48.3``	46±4	23 - 27	51 - 63
	H11	S05^{0}42`15.2`` E034$^0$45`10.7``	32±3 125±8*	29 - 31	37 - 47
Mkwese village	H12	S05^{0}35`12.9`` E034$^0$49`19.0``	52±5	23 - 25	68 - 72
	H13	S05^{0}38`19.7`` E034$^0$48`27.8``	35±3	23 - 28	57 - 74
	H14	S05^{0}37`15.3`` E034$^0$48`00.3``	43±4	25 - 26	63 - 71

Table 1b. Summary of Overall Mean Indoor Radon Concentrations, Location, Temperature and Relative Humidity

Area	House code	House Location	Radon conc. (Bq/m^3)	Temperature (Degree C)	rH (%)
Muhalala Village	H15	S05^{0}48`06.9`` E034$^{0}$52`55.1``	102±9	NR	NR
	H16	S05^{0}48`41.8`` E034$^{0}$52`33.0``	230±16	NR	NR
	H17	S05^{0}47`04.6`` E034$^{0}$52`55.9``	98±6*	NR	NR
	H18	S05^{0}47`22.8`` E034$^{0}$53`03.6``	234±42	23-29	53-59
	H19	S05^{0}47`44.2`` E034$^{0}$53`06.3``	303±19	NR	NR
	H20	S05^{0}47`00.6`` E034$^{0}$53`02.0``	135±9*	NR	NR
	H21	S05^{0}47`07.1`` E034$^{0}$53`20.0``	139±11	21-28	30-38
Mitoo Village	H22	S05^{0}40`25.7`` E034$^{0}$51`34.9``	308±20	NR	NR
	H23	S05^{0}41`04.9`` E034$^{0}$49`35.0``	305±19	25-29	60-65
	H24	S05^{0}41`12.8`` E034$^{0}$49`52.1``	442±26	25-29	50-60
	H25	S05^{0}41`32.6`` E034$^{0}$49`40.7``	286±19	28-32	43-53
Mwanzi Village	H26	S05^{0}44`28.0`` E034$^{0}$51`29.1``	83±7	25-27	55-64
	H27	S05^{0}44`14.3`` E034$^{0}$51`32.7``	259±17	24-27	55-57
	H28	S05^{0}42`25.2`` E034$^{0}$52`33.2``	518±28	NR	NR
Majengo Village	H29	S05^{0}45`36.9`` E034$^{0}$49`50.5``	242±16	NR	NR
	H30	S05^{0}45`35.9`` E034$^{0}$49`33.2``	512±29	NR	NR
Kipondoda Village	H31	S05^{0}45`32.7`` E034$^{0}$50`28.8``	182±13	NR	NR
	H32	S05^{0}45`16.2`` E034$^{0}$50`40.6``	156±12	NR	NR

Upper reference level for indoor radon for homes proposed by ICRP is 300 Bq/m^3 (ICRP 2009).

Table 1c. Summary of Overall Mean Indoor Radon Concentrations, Location, Temperature and Relative Humidity

Area	House code	House Location	Radon conc. (Bq/m^3)	Temperature (Degree C)	rH (%)
Manyoni Town	H33	S05^{0}44`54.7`` E034$^0$49`38.2``	56±5 64±5*	24 - 29	42 - 52
	H34	S05^{0}44`48.9`` E034$^0$49`52.4``	22±2 42±3*	NR	NR
	H35	S05^{0}44`33.3`` E034$^0$50`02.2``	164±10	NR	NR
	H36	S05^{0}44`14.8`` E034$^0$50`40.1``	44±3	24-33	33-63
	H37	S05^{0}44`08.3`` E034$^0$50`33.3``	54±5	27	54
	H38	S05^{0}44`04.3`` E034$^0$50`21.0``	19±3	NR	NR
	H39	S05^{0}44`00.1`` E034$^0$49`21.6``	26±3	NR	NR
	H40	S05^{0}44`37.2`` E034$^0$49`36.2``	108±10	NR	NR
	H41	S05^{0}44`51.6`` E034$^0$49`57.7``	44±3 124±9	NR	NR

* Indicate Indoor Radon Concentration recorded at night. H Means house

19% of houses surveyed in this study indicate higher indoor radon concentrations than this maximum limit. At Mitoo village 75% of surveyed houses are above of this limit. 41% of surveyed houses are higher than the maximum value of 148 Bq/m^3 recommended by EPA (EPA 1995, 2007). 53% of 32 surveyed houses in this study are above 100 Bq/m^3 recommended by WHO (WHO 2009). 100% of surveyed houses from Mitoo, Majengo and Kipondoda villages are above of this limit while 85% and 68% of surveyed houses from Muhalala and Mwanzi villages, respectively, are higher than maximum limit set by WHO.

The results of overall mean indoor radon concentrations from Kipondoda, Muhalala, Mwanzi, Mitoo and Majengo villages which are (169±13, 177±16, 287±13, 325±21 and 377±23) Bq/m^3, respectively, exceed the limit of 100 Bq/m^3 and 148 Bq/m^3 set by WHO and EPA, respectively. The value of 325±21 Bq/m^3 and 377±23 Bq/m^3 from Mitoo and Majengo, respectively, exceed the limit of 300 Bq/m^3 recommended by ICRP. Compared Indoor radon concentrations from this study to ICRP, EPA and WHO maximum limits, indicate people in the vicinity of Manyoni Uranium Deposit are living in danger. The probability of developing lung cancer and risk associated with leukemia and other cancers such as melanoma and cancers of the kidney and prostate is also high.

Comparison of Day and Night Indoor Radon Concentration

Night readings were conducted in houses with power supply and accessibility (no privacy or resistance). Only 8 data points for nights were recorded as shown in Table 2. The comparison indicates night levels were generally higher at any time than the day concentrations.

Table 2: Comparison of Observed Diurnal Indoor Radon Levels from Two Areas

Areas	House code	House Location	Radon conc. (Bq/m^3)	
			Day	Night
Kamenyanga village	H9	S05^{0}42`07.6`` E034$^0$45`05.4``	31 ±3	54±4
	H12	S05^{0}42`15.2`` E034$^0$45`10.7``	32 ±3	125 ±8
Manyoni town	H35	S05^{0}44`54.7`` E034$^0$49`38.2``	56±5	64±5
	H36	S05^{0}44`48.9`` E034$^0$49`52.4``	22±2	42±3
	H41	S05^{0}44`51.6`` E034$^0$49`57.7``	44±3	124±9

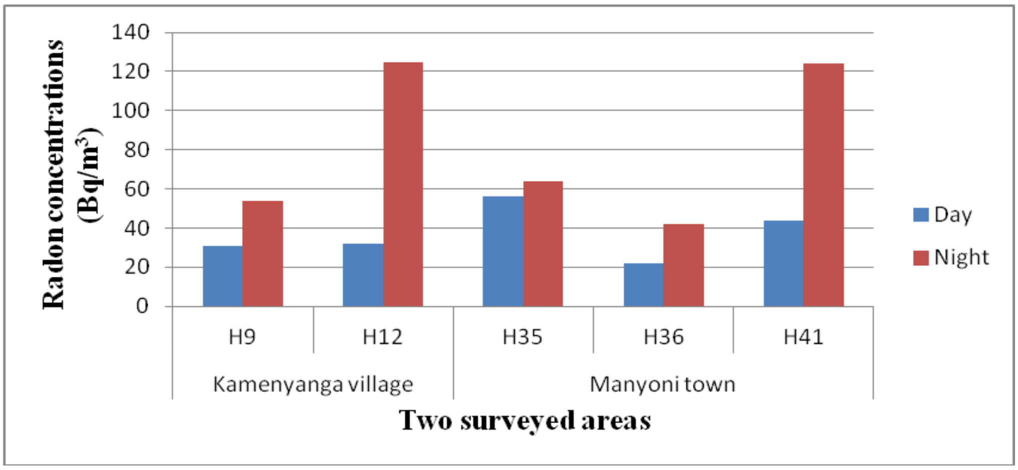

Figure 5: Comparison of Day and Night Indoor Radon Concentration Observed from Two Areas of Kamenyanga (H9 and H12) and Manyoni Town (H35, H36 and H41)

Table 3a: Mean Indoor Radon Concentrations with Distance from Deposits

Area	Nearly Deposit Location	House code	House Location	Distance from source in Km	Radon conc. (Bq/m^3)
Agondi Village	S05^{0}46`45.2`` E034$^0$40`47.1``	H1	S05^{0}45`36.9`` E034$^0$41`59.3``	3.062	74 ±6
		H2	S05^{0}46`45.2`` E034$^0$40`47.1``	0	66±6
		H3	S05^{0}46`26.5`` E034$^0$41`13.9``	1.006	37±9
		H4	S05^{0}48`31.3`` E034$^0$41`33.7``	3.582	27±3
		H5	S05^{0}48`17.6`` E034$^0$42`02.0``	3.666	59±5
Kamenyanga Village	S05^{0}39`44.1`` E034$^0$45`41.8``	H6	S05^{0}39`44.1`` E034$^0$45`41.8``	0	96±8
		H7	S05^{0}39`27.7`` E034$^0$45`45.9``	0.522	55±6
		H8	S05^{0}42`07.6`` E034$^0$45`05.4``	4.422	31±3 54±4*
		H9	S05^{0}42`42.7`` E034$^0$44`48.6``	5.754	74±6
		H10	S05^{0}41`53.8`` E034$^0$44`48.3``	4.33	46±4
		H11	S05^{0}42`15.2`` E034$^0$45`10.7``	4.764	32±3 125±8*
Mkwese village	S05^{0}35`12.9`` E034$^0$49`19.0``	H12	S05^{0}35`12.9`` E034$^0$49`19.0``	0	52±5
		H13	S05^{0}38`19.7`` E034$^0$48`27.8``	5.981	35±3
		H14	S05^{0}37`15.3`` E034$^0$48`00.3``	4.488	43±4

Table 3b: Mean Indoor Radon Concentrations with Distance from Deposits

Area	**Nearly Deposit Location**	**House code**	**House Location**	**Distance from source in Km**	**Radon conc (Bq/m^3)**
Muhalala Village	S05^{0}49`15.4`` E034$^{0}$53`01.3``	H15	S05^{0}48`06.9`` E034$^{0}$52`55.1``	2.124	102±9
		H16	S05^{0}48`41.8`` E034$^{0}$52`33.0``	1.354	230±16
		H17	S05^{0}47`04.6`` E034$^{0}$52`55.9``	4.043	98±6*
		H18	S05^{0}47`22.8`` E034$^{0}$53`03.6``	3.479	234±42
		H19	S05^{0}47`44.2`` E034$^{0}$53`06.3``	2.821	303±19
		H20	S05^{0}47`00.6`` E034$^{0}$53`02.0``	4.164	135±9*
		H21	S05^{0}47`07.1`` E034$^{0}$53`20.0``	4.004	139±11
Mitoo Village	S05^{0}41`59.3`` E034$^{0}$49`57.3``	H22	S05^{0}40`25.7`` E034$^{0}$51`34.9``	4.166	308±20
		H23	S05^{0}41`04.9`` E034$^{0}$49`35.0``	1.815	305±19
		H24	S05^{0}41`12.8`` E034$^{0}$49`52.1``	1.445	442±26
		H25	S05^{0}41`32.6`` E034$^{0}$49`40.7``	0.9698	286±19
Mwanzi Village	S05^{0}42`25.2`` E034$^{0}$52`33.2``	H26	S05^{0}44`28.0`` E034$^{0}$51`29.1``	4.274	83±7
		H27	S05^{0}44`14.3`` E034$^{0}$51`32.7``	3.849	259±17
		H28	S05^{0}42`25.2`` E034$^{0}$52`33.2``	0	518±28
Majengo Village	S05^{0}44`00.1`` E034$^{0}$49`21.6``	H29	S05^{0}45`36.9`` E034$^{0}$49`50.5``	3.119	242±16
		H30	S05^{0}45`35.9`` E034$^{0}$49`33.2``	2.98	512±29
Kipondoda Village	S05^{0}44`00.1`` E034$^{0}$49`21.6``	H31	S05^{0}45`32.7`` E034$^{0}$50`28.8``	3.528	182±13
		H32	S05^{0}45`16.2`` E034$^{0}$50`40.6``	3.379	156±12

Table 3c: Mean Indoor Radon Concentrations with Distance from Deposits

Area	Nearly Deposit Location	House code	House Location	Distance from source in Km	Radon conc. (Bq/m^3)
Manyoni Town	S05^{0}44\`00.1\`\` E034$^0$49\`21.6\`\`	H33	S05^{0}44\`54.7\`\` E034$^0$49\`38.2\`\`	1.762	56±5 64±5*
		H34	S05^{0}44\`48.9\`\` E034$^0$49\`52.4\`\`	1.78	22±2 42±3*
		H35	S05^{0}44\`33.3\`\` E034$^0$50\`02.2\`\`	1.615	164±10
		H36	S05^{0}44\`14.8\`\` E034$^0$50\`40.1\`\`	2.455	44±3*
		H37	S05^{0}44\`08.3\`\` E034$^0$50\`33.3\`\`	2.218	54±5
		H38	S05^{0}44\`04.3\`\` E034$^0$50\`21.0\`\`	1.83	19±3
		H39	S05^{0}44\`00.1\`\` E034$^0$49\`21.6\`\`	0	26±3
		H40	S05^{0}44\`37.2\`\` E034$^0$49\`36.2\`\`	1.231	108±10
		H41	S05^{0}44\`51.6\`\` E034$^0$49\`57.7\`\`	1.939	124±9*

Radon concentration is dependent on the distance from the source (Mishra et al. 2004, Zubair et al. 2011). As distance increasing from the source, the radon concentrations is expected to decrease and vice-versa. The mean Indoor radon concentrations varied with distance from deposits are presented in Table 3. The mean indoor radon concentrations from Mkwese, Mwanzi and Majengo villages were observed to vary significantly with distance from the source (deposit). However, other areas the trend was not obtained as expected. This may be due to other factors, such as building structure and design, the building materials, ventilation condition, topography of the area, soil characteristics, wind direction, atmospheric pressure, soil gas radon concentration and the life style of people, instruments location, and time of taking measurements (morning, afternoon or night).

The Mean Outdoor Radon Concentrations in the Vicinity of Manyoni Uranium Deposit

The measurements of outdoor radon concentrations were done in all eight villages in the vicinity of Manyoni Uranium deposit. The highest outdoor radon concentration of 47±4 Bq/m^3 was recorded at Muhalala village while the lowest radon concentrations of 15±3 Bq/m^3 were recorded at Mkwese and Kamenyanga villages. Outdoor radon concentrations recorded at Manyoni is 24±3 Bq/m^3

Table 4: The Overall Mean Outdoor Radon Concentrations in the Vicinity of Manyoni Uranium Deposit Used as Control

Village Name	Outdoor Radon Conc. (Bq/m^3)
Agondi	16±2
Mkwese	15±3
Muhalala	47±4
Mitoo	33±4
Mwanzi	32±4
Majengo	24±3
Kipondoda	24±3
Kamenyanga	15 ±3

Table 5 shows the mean indoor and outdoor radon concentrations in the vicinity of Manyoni Uranium deposit and Figure 5 shows their comparison in a Histogram. When compared to indoor radon concentrations from this study, outdoor radon levels are generally low. This might be due to dispersal and dilution within the atmosphere. Once inside a building, the radon cannot easily escape. The ceiling of buildings to conserve energy reduces the intake of outside air and worsens the situation (Maeda and Hobbs 1996, El-Zaher and Fahmi 2008). The overall mean Indoor radon from all areas in the vicinity of the deposit is 166±12 Bq/m^3 whilst the mean Outdoor radon is 26±3 Bq/m^3. This shows that the Indoor radon concentrations from this study are 6.4 times higher than the overall mean Outdoor radon from the surveyed areas. This implies that staying more inside the house may lead to more exposure to radon than staying outside.

Table 5: Overall Mean Radon Concentrations in the Vicinity of Manyoni Uranium Deposit

Villages	**Mean Radon Concentrations (Bq/m^3)**	
	Indoor	**Outdoor**
Agondi	53±6	16±2
Mkwese	43±4	15±3
Muhalala	177±16	47±4
Mitoo	325±21	33±4
Mwanzi	287±17	32±4
Majengo	377±23	24±3
Kipondoda	169±13	24±3
Kamenyanga	62±6	15 ±3

CONCLUSIONS

The overall mean indoor radon concentrations results from five villages out of eight surveyed villages are in range of (169±13 - 377±23) Bq/m^3 which is higher than 100 Bq/m^3 and 148 Bq/m^3 limits recommended by WHO and EPA, respectively. Two villages (Mitoo and Majengo) each have overall mean indoor radon concentrations of 325±21 Bq/m^3 and 377±23 Bq/m^3, respectively, which exceed the limit of 300 Bq/m^{3}set by ICRP. The mean outdoor radon concentration was 26±3 Bq/m^3. The results from this study have shown high indoor radon concentrations in the vicinity of Manyoni Uranium Deposit which may pose health risks. Therefore, it is strongly recommended people in the vicinity of Manyoni Uranium Deposit to be encouraged to increase more ventilation rate by building their houses with large and enough doors and windows. Improving ventilation of these houses resulting in increasing air exchange rates with the outside, thereby results in lowering the radon concentrations.

The mean indoor radon concentrations from Mkwese, Mwanzi and Majengo villages were observed to vary significantly with distance from the deposit. People are also adviced to build their houses far away from the deposits. It is recommended to stop for immigrants from areas of lower environmental radiation exposure to areas of higher environmental radiation exposure. This is because background radiation will only affect immigrants for the area not indigeneous people. It is also suggested to use other radon measuring techniques which do not require electrical power sources for sufficient measurements in both areas with electricity and with no electricity. At the same time it is suggested to use two or more techniques of measuring of indoor radon concentrations at once for references.

It is suggested to collect data over a longer period of time to smooth out any anomalous data and to determine if there is significant seasonal variation in indoor radon concentrations obtained from Manyoni uranium deposit. Also due to the fact that indoor radon concentrations depends on different factors it is strongly advised the next or the future studies, to consider and report on other remaining factors such as wind directions and conditions and topography of the area which due to limited resources and time were not investigated in this study. People in the vicinity of Manyoni Uranium Deposit should be educated on the effect of Radon concentrations, advantages for taking measurement of radon concentrations in their houses and the safety of the radon measurements techniques in order to give awareness for other people who believe radon measuring techniques inside houses can cause health effect and problem to their houses.

This study stresses the need for a more extended survey on radon risk by determining the risk of lung cancer associated with indoor radon exposure in Manyoni District in Singida in the vicinity of uranium deposit by using different models for evaluating the risk of lung cancer from radon exposure. Moreover it is recommended to conduct further study to assess the indoor radon concentrations for different places of elevated uranium levels such as Bahi and Mkuju Uranium deposits to establish the baseline.

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