Radiation Levels in Buildings on the Main Campus of Haramaya University and at the Towns of Harar and Dire Dawa, Eastern Ethiopia

Gelana Amente*, Mohammed Assen, Haftu Brhane, Endale Tamiru, and Biniyam Nigussie

Haramaya University, College of Natural and Computational Sciences, P. O. Box 138, Dire Dawa

Abstract: Indoor radiation is a concern for people living in buildings constructed from materials with high emission of radionuclides. In this study, radiation rate measurements of 39 rooms in nine buildings of three different age groups at three locations were made using Electronic Personal Dosimeter (EPD). The measurements included both interiors and exteriors of the rooms. Interior measurements were made in two perpendicular directions from two adjacent walls at distance interval of 0.5 m. The EPD measurement revealed a decrease in the magnitude of the radiation as the days of measurement progressed, and that necessitated the need of correction factors, which were evaluated using background radiation rates of each location separately. All measured radiation rates were then corrected using the respective correction factors. The results obtained are summarized as follows. Background radiation doses at HU campus and Harar and Dire Dawa towns, averaged over the measurement days is, 4.1, 2.8 and 2.4 mSv/y, respectively. These values reflect effective external doses of 0.82, 0.55 and 0.47 mSv/y, respectively, for the three locations. Dire Dawa old building differed from all the other buildings of the three locations and it exhibited the highest interior radiation of average dose of 0.027±0.011 mSv/y above the background radiation. There were no significant differences between the new and the intermediate buildings of the three locations. When averaged out, irrespective of building ages of each location, HU buildings showed average dose of 0.004±0.004 mSv/y, Harar, -0.008±0.006 mSv/y and Dire Dawa, 0.009±0.008 mSv/y. No difference in radiation rates were observed between the two directions but radiation rates slightly increased from walls to the centers of rooms up to a certain point. Radiation rates of the interior and exterior of each room did not show a significant difference. Though differences were observed among buildings of the three different ages, the differences were not uniform at the three locations. The doses from all the rooms were within the limit set by IAEA for indoor radiation.

Keywords: Background radiation variability; Indoor radiation; Electronic Personal Dosimeter; Radiation rate; Building age

1. Introduction

Ionizing radiation is one of the potential risks human beings have been experiencing ever since its existence. It occurs naturally and from man-made sources. Natural (background radiation), which has worldwide average of 2.4 mSv/y per person, at sea level (IAEA, 2010; Thabayneh and Jazzar, 2012) comes from two sources. The first source is cosmic, which is due to interaction of cosmic rays with atomic nuclei in the atmosphere, and it accounts for about 10% of the total external natural radiation. Primordial terrestrial radiation is formed by nucleosynthesis and makes up 25% of the external and about two third of the internal exposures (inhalation and ingestion) (UNSCEAR, 2010). Overall, background radiation accounts for about 80% of the total radiation (natural and manmade dose of 2.8 mSv a person is exposed to in a year) (Taskin *et al*., 2008).

Soils and rocks are the main sources of terrestrial radiation since volcanic geographic structures as well as rocks that are rich in phosphate, granite and salt contain natural radionuclides like uranium-238 (^{238}U), thorium-232 (^{232}Th) and potassium-40 (^{40}K) (EC, 1999; STUK, 2010). The three elements are the main sources of gamma radiation (Lust and Realo, 2012). Sometimes, ^{226}Ra, which accounts for 98% of ^{238}U decay subseries, is considered instead of ^{238}U (Kinsara *et al.,* 2014). Radon (^{222}Rn is the daughter of Ra) and ^{232}Th are responsible for internal radiation since they can get into the air as gases (IAEA, 2010).

Knowledge of concentrations of radionuclides in building materials is important in the assessment of population exposure as most individuals spend approximately 80% of their time indoors (Steger and Grün, 1999). The presence of the naturally occurring radionuclides in building materials is a source of indoor radioactive pollution, since building materials are obtained from soil and rocks and contain ^{226}Ra, ^{232}Th and ^{40}K. Therefore, trace amounts of these radionuclides are found in all buildings (EC, 1999). But only buildings in which there are higher concentrations of these radionuclides that increase the probability of health problems (EC, 1999; Aamidalddin *et al*., 2015).

Radiation exposure due to building materials can be divided into external and internal. External exposure is caused by direct gamma radiation, whereas internal

*Corresponding Author. E-mail: amentegelana@yahoo.com

ISSN 1993-8195 (Online), 1992-0407 (Print)

exposure is caused by inhalation or ingestion of radon and its short-lived decay products. Buildings are generally constructed using different materials, among which the predominant ones are cement, metal frames and other materials such as stones, bricks, aggregates, sand, etc. In addition, wood and any other material which at one time was living contains carbon-14 (Othman & Mahrouka 1994).

Radiation risk from buildings depends on a number of factors. These include the nature of the material and the quantity of the material used in the construction of the building, age and condition of the building, the floor level of the room in the building, the rate of ventilation and how long the inhabitants spend indoors (EC, 1999; Markkanen, 1999: Salih *et al.,* 2014).

The nature of material (type of material and where it is from) can determine the amount of radionuclides in the material since natural building materials reflect their geologic formation and origin (Lust and Realo, 2012). Generally, wood has lower amounts of the three radionuclides except trace amounts of ^{14}C (Othman & Mahrouka, 1994) and therefore, countries such as Newzeland, Iceland and USA who mostly use wood for construction of residential houses experience less than half (28 nSv/h) radiation rate than those countries with stone constructions (UNSCEAR, 2000). The worldwide average indoor effective dose due to gamma rays from building materials is estimated to be about 0.4 mSv per year (Jwanbot *et al.*, 2014).

From among the construction materials the ones containing granite or igneous rock of granite composition, are enriched with ^{238}U (average 5 ppm) and ^{232}Th (average 15 ppm) compared with Earth's crust average of 1.8 and 7.2 ppm, respectively (Alharbi *et al.,* 2011). For instance, Aamidalddin *et al.* (2015) in their study of building materials used in Saudi Arabia found highest value of effective dose of 1.17 mSv/y in granite materials and this value is in excess of the limit set for public (1 mSv/y) over background radiation (UNSCEAR, 2000; STUK, 2010; USNRC, 2015). Dose *et al.* (2014) also found high level of activity in granitoid aggregates compared with other aggregates. According to Alharbi *et al.* (2011), Kinsara *et al.* (2014) and Dose *et al.* (2014), granitoides contain higher percentages of ^{232}Th compared to other rocks.

Recycled industrial by-products containing Technologically Enhanced Naturally Occurring Radioactive (TENOR) materials may also be used in the construction industry. Industrial byproducts such as coal fly-ash, ballast furnace slag incorporated in cement and byproduct gypsum (phosphogypsum) can increase radiation from buildings and consequently internal and external absorbed doses to residents (Othman & Mahrouka 1994; Aamidalddin *et al.*, 2015). These industrial byproducts have especially high activity concentrations of ^{226}Ra compared to other building materials such as concrete, bricks, building stone and natural gypsum (EC, 1999).

In addition to the nature of material, the quantity of a specific building material used in building construction matters. The radiation limit set for materials used in bulk such as aggregates, sand, cement, stone, bricks, etc. is generally lower than materials used in small quantities such as marbles and tiles (Markkanen, 1999). Buildings with massive walls and floors can partially shield against gamma radiation from undisturbed Earth's crust (EC, 1999), but it has also a proportionally higher emission of ^{222}Rn from the massive walls and floors (Markkanen, 1999; UNSCEAR, 2000; Tzortis *et al.,* 2003).

The rate of emission, however, and hence, dose rates may decline over time due to radioisotope decay (Othman and Mahrouka 1994). Therefore, for buildings with all conditions the same, dose rates are assumed to be lower for older buildings than newer buildings (Markkanen, 1999; Othman and Mahrouka, 1994). However, buildings generally deteriorate (show up cracks in walls and floors) with age, which serve as passageways for ^{222}Rn from inside the walls by the process of diffusion and convection and from the soil underneath. In such buildings, there is a possibility of elevated radiation especially if the building materials and the soil below contain elevated concentrations of radon (EC, 1999). Such exhalation causes buildup of radon especially if the building is not well ventilated (Salih *et al*., 2014). For building levels close to the ground such as basements, the amount of radon in the rooms would be higher (Tubosun *et al.*, 2013).

Even though several studies have been done on different types of building materials as mentioned earlier, not much has been done regarding radiations in buildings. Concerns such as variability of radiation within a room, dependence of radiation on the type of building materials and ages of buildings have not been sufficiently addressed. In Ethiopia, no studies have been conducted to elucidate radiation levels and there is also little public awareness on radiation levels from buildings. In this work, total gamma emission from buildings of different ages was studied using electronic personal dosimeter at three different locations of Eastern Hararghe zone, Ethiopia. The objectives were to look at several factors such as radiation variability within a room, differences in radiation between the interior and exterior of a room and whether building age differences show significant differences in the amount of radiation both in the interior and the exterior of rooms in buildings.

2. Materials and Methods

2.1. Study Areas

This study was conducted at three locations, namely, Haramaya University's (HU) campus, Harar and Dire Dawa towns. HU campus is located at the distance of about 505 km from Addis Ababa, to the east. Geographically this area lies between 9°15'N latitude and 42°0'E longitude and has an average altitude of 2006 meters above sea level. The area has a temperature ranging from 12.6 to 28.5°C with average relative humidity of 65%. It receives an average annual rainfall of 790 mm with bimodal distribution of the seasonal pattern peaking in mid-April and mid-August of the year.

Harar town is found at the distance of 517 km to the east of Addis Ababa. The town is located at 42°04’ - 42°22’E longitude and 9°15’ – 9°27’N latitude. It has an average altitude of 1780 meters above sea level and average temperature of 22.65°C. The annual rainfall, on average is 700 mm.

Dire Dawa town is located at the distance of 527 km to the east of Addis Ababa. The area is located between 9°27’ N and 9°49’ E latitudes and 41°38’ and 42°19’E longitude. The rainfall pattern of the area is characterized by small rainy season from February to May and big rainy season from July to September. The average annual rainfall in the study area varies from 550 mm in the lowland northern part to above 850 mm in the southern mountains. The monthly average maximum and minimum temperature ranges from 34.6°C to 14.5°C, respectively. The altitude where the study was conducted is about 950 meters above sea level.

The three locations were selected for their proximity and also because they have old and new buildings made from different materials. They were also assumed to have three different background radiations because of their altitudinal differences. Figure 1 shows the location map of the three areas, namely, HU campus, Harar and Dire Dawa towns.

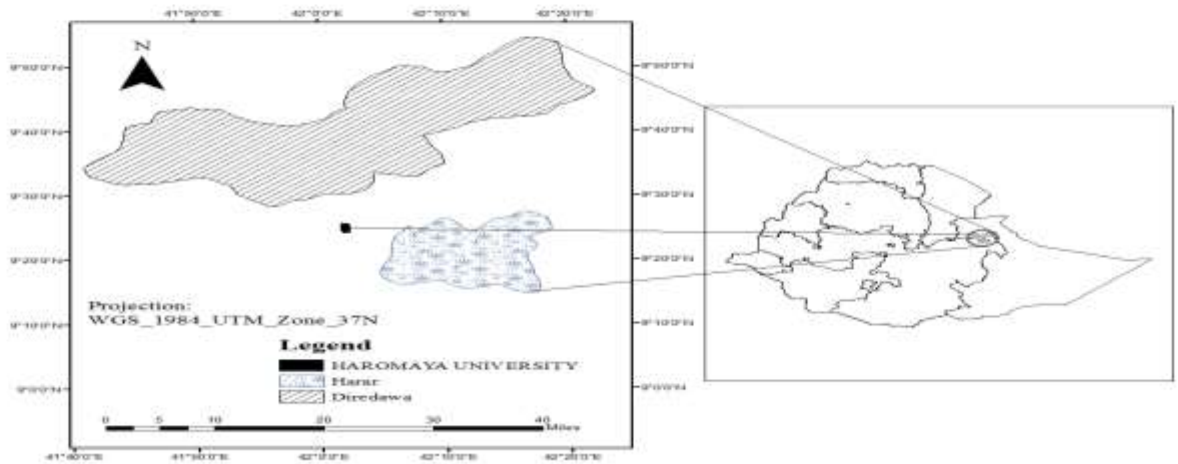


Figure. 1. Location map of HU campus, Harar and Dire Dawa towns.

2.2. Instrument Used for Data Collection

Measurements of background and building radiations were made using Electronic Personal Dosimeter (EPD model type MINI-6100), which evaluated ionizing radiation exposure by measuring the amount of visible light emitted from a crystal in the detector. The instrument measures dose, dose rate and run time. It has dose range of 0 - 9,999 mSv and dose rate range of 0 - 99.9 mSv/h.

2.3. Data Collection

A total of three locations [Haramaya University (HU) campus, Harar and Dire Dawa towns] were selected for this study. At each location, three buildings of different age (recent, those with intermediate age, and relatively old) were identified for the study. Approximate age of each building was obtained from people who know the building and the materials, from a visual assessment of predominant materials used to construct the buildings. This anecdotal method of gauging the age of the buildings was used because of lack of documentation on the history of the buildings. Selection of buildings containing classrooms was purposefully made for the study because such buildings house many people at a time and contain no household materials such as furniture and utensils other than chairs, which may bias the data and prevent easy access to rooms.

On HU campus the buildings selected were categorized as relatively recent, intermediate and old buildings. The selected buildings included two new classroom buildings, which are about 15 years old; one building of intermediate age, which belongs to the College of Natural and Computational Sciences (a little over 40 years of age), and one old building belonging to the College of Agriculture and Environmental Sciences (over 60 years of age). A total of six rooms were selected from the recent buildings, and five and four rooms from the intermediate and the old buildings, respectively.

The three buildings selected in Harar town included one of the new classroom buildings of the College of Medical Science (about 10 years old) and one building of an intermediate age and another one of an old age both on the campus of Harar Teachers’ Education and Business College. Four rooms were selected from each building at this location.

In Dire Dawa, the new building used for this test was on Dire Dawa University campus. The old building was selected from Dire Dawa Alliance France School whereas Mariam Sefer Junior Secondary school was selected as a building of intermediate age. The number of rooms selected here were similar to those of Harar town.

Even though it is generally recommended to take background radiation at 1 m height (Markkanen 1999), prior to each day study background radiations were always measured outside, far from any building at five different heights, i.e., zero or ground level, 0.5, 1.0, 1.5 and at 2.0 meters. The purpose was to verify by how much the 1 m height differed from the values obtained at other heights. This test was necessary since we conducted all other measurements at ground level. Since rooms of different buildings at different locations were numbered differently (sometimes with identical room numbers), the rooms were re-numbered sequentially (for ease of reference) as shown in Table 1.

Table 1. Sequential numbers given to each room of the three locations and buildings of three age groups.

Building type	Recent		Intermediate		0ld	
Location	Actual Room No.	Given Rm. code	Actual Room No.	Given Rm. code	Actual Room No.	Given Rm. code
HU	XXI-4	1	R-201	7	R-007	12
	XXI-3	2	R-202	8	R-206	13
	XXI-7	3	R-203	9	R-207	14
	XII-12	4	LTH-III	10	R-208	15
	XI-3	5	R-12	11		
	XII-10	6				
Harar	LTH-1	16	R-10	20	R-5	24
	LTH-3	17	R-11	21	R-6	25
	R-B	18	R-7	22	R-7	26
	R-C	19	R-8	23	R-8	27
Dire Dawa	R-5	28	R-1	32	R-1	36
	R-6	29	R-2	33	R-2	37
	R-3	30	R-3	34	R-3	38
	R-4	31	R-4	35	R-4	39

2.4. Data Analysis

In this work six points were considered. In order to test whether the background radiation measured at 1 m height differed from the background radiation values measured at different heights, the 1 m values were compared with the values of other heights. The daily measured background radiations for the same location showed a declining trend that also reflected on hourly values. Since we took the background radiation measurement only once per day (during morning hours), it was imperative to find the mathematical pattern the background radiation followed so as to make corrections on the hourly values. For this purpose, curve fittings were made for all the three locations and the values obtained were used as correction factors for the respective locations.

Variation in radiation from walls was also considered first by making time corrections and comparing the measured values. In addition, since the rooms did not have equal width and length, comparisons were made to check whether radiation rates measured in the two directions depended on the directions of measurement from the wall. Comparisons were also made to see differences between the interior and the exterior (not the background) radiations. Finally, radiation rate dependence on the age of each building was considered by comparing radiation values obtained for the recent, intermediate and old buildings, at the three locations.

2.5. Mathematical Formulations Used for Data Analysis

Understanding the concept of dose and dose rate helps to control the dose an individual can receive while staying around any radiation source. Dose is the total amount of radiation absorbed over time. Dose rate is the rate at which the radiation is absorbed. Dose *(D)* and dose rate *(D_r)* are related as (RSSC, 2013).

$$D = D_r t \qquad (1)$$

Where: t = time. The radiation dose a person receives is equal to the time the person spends in the area multiplied by the dose rate of the area. Generally, the unit of dose rate is Sievert per hour (Sv/h) such that the dose calculated over a year ((24 h/day × *365 days/y =8.76* × 10^3 h/y*) is:*

$$D = \left(D_r \times 8.76 \times 10^{-3}\right)\ m\text{Sv/y} \qquad (2a)$$

D can also be given in milli-Sievert per year (mSv/y) or micro-Sievert per year (μSv/y)such that:

$$D = \left(D_r \times 8.76 \times 10^{-3}\right) \text{mSv/y} = \left(D_r \times 8.76 \times 10^{-6}\right) \mu\text{Sv/y}. \qquad (2b)$$

When outdoor and indoor radiation rates are different, the indoor radiation *(D_{in})* is obtained by multiplying the indoor rate, D_{rin} by a factor of 0.8 (taking into consideration the 80% time a person spends indoors).

Hence,

$$D_{in} = \left(D_{rin} \times 7.008 \times 10^{-3}\right)\ m\text{Sv/y}. \qquad (3a)$$

If the value of dose is very small, sometimes using a unit of micro-Sievert ($\mu Sv/y$) is preferable as shown next.

$$D_{in} = \left(D_{rin} \times 7.008 \times 10^{-6}\right)\ \mu Sv/y. \quad (3b)$$

Similarly, for outdoor *(D_o)* a factor of 0.2 of the outdoor rate, D_{ro} is used (i.e., assuming a person spends 20% outdoors) and

$$D_o = \left(D_{ro} \times 1.752 \times 10^{-3}\right)\ mSv/y. \quad (4)$$

Since the magnitude of the radiation dose rate is in the order of Nano-scale (10^{-9} Sv/h), the radiation annual dose is in the order of $10^{-6} \sim 10^{-4}$ Sv/y, $10^{-3} \sim 10^{-1}$ mSv/y or $1 \sim 10^{2}$ μSv/y.

The total dose a person receives per year is then given as the sum of the indoor and the outdoor radiation;

$$D = D_{in} + D_o. \quad (5)$$

After calculating the dose, the value is compared with the international limits to know whether the dose is within the acceptable limit or not. In the case of net radiation, it can independently be compared with the limit (1 mSv/y) above the background radiation (USNRC, 2015). All calculations were performed and graphs were drawn using Microsoft Office Excel.

3. Results and Discussion

3.1. Dependence of background radiation on height of measurement

Background radiation is dependent on cosmic and terrestrial radiations. Out of the two, only cosmic radiation is dependent on altitude (height from ground surface). Because of this, when background radiation is measured it is important to choose the height at which to measure it. Though the height of 1 m is recommended (Markkanen, 1999) it is important to know how much error is committed from the recommended value by variation in small heights. For this reason, measurements were made at five different heights to see the influences of small height differences. Table 2 shows the result of percent difference *(P_d)* calculated as

$$P_d = \frac{D_{rh} - D_{rr}}{D_{rr}}(100\%) \quad (6a)$$

Where: D_{rh} = dose rate at height h and D_{rr} = dose rate at reference height, which in this case is the dose rate at 1 m height as shown in Table 2.

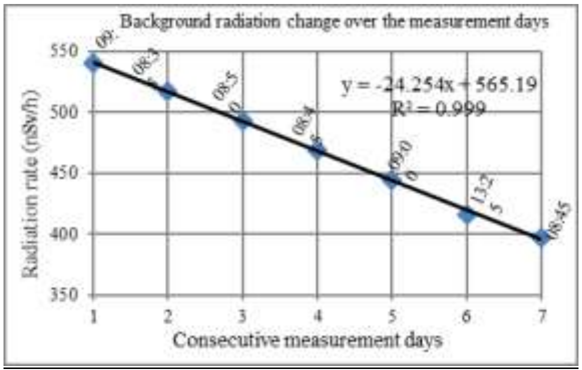
Table 2. Percent differences between background radiation rates measured at different heights and the values measured at 1 m height.

		Percent differences from values measured at 1 m height					
		Day					
Location	Height (m)	1	2	3	4	5	6
HU campus	0.0	0.02	0.03	0.01	0.10	0.01	0.01
	0.5	0.01	0.01	-0.01	0.10	-0.01	-0.01
	1.0	0.00	0.00	0.00	0.00	0.00	0.00
	1.5	0.01	0.01	-0.01	0.01	-0.02	-0.02
	2.0	0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Harar	0.0	0.01	**0.14**	0.01			
	0.5	-0.01	-0.01	-0.01			
	1.0	0.00	0.00	0.00			
	1.5	-0.02	-0.02	**-0.15**			
	2.0	-0.01	-0.01	**-0.14**			
Dire Dawa	0.0	0.01	-0.03	0.01			
	0.5	0.02	-0.01	0.03			
	1.0	0.00	0.00	0.00			
	1.5	0.01	0.01	0.01			
	2.0	0.02	-0.01	-0.01			

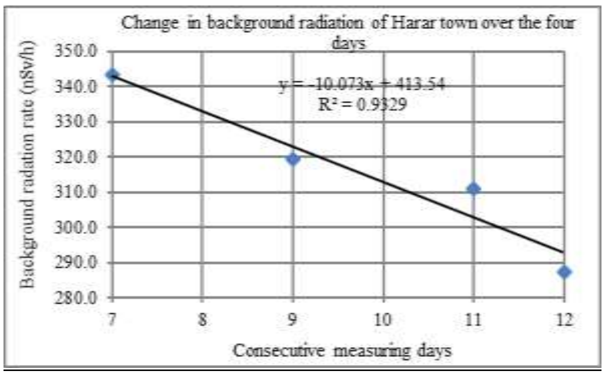
As observed in Table 2, only in three instances (shown in bold face in the Table) did the percent difference come to a little over one thousandth of the value measured at 1 m height. It is not surprising to find such closeness in the values since for the same location the only difference with height is in cosmic radiation, which is not high at such small differences in height. Hence, there were no significant differences in dose rates measured at other heights compared with the 1 m values.

3.2. Variation in Background Radiation over Time

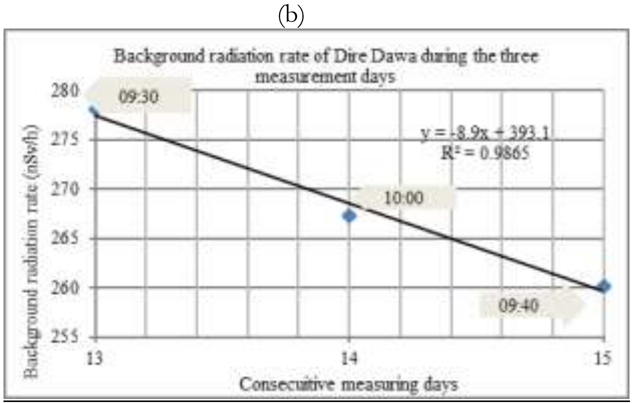
Over the entire days of measurement, background radiation showed time dependence. To know whether the time dependence followed a certain pattern or not, data of the three locations were taken independently and plotted against time. For illustration, the plots of background radiations against time of the three locations are shown in Fig. 2.



(a)



(b)



(c)

Figure. 2. Background radiation rates measured on (a) HU campus over seven consecutive days (8/5/2015 – 8/11/2015), (b) Harar town and (c) Dire Dawa town. The numbers written adjacent to the data points are the ltimes during which measurements were conducted on the respective day.

As observed in Figure 2, background radiation rate on HU campus showed a decline from one day to the next and the amount of decline was 24.25 nSv/h per day (slope of the linear fit). The curve showed a very good linear fit (R^2 = 0.999), which is indicative of a decreasing linear trend for the particular location. Hourly variability was obtained from interpolation of the daily variability, i.e., about 1 nSv/h (= 24.25/24) every hour.

Similar linear fits were observed for Harar and Dire Dawa towns with slopes and correlation coefficient values of 10.07 and 0.933, and 8.9 and 0.987, respectively. What they translate into is declines of about 0.42 nSv/h and 0.37 nSv/h every hour, for Harar and Dire Dawa towns, respectively.

Plot of background radiations of the three locations together indicates lower reduction at lower altitudes. The combined background radiation data of the three locations showed better quadratic fit than linear fit as shown in Fig. 3. The quadratic relationship takes care of both altitude and daily decline in background radiation, which was perhaps due to power reduction in the EPD in sensing gamma radiation. When power reduces the sensing ability of EPD also decreases (Kinsara *et al.*, 2014). According to Döse *et al.* (2014) there is partial loss of radon when measuring in an open space. Variability in temperature and speed and direction of wind (Aamidalddin *et al.,* 2015), humidity, cosmic radiation and terrestrial background affect radiation rate measurement in the field using portable hand-held radiation sensors (Döse *et al.*, 2014). In our case all these did not matter since we followed the method suggested by Markkanen (1999) and Hameed *et al.* (2014), and considered the net radiation (difference between the background radiation and radiations measured both indoors and on the exteriors of the rooms).

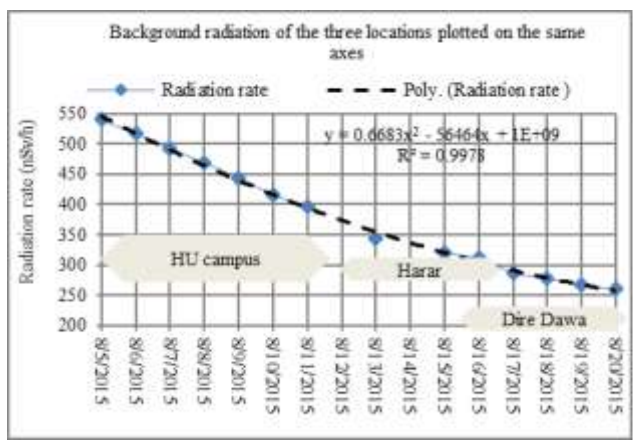


Figure. 3. Plot of background radiation against days of measurement at the three locations.

3.3. Dependence of Radiation rate on Distance from Wall

For this particular test, large rooms with measured radiation rates up to distance of 4 m were considered. Only five rooms from HU campus' recent building satisfied this condition and considered. The patterns of the plotted lines are as shown in Fig. 4.

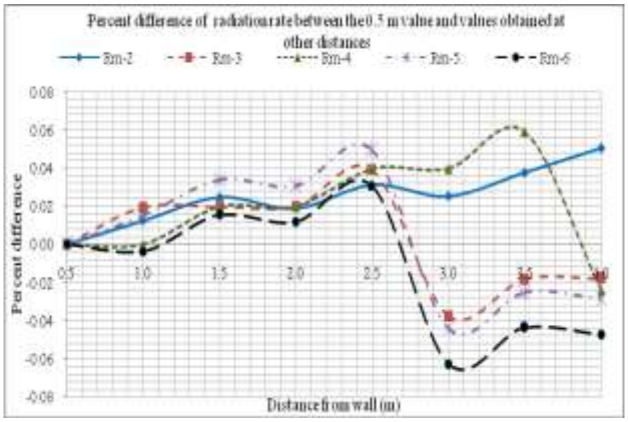


Figure. 4. Percent differences between the actual indoor radiation rates measured at 0.5 m distance and the other distances. Room numbers are as given in Table 1.

The percent difference (P_d) was calculated as,

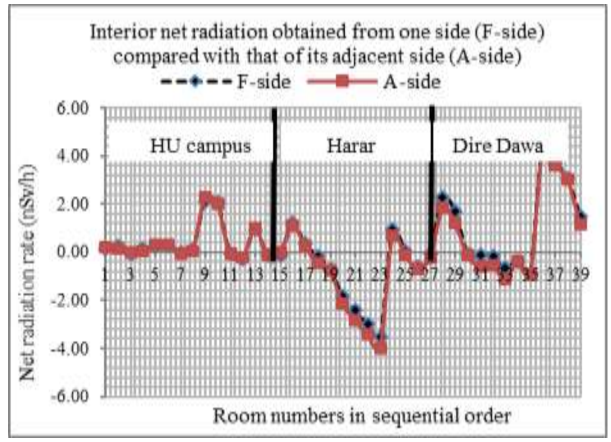
$$P_d = \frac{D_{r(0.5)} - D_{r(x)}}{D_{r(0.5)}}(100\%) \qquad (6b)$$

Where: $D_{r(0.5)}$ is the dose rate at 0.5 m and $D_{r(x)}$ is the dose rate at any other distance x where x represents any one of the distances from 1.0 to 4.0 m.

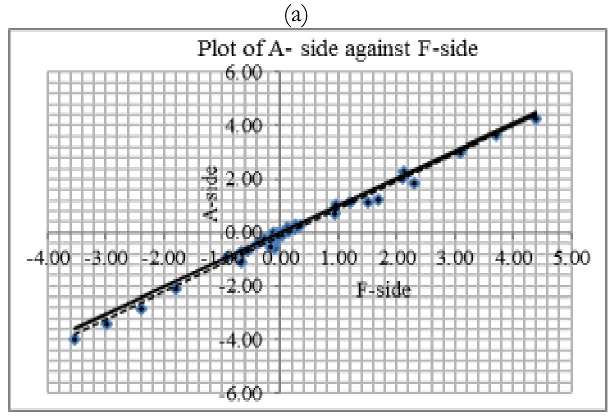
Hence, the points above the 0.00 percent difference line indicate that the measured value at 0.5 m was higher than that of the other distance while points below the 0.00 line indicate the opposite. As observed in Fig. 4, the curves for all the rooms, though slightly oscillating, showed an increasing trend in percent difference up to 2.5 m from the wall and showed mixed patterns thereafter. Such positive percent difference is interpreted as decreasing tendency (value at 0.5 m exceeding the value at the other point) of actual radiation a little distance before reaching the center of the room, for the three rooms (3, 5 and 6). For these rooms there were shifts to the negative percent difference at around 2.75 m. Since the lengths of the rooms were around 7 m on average, the shift of P_d from the positive to the negative shows high net radiation at the center of the rooms. This is perhaps due to the contribution of radionuclides emitted from the other walls as one moves toward the center. Lust and Realo (2012) mentioned about the dimensions of rooms having relatively small effect on dose rate in a room but for the rooms they considered they calculated the dose rate in the middle of the rooms. For room 4 the decreasing trend continued up to 3.5 m while for room 2 it did not stop even at 4 m. Since all the rooms were roughly identical in terms of ventilation and room sizes (except small differences in their lengths), we could not find adequate explanations for the differences between the two rooms.

3.4. Comparison of Radiation Rates obtained from Two Directions (from Walls) in a Room

A room wall which extends to the exterior and a partition wall are assumed to be different in the amount of radiations they emit since they are made from different materials. Radiation rate is assumed to be high on the side of the wall which has higher emission of radionuclides. Fig. 5 is plotted to check if there is indeed a difference in net radiation rates emitted when measured from two perpendicular directions in the room.



(a)



(b)

Figure. 5. Plot of interior net radiation rates obtained from measurements made from two adjacent walls. The first direction is named as F-side while, the second adjacent direction is named as A-side. (a) Plot of net radiation against room number and (b) Linear fit between A-side against F-side. The room numbers are as given in Table 1. The plots are shown for the three locations together.

In Fig. 5, plots of net radiations obtained from two perpendicular directions were compared by plotting them together for all the three locations. As observed in Fig.5a, for almost all of the rooms, the two curves (except their irregularities) are almost overlapping at all the three locations. The linear fits shown in Fig. 5b with the solid line drawn as 1:1 line and the dotted line as the linear fit line (of slope 0.0106 and $R^2 = 0.98$) are also almost overlapping. This means, the direction of measurement did not make significant difference in the amounts of radiation rates measured. This happened regardless of the differences in the widths and lengths of the rooms. It also did not matter if one of the walls had windows and the other, a solid wall. Generally, such directional differences could be observed if the amount of radiation emitted from one wall differed from that of the other possibly because of differences in materials from which the wall was constructed. In the rooms selected, the interior walls were of similar nature and that must have contributed to their identical results. The fact that there were adequate ventilations in the rooms could also have affected the result since ventilation immediately circulates radon emitted from the walls such that the room shows identical results in the two directions.

3.5. Comparison of Radiation Rates of Buildings of Different Ages

Radionuclides decay overtime and given all other conditions to be the same, one may expect lower emissions from older buildings compared with the recently constructed buildings (Othman and Mahrouka, 1994). But the science of building construction has evolved over the years and one can see differences in the types and quantities of materials used in old and recent buildings. Such differences can also reflect in the amount of radionuclides emitted from buildings of different ages. Fig. 6 shows two things at the same time. First it shows net radiation differences among buildings of different age groups. Along the x-axis, the three locations are separated by long and solid vertical lines and within each location; differences among buildings of three different ages are separated using shorter solid lines. The figure also shows differences between interior and exterior radiations of all the rooms of all the buildings at the three locations together. In the figure, instead of taking the raw data, background radiations were subtracted from the measured interior and exterior radiations to get net radiation as suggested by Markkanen (1999) and Hameed *et al.* (2014).

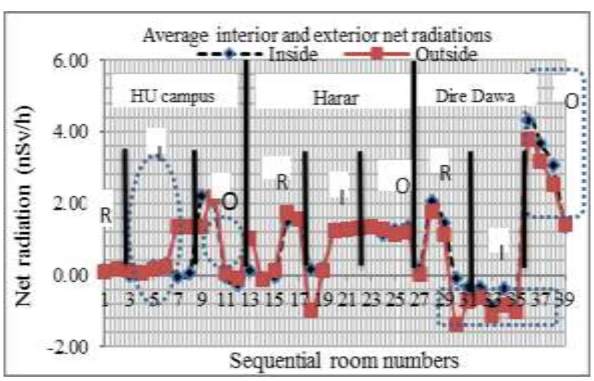


Figure. 6. Interior and exterior net radiation rates of rooms of buildings of three age groups at the three locations shown together. The letters R, I and O shown in white backgrounds represent recent, intermediate and old, respectively, to indicate the relative ages of the buildings.

As far as age differences are concerned, the figure reflects three different scenarios. The first is the case where the data points are overlapping with the zero net radiation rate line. For example, the recently erected buildings and two rooms from the old building on HU campus reflected this case. This case indicates that the rooms have radiation rates identical to the background. It does not, however, imply that the rooms lack indoor radiation. What it actually reflects is that, what is emitted within the room is balanced with what the walls of the room prevent from getting into the room from outside. The explanation is consistent with the proposition that building materials act as sources of radiation and also as shields against outdoor radiation (EC, 1999; Tzortzis *et al.,* 2003). A person living in such a room is experiencing the same radiation effect as outdoor.

The second case is where the net radiations are positive. Rooms with such values reflect higher indoor radiation rates compared with the background. The building of intermediate age (shown within dotted ellipse) and one room from old building of HU campus (shown within a dotted circle), all buildings of Harar town (except room 16) and the recent and old buildings (shown in dotted rectangle) of Dire Dawa town fall under this category. What it reflects is indoor radiation exceeding the background radiation. Manifesting positive net radiations is not a concern unless the values exceed the limit of 1 mSv/y in dose (EC, 1999; STUK, 2010). In this particular case none of the rooms exceeded this limit and details are given in Table 3 (section 3.7).

The fact that in some cases new buildings and in others old buildings showed slightly higher net radiations deserves explanation. HU intermediate building was constructed from massive concrete and red clay bricks on the exterior and the rooms are separated by unplastered hollow blocks on the inside. Rooms 7, 8 and 9 showed slightly elevated radiations perhaps because of the clay bricks and massive concrete materials both of which inherently have higher emissions next to stones (EC, 1999; Kinsara *et al.,* 2014; Aamidalddin *et al.,* 2015). Besides, the rooms do not have adequate ventilation. For instance, room 7 is a lecture theater with exposed clay bricks on two of the walls on the inside. Such bricks have radionuclide concentrations slightly less than masonry stones but higher than concrete (EC, 1999). Rooms 8 and 9 are small office rooms with additional items such as computers, printers and other materials and those must have slightly elevated the net radiation. Rooms of HU old building all showed radiations comparable to those of the new building (except for Room no 13). The reason why old buildings show lower rates of radiation may be because of the gradual decay of radioactive elements in the building materials. The difference between the recent and the intermediate buildings is attributable to the materials from which the buildings were constructed. Concrete and bricks have slightly higher emissions than hollow cement blocks (Salih *et* *al.,* 2014) because of differences in the materials and their bulk densities.

The recent building in Harar town showed slightly elevated radiation (especially rooms 16 and 17) both on the inside and on the outside. These rooms are lecture theaters with fixed chairs anchored to metal frames and massive floors made of concrete. The two could be the reason for such elevated rates of radiation. Whatever small emissions there were from the two, they were active on account of their young age (not yet decayed enough). The rate of radiation in the new buildings is higher because of its age, i.e., the radionuclides in the materials of the building might have not decayed sufficiently. Buildings of intermediate and old ages of Harar also showed slightly elevated net radiations. On the other hand, radiation rates from old buildings were higher because of the large quantities of materials used for construction and lack of adequate ventilation (at least these were observed in rooms of Dire Dawa old building). Radon diffusion from the walls or the floors (Masok *et al.,* 2015) can only be minimized with adequate ventilation. Some old buildings which are over sixty years were generally made from stones without or with fewer iron reinforcements. In order to make the structures safe, walls were generally made thicker than what is observed in the recent buildings. The bulkiness of the structure and the nature of the materials are assumed to have effect on how much radiation is emitted.

In Dire Dawa recent and old buildings showed slightly more elevated radiations than the building of intermediate age. Elevated net radiations from recent buildings are due to the materials from which they are constructed and due to their recent age. The old buildings generally show higher emissions because of their massive structures or possibly due to radon diffusions from the walls or floors.

The last case is where the net radiation remained in the negative territory. Rooms of Dire Dawa intermediate age building fall under this group. Such rooms generally play significant roles in shielding background radiation while the amount they emit is slightly lower than the amount they shield. The rooms are found in low cost school building and the low emission may be due the use of low quantities of materials.

3.6. Comparison of Radiation Rates of the Interior and Exterior of Rooms

As shown in Fig. 6, differences between net radiation rates of the interiors and exteriors of rooms were observed in few instances. Only three rooms (7, 8 and 9) of HU building of intermediate age, room number 13 of HU building, room 18 from Harar and all except room 39 of Dire Dawa showed slightly different values between the interior and the exterior. In most cases, however, the two were identical. Radiation on the inside equals that of the outside when the rooms have identical materials on both sides and when the inside has adequate ventilation (Salih *et al.*, 2014). The presence of multiple windows, which allows the radon that is possibly emitted from the walls to disperse to the outside, has one impact on the similarity of the two sides. The other reason is possibly very low emission from the materials from which the building was constructed. This can be attributed to the plastering and painting of the inside walls which has lower gamma emission compared to granite and concrete walls. For instance, Aamidalddin *et al.* (2015), while they found effective dose of 1.17 mSv/y for granite, they only obtained 0.03 mSv/y in paints. Since building materials can shield against gamma radiation emitted from the soil (UNSCEAR, 1993; Tzortis *et al.,* 2003), it is possible to also assume that what is exhaled from the building material of the room is balanced with what is kept out.

Table 3. Annual doses of net indoor radiations calculated for all the rooms.

HU			Harar			Dire Dawa		
Room No.	NIR rate (nSv/h)	Annual Dose (μSv)	Room No.	NIR Rate (nSv/h)	Annual Dose (μSv)	Room No.	NIR rate (nSv/h)	Annual Dose (μSv)
1	0.17	1.16	16	1.17	8.17	28	2.07	14.53
2	0.20	1.37	17	0.31	2.15	29	1.45	10.16
3	-0.03	-0.20	18	-0.30	-2.11	30	-0.09	-0.61
4	0.10	0.67	19	-0.70	-4.92	31	-0.35	-2.48
5	0.28	1.93	20	-1.96	-13.72	32	-0.35	-2.45
6	0.29	2.03	21	-2.62	-18.33	33	-0.89	-6.25
7	-0.04	-0.25	22	-3.20	-22.41	34	-0.38	-2.64
8	0.07	0.50	23	-3.77	-26.41	35	-0.92	-6.44
9	2.21	15.47	24	0.81	5.70	36	4.33	30.38
10	2.07	14.47	25	-0.04	-0.31	37	3.68	25.79
11	-0.06	-0.43	26	-0.63	-4.38	38	3.05	21.39
12	-0.26	-1.79	27	-0.13	-0.90	39	1.34	9.37
13	0.49	3.44						
14	-0.10	-0.67						
15	-0.06	-0.45						

Note: NIR rate = net indoor radiation rate (radiation rate above the background); Room numbers are as given in Table 1.

3.7. Dose Comparisons with the Radiation Limit

Annual dose is the amount of radiation a person absorbs while staying indoors. Values in Table 3 were calculated using Eq. (3b) based on the assumption that inhabitants spend 80% of their time indoors.

Any dose above background to which a public is exposed is limited to 1 mSv/y (USNRC, 2015). Since the dose values given in Table 3 are in micro-Sievert (μSv), even the extreme values are lower by more than an order of magnitude. Because almost all of the rooms tested were classrooms, the percentage that the students use these classrooms is even lower than 80%, which means the risk is even lower than what is indicated in the table.

What was observed in the table was less than what was estimated for indoor radiations. Worldwide average effective indoor dose is 0.42 mSv/y (Thabayneh and Jazzar, 2012). EC (1999) estimated effective dose from apartment blocks to be about 0.25 mSv/y in excess of the background radiation. Aamidalddin *et al.* (2015) estimated dose of indoor radiation of 0.39 mSv/y for masonry buildings. Tzortzis *et al.* (2003) in their work on commercially-used natural tiling rocks found indoor radiation doses between 0.02 -2.97 mSv/y. Hameed *et al.* (2014) found mean indoor annual effective dose of 0.58 mSv from igneous rock but one order of magnitude less (0.056 mSv) for sedimentary rocks. None of the net radiations in our study came close to any one of the values mentioned.

4. Conclusion

This study has demonstrated that, all the rooms of buildings of the three locations exhibited radiation doses below the IAEA recommended limit of 1.0 mSv/y, and hence pose no radiation threat to the occupants. From among buildings of the three age groups the Dire Dawa old building was different and had the highest dose of 0.027±0.011 mSv/y. Even though the highest indoor radiation dose was observed at Dire Dawa (0.03 mSv/y over the background), the value is still below the world average by an order of magnitude. The corresponding highest values at Harar and on HU campus are 0.008 mSv/y and 0.015mSv/y, respectively.

In all the rooms studied, direction of radiation rate measurement from walls did not affect the outcome of the radiation rate. However, when it comes to distance from walls, net radiation rate slightly increased close to the center of the room. For all the buildings, radiation rates in the interior and exterior of the rooms did not show distinct differences. Except for rooms with materials of different emission rates on the inside and the outside, in most cases the inside and outside emissions were mostly identical. Even though we observed radiation differences between the recent, intermediate and old buildings, we did not observe similarity at the three locations. It seems rather than age, the material from which the buildings were constructed (in terms of quantity and its rate of radionuclide emission) and the amount of ventilation in the building seem to have a profound influence on the amount of net radiation. Higher net radiation in area of low background radiation indicates the relative risk (with respect to background radiation) rather than the total risk.

The general recommendation that can be given based on this study is first, to use less quantity of materials in the construction of new buildings. Secondly, it is advisable to regularly maintain and paint buildings to minimize cracks and pores. Besides, interior radiations have to also be studied in relation to ventilation, especially for old buildings.

5. Acknowledgements

The authors thank Haramaya University for providing the fund required to do the research and for facilitating the work. Thanks are also due to Dire Dawa University, Harar Teachers' Education and Business College, Alliance France School and Mariam Sefer Junior and Secondary school for allowing the study to be conducted in their buildings and for facilitating selection of rooms for the study. The authors also thank the Ethiopian Radiation Authority for lending them the Electronic Personal Dosimeter used in this study.

6. References

Aamidalddin, S. Q., Alzahrani, J. H., Aamoudy, Z. M., Fakeha, A. A., Al-Habeaddi, H. H. M. and Ibrahim, N. M. 2015. Study of natural radionuclides and its radiation hazard index in building materials used in Saudi Arabia, *Life Science Journal.*, 12 (2): 163-168.

Alharbi, W. R., Alzahrani, J. H. and Abbady, A. G. E. 2011. Assessment of radiation hazard indices from granite rocks of the Southeastern Arabian Shield, Kingdom of Saudi Arabia. *Australian Journal of Basic and Applied Sciences*, 5 (6): 672-682.

Döse, M., Silfwerbrand, J., Jelinek, C. and Trägardh, J. 2014. Evaluation of the I-index by use of portable hand-held spectrometer and laboratory methods in a rock assessment of Swedish concrete by use of different crushed aggregates. *Mineralproduksjon,* 5: A55-A52.

EC, 1999. Radiological protection principles concerning the natural radioactivity of building materials. Environment, Nuclear Safety and Civil Protection. Radiation Protection, .pp. 112.

Hameed, P. S., Pillai, G. S., Satheeshkumar, G. and Mathiyarasu, R. 2014. Measurement of Gamma radiation from rocks used as building material in Tiruchirappalli district, Tamil Nadu, India. *J. Rad. Nuc. Chem.,* 300: 1081-1088.

IAEA, 2010. Radiation Biology. A Handbook for Teachers and Students. Training Course Series No. 42.

Jwanbot, M., Izam, M., Nyam G. G. and Yusuf M. 2014. Indoor and outdoor gamma dose rate exposure levels in major commercial building materials' distribution outlets in Jos Plateau State, Nigeria. *Asian Review of Environmental and Earth Sciences*, 1 (1): 5-7.

Kinsara, A. A., Shabana, E. I. and Qutab, M. M. T. 2014. Natural radioactivity in some building materials originating from high background radiation area. *International Journal for Innovation Education and Research,* 2 (6): 70-78.

Lust, M. and Realo, E. 2012. Assessment of natural radiation exposure from building materials in Estonia. *Proceedings of the Estonian Academy of Sciences,* 61 (2): 107-112.

Markkanen, M. 1999. Challenges in harmonizing controls on the radioactivity of building materials within the European Union. *Radon in the Living Environment*, 166: 1379-1386

Masok, F. B., Dawam, R. R. and Mangset, E. W. 2015. Assessment of indoor and outdoor background radiation levels in Plateau State University Bokkos Jos, Nigeria. *Journal of Environmental and Earth Science*, 5 (8): 1-5. ISSN 2224-3216.

Othman, I. and M. Mahrouka, 1994. Radionuclide content in some building materials in Syria and their indoor gamma dose rate. *Radiation Protection Dosimetry,* 55 (4): 299-304.

RSSC (Radiation Safety Subcommittee). 2013. Radiation problems. Oxford, Clarendon Press

Salih, I., Ali, S., Eisa, S. and Idriss, H. 2014. Radiation exposure of workers in storage areas for building materials. *Journal of Taibah University of Science,* 8: 394-400.

Steger, F. and Grün, K. A. 1999. Standard in AUSTRIA to Limit Natural Radioactivity in Building Materials, IAEA, Vienna.

STUK, 2010. The radioactivity of building materials and ash. Radiation and Nuclear Safety Authority, Guide ST 12.2, Helsinki, Finland.

Taskin, H. M., Karavus, P. A., Topuzoglu, A., Hadiroglu S. and Karahan, G. 2008. Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity*, 100 (1): 49–53.

Thabayneh, K. M., and Jazzar, M. M. 2012. Natural radioactivity levels and estimation of radiation exposure in environmental soil samples from Tulkarem province-Palestine. *Open Journal of Soil Science,* 2: 7-16.

Tubosun, I. A., Tchokossa, P., Okunlola, G. A., Balogun, F. A., Fasasi, M. K. and Ekhaeyemhe, S. 2013. Natural radioactivity associated with mining of rare metal pegmatite of Oke-Ogun field, Sepeteri, Southwestern Nigeria. *International Journal of Science and Technology*, 3 (10): 2224e3577.

Tzortzis, M., Tsertos, H., Christofides, S. and Christodoulides, G. 2003. Gamma radiation and dose rates in commercially used natural tiling rocks (granites). *J. Environ Radioact,* 70 (3): 223-235.

UNSCEAR (United Nations Scientific Committee on Effects of Atomic Radiation). 2010. Sources and Effects of Ionizing Radiation. Report to the General Assembly, Vol. 1. UN. NY

UNSCEAR. 2000. Sources and Effects of Ionizing Radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly. United Nations, New York.

USNRC (United States Nuclear Regulatory Commission). 2015. Biological Effects of Radiation. Backgrounder, Office of Public Affairs.