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Background Radiations and Radon Concentrations in the Dormitories of Secondary Schools in Otuke District, Uganda

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Abstract: Inhalation of radon and its progeny is the most significant source of natural radiation exposure to human population. Over 50% of the natural background radiation comes from radon (^{222}Rn). This paper presents measured background radiations, indoor radon concentrations, and calculated effective doses to students due to radon inhalation in the dormitories of five selected boarding secondary schools in Otuke District. Background radiations in the dormitories were measured using survey meters, and radon concentrations determined using activated charcoal canister method. Effective doses were calculated basing on the radon concentrations in the dormitories. Data collection was done for a period of seven months in two shifts; between September 2016 and March 2017, and between April and May 2018, respectively. Background radiations in counts per second were found to range from 0.8±0.2 to 1.7±0.3 with an average of 1.2±0.2 cps. Radon concentrations were in the range of 18±3 Bq m^{-3} to 49±5 Bq m^{-3} with an average of 30±4 Bq m^{-3}, and the corresponding annual effective doses ranged from 0.14±0.02 mSv y^{-1} to 0.39±0.04 mSv y^{-1} with a mean of 0.24±0.02 mSv y^{-1}. Radon concentrations measured were below the World Health Organization action level of 100 Bq m^{-3} and the mean effective dose was well below 1.0 mSv y^{-1} which is the dose limit set for members of the public by the International Commission on Radiological Protection. Basing on these set limits, students sleeping in the studied dormitories are not exposed to high doses of indoor radon and are therefore not vulnerable to effects associated with high doses of radiation. It is recommended that, strategies for radon prevention in new dormitories could be put in place to minimize radon concentrations below the values reported, and a national radon survey be done to establish a reference level for Uganda.

Keywords: Lung cancer, Radiation dose, Radioactivity, Radon progeny.

1 Introduction

Radon is a colourless, odourless, and tasteless radioactive gas that evades detection by human senses [1, 2, 3, 4]. Its density of 9.73 kg m^{-3} [5] is high compared to air with a density of 1.225 kg m^{-3}. Radon comes from the decay of radium which is part of uranium decay series, shown in Equation (1).

$$^{234}_{92}U \rightarrow ^{230}_{90}Th + \alpha \rightarrow ^{226}_{88}Ra + \alpha \rightarrow ^{222}_{86}Rn + \alpha + \gamma \quad (1)$$

Other radon isotopes, radon-219 (^{219}Rn) and radon-220 (^{220}Rn), come from the decay series of uranium-235 (^{235}U) and thorium-232 (^{232}Th), respectively. These isotopes have half-lives of 4 seconds and 55 seconds, respectively [6]. Although they are both radioactive, their short half-lives make their contribution to indoor radon concentrations insignificant. Therefore, ^{222}Rn is the only isotope present in air in significant quantity.

All rocks contain some uranium or thorium; most of which are directly related to radon [2, 7]. However, some types of rocks have higher than average uranium/thorium contents. These include volcanic rocks and sedimentary rocks [7]. Rocks and their soils contain relatively higher concentrations of uranium/thorium than other minerals. The higher the concentration of uranium/thorium in the soil samples, the greater is the concentration of radon. This could implies that there is much radon underneath the floors of buildings, because rocks and soils are commonly used as building materials. It can then find its way into indoor air through cracks in the floor and other holes in the foundation [2, 8]. Therefore, poorly ventilated buildings with many cracks in the floor are likely to have high indoor radon concentrations [9]. When water supplies are drawn from aquifers in radium bearing strata, water usage can be another contributor to indoor radon [10], and yet water

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plays an important role in human nutrition [11]. In this case, even in a well-ventilated house, soil gas and water can lead to high radon concentrations.

Radon also undergoes radioactive decay emitting alpha particles to form daughter radioactive nuclides (or progeny), shown in Equation (2).

$$^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + \alpha \rightarrow {}^{214}_{82}Pb + \alpha \rightarrow {}^{214}_{83}Bi + \beta + \gamma \quad (2)$$

The progeny are solid particles which easily attach to the dust particles and when inhaled, they impart radiation dose to the lung tissues leading to lung cancer. Statistics reveal that, on average, radon in room air contributes over 50% of the natural background radiations [12]. It is estimated to contribute 3-14% of all lung cancer cases in the US [13]. Exposure to radon, therefore, poses risks of contracting lung cancer to all members of the public but children up to teenage are more susceptible than the adults when exposed to the same radiation dose [14]. This is because children have rapid growth of cells which are very sensitive to radiation and chances are also high that cancer manifests in children in their lifetime as they have longer time to live than the adults who may die with cancer before it manifests in them. Since children up to teenage are mostly at schools, school premises could be one of the contributors to their radon exposure.

The United States Environmental Protection Agency (EPA) recommends that school buildings be tested for radon [15]. The International Commission on Radiological Protection (ICRP) sets an average annual effective dose to the general population of 1.0 mSv y^{-1} [16] to be attributable to inhalation of radon and its progeny [17]. For this reason and also considering that people spend most of their night time indoor, many investigations of radon exposure have been conducted both in schools and dwellings worldwide. The results obtained are then compared with the concentration limit set by the World Health Organization (WHO) of 100 Bq m^{-3} and ICRP annual effective dose. The EPA conducted a National School Radon Survey which provides a statistically valid representation of the levels of radon in schools at the national level in the US [15]. The results show widespread radon contamination in schools, in which nearly one in five schools has at least one schoolroom with radon concentration above 100 Bq m^{-3}, the level at which WHO recommends that schools take action to reduce on the concentration.

In Uganda, few studies have been reported on indoor radon concentrations and data is only collected from some selected districts in Central, Eastern and Western regions. Central region has been found to have high radon concentrations ranging from 10 to 420 Bq m^{-3} in Kampala City [18]. Eastern region has concentrations ranging from 28±1 to 97±5 Bq m^{-3} and the effective doses ranging from 0.71±0.03 to 2.44±0.03 mSv y^{-1} in Tororo and Busia [19]. In Western Uganda, a study was conducted at Kilembe copper-cobalt mines situated on the South-eastern slopes of Mt. Rwenzori [18]. Radon gas concentrations ranged from 330 to 6980 Bq m^{-3}. Although this was not an indoor study, there was evidence of data collected from the region, unlike Northern Uganda which had no substantial report, meaning not studied. Therefore, Otuke District was piloted and reported in this paper. Figure 1 is a map of Uganda showing the location of Otuke District, indicated by the brown colour.

Otuke District was carved from Lira District in 2010. From google map, the district is located between latitudes 02^0 20' 05" N and 02^0 37' 27" N, and longitudes 33^0 39' 30" E and 33^0 39' 30" E, respectively. By the time of this study, The National Population and Housing Census 2014 showed that Otuke District had eight sub-counties, namely: Adwari, Alango, Ogor, Ogwette, Okwang, Olilim, Orum and Otuke Town Council, respectively [20]. The district was considered for study because of the availability of rocks and soils, which are a source of construction materials for floors and walls of most buildings. Five government aided secondary schools (S. S.) in five sub-counties were selected because they contained the highest students' population and had well established dormitories. Of these schools, only Adwari S. S. had permanent dormitories. Table 1 summarizes the basic information obtained about the schools.

Fig. 1: The location of Otuke District in Uganda, showing district boundaries as they stood in June 2017 [21].

The study covered the measurements of ambient background radiations and indoor radon concentrations in the five secondary schools, and determination of annual effective doses received by students in sampled dormitories of the schools.

Table 1: Selected secondary schools in Otuke District where data were collected.

S/no	School	Students	Dormitories	Sub-couty
1	Adwari S. S.	1250	6	Alango
2	Ogor Seed S. S.	247	2	Ogor
3	Okwang S. S.	815	4	Okwang
4	Orum S. S.	337	2	Otuke T/C
5	Otuke S. S.	134	2	Olilim

2 Materials and Methods

2.1 Determination of Background Radiations

Background radiation comes from naturally occurring radioactive materials contained in the earth and in living things and other sources in space like cosmic rays [22]. Natural sources of radiation account for the largest amounts of radiation exposure received by most people each year. Radon contributes about fifty percent of the natural background radiation, gamma radiation (20%), water and food (12%), and Cosmic rays (18%), as illustrated in Figure 2 [12]. Survey meters (mini-con series 1000 & Polimaster PM1703M) were used to measure the background radiations. The mini-con series 1000 (hereafter MCS1000), powered by a readily available 9 V primary battery, is suitable for monitoring alpha, beta and gamma radiations above 3 MeV. The magnitude of radiation detected was read from the scale, in the range of 0-1000 cps. The window area was opened to allow the instrument detect all the three radiations, the main interest being the detection of alpha and gamma radiations emitted by radon decay daughters. However, this survey meter would not identify the particular radiation being measured. The Polimaster PM1703M operates in the temperature range of -20 ^{0}C to +500 ^{0}C. It was first adjusted using the operation mode to take readings in cps (with uncertainty of ±1% cps) so as to have uniform unit with MCS1000. Each of the survey meters was switched on and held approximately 0.5 m above the floor at various positions in the visited room or dormitory. After about three minutes, the background radiation in each case was recorded. The average background radiation in the room was then calculated.

2.2 *Determination of Indoor Radon Concentrations*

Radon concentration is the amount of radon gas in a given

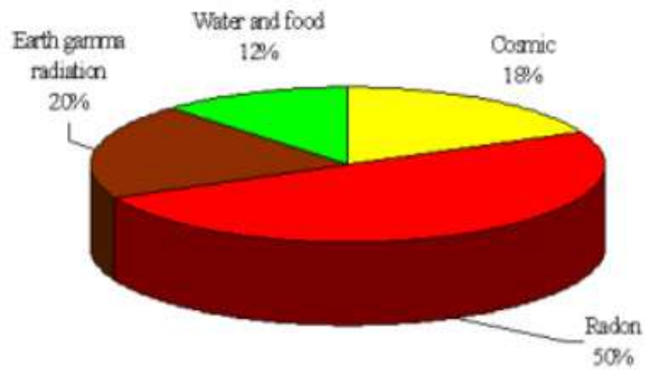

Fig. 2: Sources of background radiations [12].

volume, i.e., a measure of the amount of radioactivity (Bq) in a cubic metre of air. Therefore, its unit is becquerel per cubic metre (Bq m^{-3}) [23], where 1 Bq corresponds to one disintegration per second. Activated charcoal canisters were deployed in the dormitories in the determination of radon concentrations. Before deploying the canisters, they were first annealed by heating in an oven to a temperature of about 150 ^{0}C for 12 hours to drive off moisture. After removing from the oven, the canisters were left to cool for about 10 minutes and then sealed. Each of the canisters was then labeled and weighed on an electronic balance. The initial mass of each canister was recorded. Ten canisters, labeled C1 to C10, were used, and two were deployed in each school, i.e., C1 and C2 in Adwari S. S., C3 and C4 in Orum S. S., C5 and C6 in Ogor Seed S. S., C7 and C8 in Okwang S. S., and C9 and C10 in Otuke S. S., respectively. The codes were assigned to ensure proper identification of canisters. The canisters were opened and deployed in the rooms of different dormitories for three consecutive days chosen at random in a given month. This allowed activated charcoal to adsorb radon, radon progeny, and water vapour in the indoor air. The canisters were placed away from the door, window, or ventilation to avoid measuring radon concentration from outdoor air. In the subsequent deployment, canisters were placed in another room and/or dormitory and the average radon concentrations for the schools (dormitories) were computed. Schools with only two dormitories (Otuke S. S. and Ogor Seed S. S.) had canisters deployed seven times in the period of seven months data were collected. The room temperature was also measured using alcohol-in-glass thermometer calibrated to take readings in degree Celsius with uncertainty of ±1 ^{0}C. Temperature measurement was done because increase in temperature decreases the ability of activated charcoal to adsorb radon. At the end of exposure period of three days (72 hours), the canisters were re-sealed firmly and returned to the laboratory for analysis. Each canister was re-weighed and the mass gain, *m*, was obtained. The samples were then analyzed using the 7.5 cm sodium iodide scintillation detector (GDM 20), connected to a Personal Computer (PC) with a serial port, to give the exact radon concentration. The GDM 20 was first calibrated for energy and efficiency. Each canister was mounted on the detector, one at a time and the details of its deployment (namely: mass gain, end date and time of exposure, and average room temperature) entered in the PC. After a period of 20 to 30 minutes, radon concentration in Bq m^{-3} was automatically calculated and displayed, with error limits. For each month, ten canisters were analyzed (two for each school) for a period of seven months. The average indoor radon concentration, *R*, per room was then calculated using the expression in Equation (3).

$$R = \frac{\sum Concentration\ sperroom}{Number\ of\ measure\ mentsperroom}. \quad (3)$$

The average radon concentration for each school per month, *Rn*, was then calculated.

2.3 *Determination of Effective Doses*

Effective dose is the summation of the tissue equivalent dose, each multiplied by the appropriate tissue weighing factor [24], i.e,

$$E_d = \sum_{allT} w_T \times H_T, \quad (4)$$

where E_d is the effective dose, w_T is the tissue weighing factor for tissue T, and H_T is the equivalent dose in the tissue T. Effective dose is a mathematical construct or concept of risk, used in radiation protection as the basis for calculating annual radiation limits to workers and members of the public from exposure to radiation and intakes of radionuclides [25]. It is therefore the best single parameter for quantifying the total amount of radiation received by an individual. Effective dose is measured in sieverts (Sv), and knowing the measured radon concentration *R*, the effective dose can then be calculated using the expression,

$$E_d = R \times EF \times OT \times DCF, \quad (5)$$

where E_d is the effective dose (in mSv y^{-1}), *R* is the Radon concentration per room, *OT* is the occupancy time (in hours per year), and *EF* is the equilibrium factor. The equilibrium factor is used to describe the ratio between radon and its progeny [26]. An equilibrium factor of 1 means equal amounts of radon and its progeny. The *EF* is taken on average to be 0.4 [27], occupancy factor is 0.8 and is used to calculate *OT*. The *DCF* is the dose conversion factor and is given as 9.0×10^{-6} mSv h^{-1}(Bq $m^{-3})^{-1}$ [28].

From the measured radon concentrations, the effective doses were calculated using Equation (5). In this paper, the occupancy time (*OT*) used is 2160 hours per year (h y^{-1}), not 7010 h y^{-1} used in other studies [28]. The 2160 h y^{-1} was derived from the estimate that students spend about 8 hours per day in the dormitories, i.e., from 6:00 p.m. to 7:00 p.m. during super time, and from 10:00 p.m. to 5:00 a.m. after evening preps. Also, there are three terms in a year, each having three months. Taking an average month of 30 days, then:

$$OT = 8 \times 30 \times 3 \times 3 = 2160hy^{-1}. \quad (6)$$

Table 2: Background radiation measurements with MCS1000 and PM1703M survey meters.

Pos	Adwari S.S.	Ogor Seed S.S.	Okwang S.S.	Orum S.S	Otuke S.S
MCS1000 measurements (cps)					
1	1.4	1.5	1.0	1.0	1.9
2	1.6	1.5	0.9	0.9	2.1
3	1.5	1.4	1.1	0.9	2.0
Av.	1.5±0.1	1.5±0.1	1.0±0.1	0.9±0.1	2,0±0.1
PM1703M measurements (cps)					
1	1.8	0.9	0.6	0.6	0.9
2	1.8	1.2	0.8	0.7	1.0
3	1.7	1.0	0.7	0.5	0.8
Av.	1.8±0.1	1.0±0.1	0.7±0.1	0.6±0.1	0.9±0.1
Combined measurements (cps)					
Av.	1.7±0.1	1.3±0.1	0.9±0.1	0.8±0.1	1.5±0.1

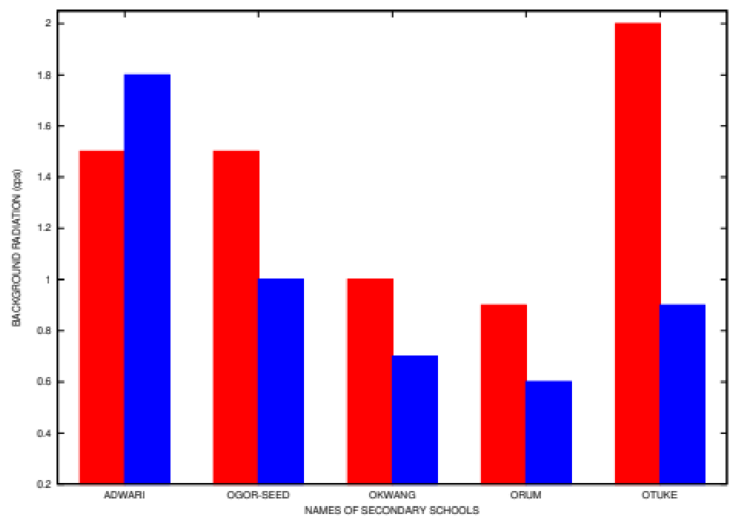

Fig. 3: Background radiation measurements with Mini-con Series 1000 (red) and PM1703M (blue).

3 Results and Discussion

3.1 Background Radiations

Table 2 shows background radiation measurements using the two survey meters, and Figure 3 shows the comparative bar graphs. Fluctuations in readings were noticed because not all radiations were equally likely to strike the detector window at the same rate. So, the averages from the survey meters were taken. Therefore, the average background radiation readings ranged from 0.8±0.1 cps in Orum S. S. to 1.7±0.1 cps in Adwari S. S., with an average of 1.2±0.1 cps for the district. The low background radiation values in Okwang S. S and Orum S. S. could have been due to some of the building materials used like murram/soil which seemingly had little radioactive materials. Besides, these schools are far from Otuke Hills and do not have any other nearby rocks. The relatively high values of background radiation in Adwari S. S., Ogor Seed S. S., and Otuke S. S., could have been due to usage of some building materials, such as rocks, which are rich in radioactive materials like uranium. Apart from Adwari S. S., Otuke S. S. and Ogor Seed S. S., with high background radiations are close to Otuke Hills, that is, Otuke S. S. is about 7 km from the hills and Ogor Seed S. S. is about 5 km from another part of the hills. Since radon is the greatest source of natural background radiations [29], it could therefore imply that the readings of the survey meters depicted some levels of radon concentrations in the selected schools which therefore had to be determined using activated charcoal canister method.

3.2 Indoor Radon Concentrations

Table 3 shows the average radon concentration measurements for each of the selected schools. Figure 4 shows the bar graphs plotted for Adwari S. S. The average radon concentrations ranged from 18±3 Bq m^{-3} in Adwari S. S. to 49±5 Bq m^{-3} in Otuke S. S., giving an average of 30±3 Bq m^{-3} for the district, as illustrated in Figure 5. Seasonal variation had an impact on radon concentrations for all the selected schools. For example, most schools had low radon concentrations in the months of September and October and also May, but high radon concentrations in January, February and March. The low radon concentrations were due to high relative humidity in the atmosphere. In months of rainy season, radon movement is greatly affected by moisture [7], that is, water slows down the speed of radon moving, thus most of the radon atoms may decay before reaching the canisters. For the same season (month), however, the schools had different radon concentrations. This was attributed to some other factors, for example, cracks in the floor of dormitories in Otuke S. S. may have increased radon concentrations while Adwari S. S. with no or fewer cracks had low radon concentrations; poor ventilation of dormitories in Ogor Seed S. S. may have led to high radon concentrations while Orum S. S. and Okwang S. S. with large windows had relatively low radon concentrations; and different building materials were used for different schools, hence variations in radon concentrations in the schools [30].

The high radon concentration measurements in Otuke S. S. was due to the availability of many cracks in the floor, and Otuke Hills being close to the school. Similarly, the high radon concentrations measured in Ogor Seed S. S. was attributed to the poor ventilation in the dormitories, and the school also being close to Otuke Hills.

Table 3: Average monthly radon concentrations measured (Bq m^{-3}).

School	Adwari S.S.	Ogor Seed	Okwang S.S.	Orum S.S.	Otuke S.S.
Sep 2016	16±3	24±4	23±3	24±3	47±4
Oct 2016	17±3	28±3	25±3	23±3	46±5
Jan 2017	19±3	34±3	28±0.1	31±3	51±5
Feb 2017	21±3	36±4	30±3	30±4	52±5
Mar 2017	20±3	35±3	26±3	32±3	52±4
Apr 2018	16±3	31±4	32±3	17±3	56±6
May 2018	18±3	28±3	20±3	24±3	42±4
Av.	18±3	31±3	26±3	26±3	49±5

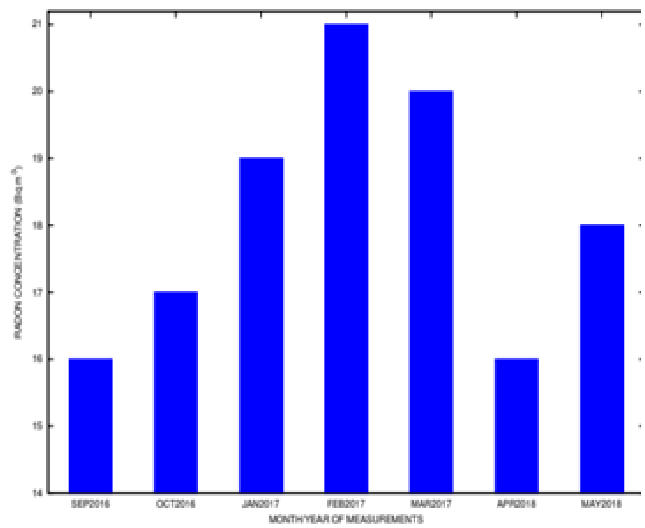

Fig.4: Radon concentration measurements for Adwari S. S.

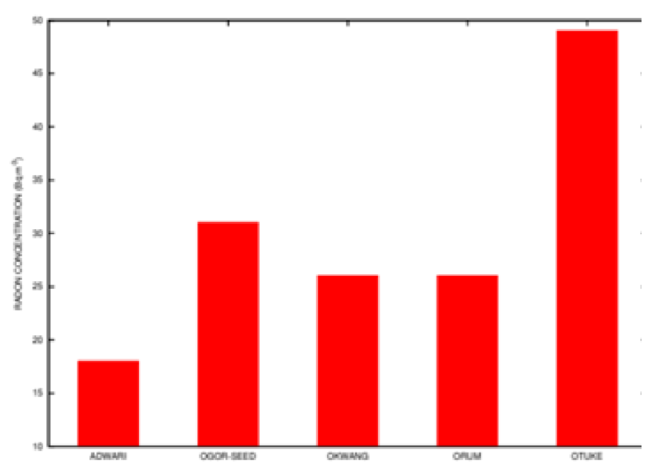

Fig. 5: Average radon concentrations for the schools.

The dormitories in Ogor Seed S. S. were once classrooms for a primary school and only turned into dormitories by blocking the windows using bricks. For Otuke District in general, a high positive correlation was found between radon concentration measurements and background radiations (Figure 6), except for Adwari S. S. (black dot), which had good ventilation and negligible cracks in the floors. In Figure 6, a linear fit was used, and a correlation coefficient of 0.88 was obtained.

3.3 Annual Effective Dose

Table 4 shows the average annual effective doses, E_d, received by students in each of the selected schools. The annual effective doses were obtained from measured radon concentrations using Equation (5). The corresponding bar graphs for E_d are shown in Figure 7. The highest dose was 0.39±0.04 mSv y^{-1} in Otuke S. S. and the lowest was 0.14±0.02 mSv y^{-1} in Adwari S. S., in line with the measured radon concentrations and conditions at the selected schools. The average effective dose was 0.24±0.02 mSv y^{-1} for the entire district.

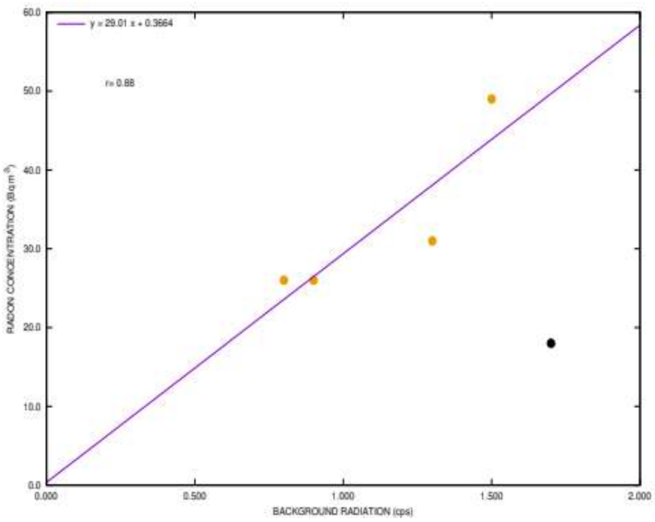

Fig. 6: Relationship between average radon concentration and average background radiation.

In Table 5 and Figure 8, the results obtained for Otuke District (Northern Uganda) are compared with findings from other parts of Uganda, namely; Kampala City (Central Uganda), and Tororo/Busia districts (Eastern Uganda), respectively. The indoor radon concentration was highest in Kampala and least in Otuke. The high indoor radon concentration measured in Kampala City could be due to many buildings, constructed with materials mainly imported from places rich in uranium. Tororo and Busia districts have radon concentrations higher than Otuke District because the environments studied were different in the two regions. Study in Otuke was focused on the school dormitories, while Tororo and Busia were in the factories and nearby homes. Therefore, the high radon concentration in Tororo/Busia could have been due to the availability of factories such as Tororo cement, which is also a source of radon emanation [31]. The factories are built using mainly rocks of hard cores, and if the rocks used were rich in uranium, then they may have contributed to high radon concentration measured. Effective doses also followed the same trend, that is, highest in Kampala and least in Otuke, and for the same reasons for the variance in the three regions studied [32-33].

Table 4: Average radon concentrations and annual effective doses for the selected schools.

School	Radon Concentration (Bq m^{-3})	Effective dose (mSv y^{-1})
Adwari S.S.	18±3	0.14±0.02
Ogor Seed S.S.	31±3	0.25±0.02
Okwang S.S.	26±3	0.21±0.02
Orum S.S.	26±3	0.21±0.02
Otuke S.S.	49±5	0.39±0.04

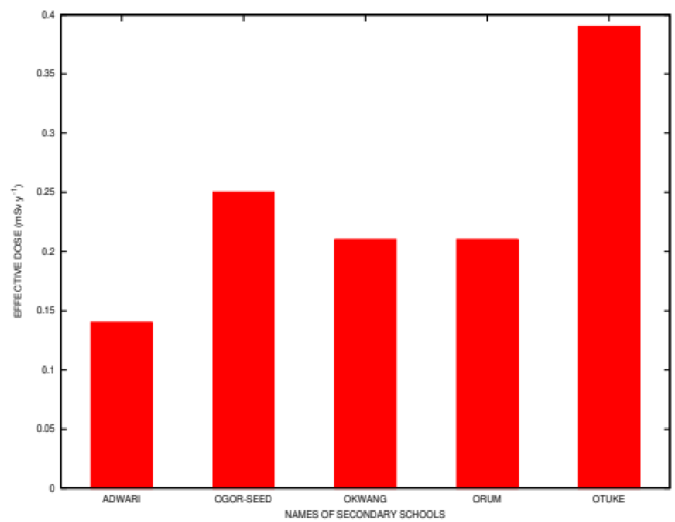

Fig. 7: Annual effective doses for the selected schools.

Table 5: Indoor radon concentrations and effective doses in different regions of Uganda.

District (Region)	Radon Concentration (Bq m^{-3})	Effective dose (mSv y^{-1})
Kampala (Central)	215	17.12
Otuke (Northern)	30	0.24
Tororo (Eastern)	63	1.58

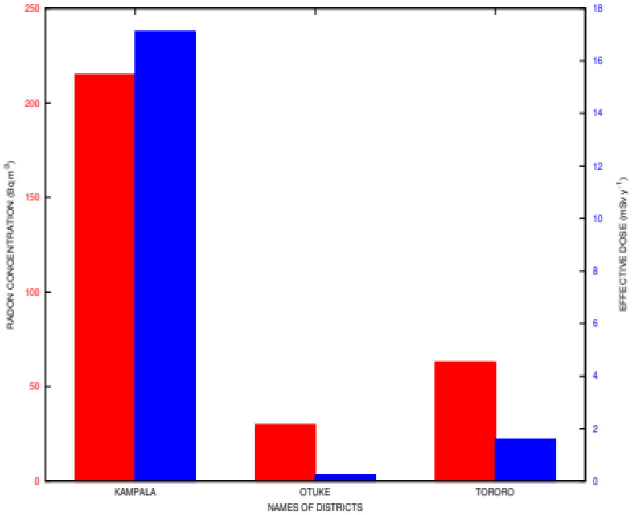

Fig.8: Comparative bar graphs showing radon concentrations (red) and effective doses (blue) for districts in Uganda.

4 Conclusions

The highest average background radiation of 1.7±0.3 cps, measured in Adwari S. S., is below the background radiation of 1.33 cps level given by the International Commission on Radiological Protection (ICRP). High background radiation readings in Adwari S.S. could be due to mainly gamma radiation since the radon concentrations were low, as radon and its progeny decay by emitting mainly alpha particles. The highest average radon concentration of 49±5 Bq m^{-3}, measured in Otuke S. S. (with average of 30±3 Bq m^{-3} for Otuke District), is much less than the World Health Organization (WHO) action level of 100 Bq m^{-3}. This means that there is no significant health risk posed by indoor radon concentrations in the selected schools. Similarly, the average annual effective dose of 0.24±0.02 mSv y^{-1} received by students in the selected schools, is far below the ICRP and UNSCEAR action level of 1.0 mSv y^{-1}. The results obtained for Otuke District have depicted a better level of safety compared to Tororo and Busia districts. Very high indoor radon concentration of 420 Bq m^{-3} obtained in Kampala City, raises concern for most cities in Uganda, and should be of interest to the government and EPA. Therefore, a national radon survey could be done by taking measurements from other regions, so as to establish a reference radon level for the country.

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