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Research Article

Assessment of Radon Concentrations Inside Houses of Siltie, Wolayta and Sidama Zones of Southern Ethiopia

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Abstract

Radon gas is one of the major terrestrial radiation sources that affect the general population. Its primary indoor sources are from the floor (especially if the floor is soil) and from building materials. It can be the source of alpha particles and gamma radiations, but the more dangerous one is the alpha particle because when inhaled, it is capable of harming the internal organs, especially the lungs. This study aimed to assess net radiation levels inside rural houses of Siltie, Wolayta and Sidama zones of Southern Ethiopia. The experiment was conducted in 12 village houses of the three locations and measurements of radon-222 (^{222}Rn) concentrations were carried out both outside and indoor, using Alpha Guard, from December 2 - 13/2017. The houses differ in terms of ventilations and their floor covers. For each house, outdoor measurements were taken (to serve as background radiation) at three different locations, far from houses. The measurements were taken at four different heights (0, 0.5, 1.0 and 1.5 m) from the ground, always prior to indoor measurements. Indoor measurements were taken in four replications, at similar heights. Measurements were taken in morning hours starting from the time when the residents wake up and open their doors. The results obtained are summarized as follows. Both indoor and background radiations showed exponential decay of radon concentration with height. ANOVA tests among houses and among zones did not show significant differences both among houses and among zones. Ventilated houses showed lower mean values (reduction of 27.9%) and standard deviations of radon concentrations. Houses with covered floors also showed lower radon concentrations (reduction of 33.6%) compared to houses of uncovered floors. Based on IAEA limit, only one house from Wolayta zone exceeded the limit of 200 Bq/m^3 based on indoor floor-level radon concentration values. None of the houses exceeded the limit at heights of 0.5 m or above. More study may be needed to assess radiation levels of the surrounding soils to know more about the differences among the zones.

Keywords: Alpha Guard; House Floor Cover; Indoor Radiation; Outdoor Radiation; Ventilated Houses

Abbreviations

222Rn: Radon-222; ANOVA: Analysis Of Variance; IAEA: International Atomic Energy Agency; Msv: Millisievert; 238U: Uranium-238; UNSCEAR: United Nations Scientific Committee On The Effects Of Atomic Radiation; EC: European Commission; NCRP: National Council On Radiation Protection And Measurements; WHO: World Health Organization

Introduction

Most of the environmental radiation contribution comes from radionuclides which are members of the natural radioactive series of uranium. Uranium is present in variable quantities in the earth's crust. Radon-222 (^{222}Rn) is a naturally occurring radioactive nuclide and is one of the decay products of uranium-238 (^{238}U). ^{222}Rn, which is the daughter product of radium (^{226}Ra) decays into stable end products of helium and lead. Both radon and its short-lived secondary products lead to exposure of alpha particles [1]. In the ^{238}U decay chain segment ^{226}Ra is radiologically the most important and is often mentioned instead of ^{238}U [1]. ^{220}Ra contributes about 40% of the 2.4 mSv annual average natural radiation [2,3].

Radon is a natural part of the earth's atmosphere. It is a gas and has high mobility in the environment thereby contaminating much of the environment with which humans come in contact. But the primary source of exposure to radon is from soil beneath homes, where it enters through cracks or openings in structures and concentrates in indoor air. Radioactivity in soils is due to ^{238}U, ^{40}K and ^{226}Ra [3]. The three are formed by the process of nucleosynthesis in stars and are of half life comparable to the age of the cooled planet [4,5]. Building materials are also the sources of indoor radon gas emission. Radon gets into the indoor environment from the ground through cracks in the bottom slabs and cellar walls of buildings because of concentration gradient [6]. Other factors that predispose homes to elevated levels of radon include soil porosity, foundation type, building ventilation rates, and source of water supply. But the underlying soil is the most important source of indoor radon [7]. When warm air rises in homes, it creates a vacuum in the lower areas of the house and this compels something (e.g. radon) to rush in to fill the space [8]. Radon is also soluble in water and is often found in the groundwater.

Radon gas tends to concentrate in enclosed spaces like underground mines or houses and it is a major contributor to the terrestrial ionizing radiation dose received by the general population. Its average indoor absorbed dose rate in air from terrestrial sources of radioactivity is estimated to be 0.4 mSv/y [9]. Radon is inert and can move freely through porous media such as building materials, but only a small fraction reaches the surface and enters the indoor air [10]. Hence building materials rarely cause radon problems by themselves.

Radon migrates through pores and faults in the soil to the surface of the earth by means of three mechanisms; namely, diffusion, convection and by gas carriers. The first process, diffusion, is a spontaneous movement of radon gas from higher concentrations to lower concentrations. Due to the short half-life of radon (3.82 days) this process is rather slow and can only account for a migration of few meters in the soil [3]. When the soil is subjected to a steep temperature gradient the gas is transported by convection. The last mechanism is transportation with gas carriers. This process predominates during volcanic activities, where large fluxes of radon gases associated with the eruptive phases move from the soil into the atmosphere.

The amount of radon that reaches the soil pores is described by the emanation fraction and for typical soils or bedrocks; the emanation fraction can range from 5% to 50% [11]. Average value in soils is 1.81 mSv/y [5]. Home traps radon inside, where it can build up. This includes new and old homes, well- sealed and drafty homes and homes with or without basements.

Radon decays into charged particles that can easily attach to and be transported by dust and other particles in the air. Its decay continues until stable, non-radioactive progeny, lead is formed. At each step in the process, radiation is released. When it decays it produces charged particles, especially alpha particles [9] that adhere to dust and other fine matter that can be inhaled by people. The radon gas, once inhaled, circulates uniformly throughout the whole body via the blood stream and for this reason; the estimation of the dose delivered to the lung is mainly based on the contribution from the alpha emitting daughters of radon gas [12]. When radon gas and its short-lived byproducts are inhaled, densely ionizing alpha particles emitted by the deposited short-lived decay products of radon (^{218}Po and ^{214}Po) with energy of 6.0 MeV in the case of ^{218}Po and 7.69 MeV in the case of ^{218}Po [3] can interact with biological tissue in the lungs leading to DNA damage [13,14].

From the natural risk point of view, it is necessary to know the dose limits of public exposure and to measure the natural environmental radiation level provided by ground, air, water, foods, building interiors (houses), etc., to estimate human exposure to natural radiation sources. The worldwide average annual effective dose from natural sources is estimated to be 2.4 mSv, of which 1.1 mSv is due to the basic background radiation and 1.3 mSv of this is due to exposure to radon. In terms of indoor radon, the general recommended permissible limit of exposure set by WHO is 100 Bq/m^3 [14,15]. But the European commission's and IAEA limit for indoor environment is slightly higher, 200 Bq/m^3 [2,7,10].

The amount of radon emanating from the earth and concentrating inside homes varies considerably by region and locality, and is greatly affected by the residential structure as well as soil and atmospheric conditions. Areas that are likely to have homes with elevated radon levels are those with significant deposits of granite, uranium, shale and phosphate, which are all high in radium content and, therefore, potential sources of radon gas. However, due to the many determinants of indoor radon levels, local geology alone is an inadequate predictor of risk and therefore the only way to determine indoor radon concentration is by testing [16].

Indoor radon concentration varies with the construction types and ventilation [7]. Even though radon can accumulate to high levels in closed or poorly ventilated areas [14], a small amount of this gas will not pose a health risk in open air spaces or well-ventilated areas. The concentrations vary substantially with the season, from day to day and even from hour to hour. Because of these fluctuations, estimating the annual average concentration of radon in indoor air requires reliable measurements of mean radon concentrations for at least three months and preferably longer [17].

This study is designed to assess the net radon concentration levels of rural houses of three zones in southern Ethiopia, whose walls and floors are constructed from different materials. Most of the houses in these zones are traditional houses in which sometimes, small domestic animals share the house with people. The ventilations of the houses (if any) are inadequate. The houses also lack proper floor cover. The two reasons are assumed to expose the indoor environment to elevated radon concentrations, particularly at night times when the doors are closed. The fundamental need for this study was to assess the risk level for people living in different types of houses at the three locations of Southern Ethiopia and to know the differences among houses with covered and uncovered floors, and those with ventilation and without ventilations. The ultimate goal is to know to what extent the measured radon concentrations vary from the limit set by the IAEA.

Materials and Methods

Study sites

This study was conducted at three locations in southern Ethiopia. The three are: Siltie, Wolayta and Sidama zones. The area selected in Siltie zone is around Worabe town Wogercha village. In Wolayta zone the area selected is around Soddo town, Gulgula village and in Sidama zone, around Hawassa city, Abakotoroshe village. The locations of the three areas are shown in figure1 and their geographical coordinates are given in (Table 1).

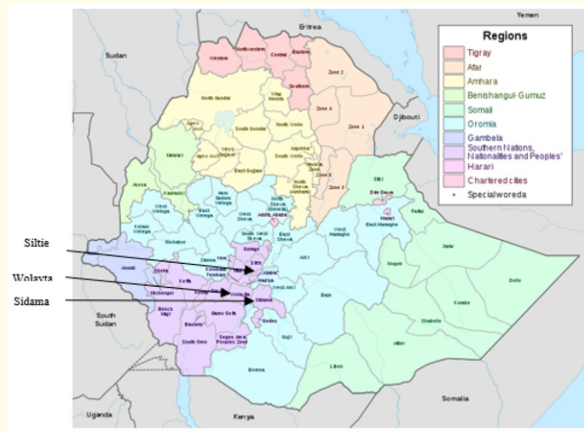

Figure 1: (a) Map of Ethiopia with the locations of the three zones shown with arrows.

Zone	Latitude (deg)	Longitude (deg)	Altitude (m)
Siltie	7°46΄N	38°15΄E	2113
Wolayta	6° 54'N	37°45'E	1800 - 2000
Sidama	6° 39΄N	38°29΄E	500 - 1500

Table 1: Geographical locations of the three zones.

The three locations in the region were selected because the houses have different wall and floor structures. Besides, some of the houses are vented (have some type windows), some have their floors covered (either with cow dung or some type of material), while the others are not vented and the floors are also not covered. The three zones were also assumed to have three different background radon concentrations because of their slight location differences.

The house of the first two zones is from wood and mud. The third zone houses are, all in all, constructed from bamboo sticks (Figure 2).

Instrument used for data collection

Measurements of background and indoor radon concentrations were made using Alpha Guard (Figure 3), which evaluates ionizing radiation exposure by measuring the amount of radon every ten minutes. The instrument measures the amount of radon in Bq/m^3, temperature of the place in degree centigrade, humidity in percent and pressure in millibar for each measuring point.

Figure 2: House style (left), internal roof structure (middle) and internal wall structure (right) of (a) Siltie, (b) Wolayta and (c) Sidama houses.

Figure 3: Instrument used for measurement.

Data collection

External radiation exposure can be measured either by direct exposure measurements in a building (house) or by radionuclide analysis of building materials [9]. In this case direct exposure measurements were made. At each location, four village houses were selected. The construction materials of the houses, the condition of the floors and the presence or absence of ventilation of the houses are summarized in Table 2.

Even if the recommended duration of study is at least three months [17] in this study, measurements were conducted for 12 days, from December 2-13/2017 during morning hours. The time was limited for two reasons. Longer duration could have impact on the patience of the home owners. Besides, the instrument was obtained for a limited duration.

Location	House code	Floor	Material	Ventilation	Wall cover	Floor cover
Siltie	H1	C	Local materials	V	Wood and Mud	Cow dung
	H2	C	(wood, mud	V		
	H3	C		V		
	H4	C	and thatched roof)	V		
Wolayta	H1	C	Local materials	NV	Wood and Mud	Cow dung
	H2	UC	(wood, mud	NV		
	H3	UC		NV		
	H4	UC	and thatched roof)	NV		
Sidama	H1	UC	All bamboo	NV	Bamboo	
	H2	UC		NV		
	H3	UC		NV		
	H4	C		V		Bamboo

Table 2: Materials from which the houses were built and conditions of the houses

C = covered, NC= not covered, V = ventilated and NV = not ventilated.

External radon concentration measurements were conducted at three different locations, far from any of the houses, prior to indoor measurements, at four different heights (0 (ground level), 0.5, 1.0 and 1.5 m). Even if the recommended level to measure background concentration is 1 m [7], the other heights were included to compare the indoor and the outdoor concentrations at the corresponding heights. Internal measurements of radon gas concentrations were done at similar heights as those of the external. Measurements were carried out during morning hours just after the residents woke up and opened their doors. The time was deliberately chosen to detect nearly maximum concentration of the gas because of the accumulation that has taken place at night.

Data analysis

Comparisons were made to see differences between the interior and the exterior (background) radon concentrations. Concentration comparisons of different heights from the floor were done for all the indoor and the external measurements. Then, additional comparisons were made between houses of covered and uncovered floors. Comparisons were also made between houses with ventilations and the ones without any ventilation. Data were analyzed graphically and by using ANOVA to compare concentration levels among the different zones and among the houses of the same zone, separately.

Results and Discussion

Radon concentration with height

Since radon is a gas and emanates from the ground. Depending on the nature of the floor and the structure and conditions of the houses, it is assumed that radon varies with locations and height from the ground. The differences in averaged radon concentrations in the houses of the different zones along with the corresponding averaged background concentrations are shown in Table 3.

Zone	Height (m)	Radon concentration (Bq/m^3)							
		H1	H1 bkgd.	H2	H2 bkgd.	H3	H3 bkgd.	H4	H4 bkgd.
Z1	0	71	78	134	29	105	49	98	89
	0.5	54	57	79	21	85	39	65	71
	1	40	50	41	18	52	35	51	53
	1.5	29	39	30	16	36	26	36	34
Z2	0	82	79	225	52	80	71	86	108
	0.5	51	57	87	42	43	48	60	86
	1	31	47	60	35	28	37	40	58
	1.5	27	28	52	27	25	36	26	43
Z3	0	107	39	183	58	140	75	57	80
	0.5	78	35	128	49	113	61	42	51
	1	53	32	84	36	74	44	29	41
	1.5	47	26	58	28	39	27	19	26

Table 3: Height-variability of mean radon concentrations indoor and background of the three zones.

H bkgd. represents the background radon concentrations of the respective houses at the corresponding heights As indicated in the table, the background concentrations show reduction with height as indoor concentrations. This indicates the ground level to be the primary source of radiation. For some houses the indoor concentration is almost as close to the outdoor background concentration (e.g. H1 and H4 of Siltie zone both of which have floor-cover and are ventilated and H1 (covered) and H3 of Wolayta zone). These houses have either low radon emission from the floor because of the floor cover or due to their ventilations or both. H3 of Wolayta zone has neither, but perhaps there could be some sort of wall opening in the house that acted as ventilation. For others, the indoor concentration is larger than the background concentration by a significant margin (e.g. H2 and H3 of Siltie zone and H1 – H3 of Sidama zone).

This indicates indoor buildup of radon concentration because of inadequacy of ventilation and the floor cover. Still in others (e.g. H4 of Wolayta zone and H4 of Sidama zone), the background radon concentration exceeded the indoor concentration at all heights. H4 of Sidama zone shows less indoor concentration since its floor is covered and it is also ventilated. The reason for H4 of Wolayta zone is unclear since the house has neither ventilation nor floor cover. There might be undetected wall opening in the house or the emission from floor of this house may be unusually low. Table 3 shows a certain pattern in the variation of radon concentration with height. These patterns are obtained by plotting radon concentration against height as shown in Figure 4.

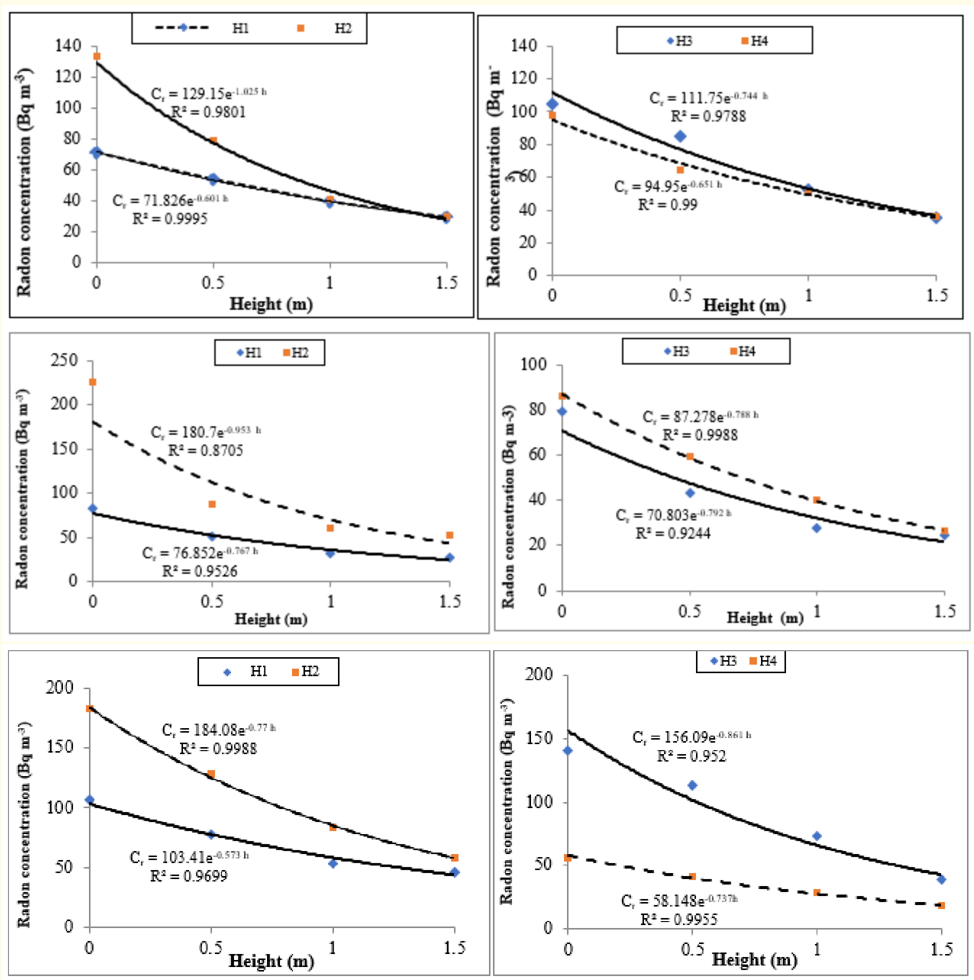

Figure 4: Radon concentration variation with height shown for houses of the three zones.

As observed from the figures, the radon concentrations show exponential decay with height with R^2 values ranging from 0.871 to 0.999, which indicates very good fit to the exponential function. In the equations, C_r represents radon concentration (Bq/m^3) and *h* represents height (m) from the floor. The radon concentration reduces by more than half as the height is increased from zero to 1.5 m.

There can be two reasons why such exponential reduction with height is observed. Since concentration decreases with distance from the source, as the height increases reduction in concentration is expected. The second reason could be due to variability of time of measurement. Every morning the first measurements were taken at the floor level. The differences of 30 minutes between successive measurements can introduce more air into the houses because of the opening of the doors and this could have resulted in dilution effect. Hence, as time progresses, there would be more dilution, which could have resulted in reduction of the concentration of the radon gas. In order to know which one is the viable reason, it is necessary to see the variation of the background radon concentration with height as well (Figure 5).

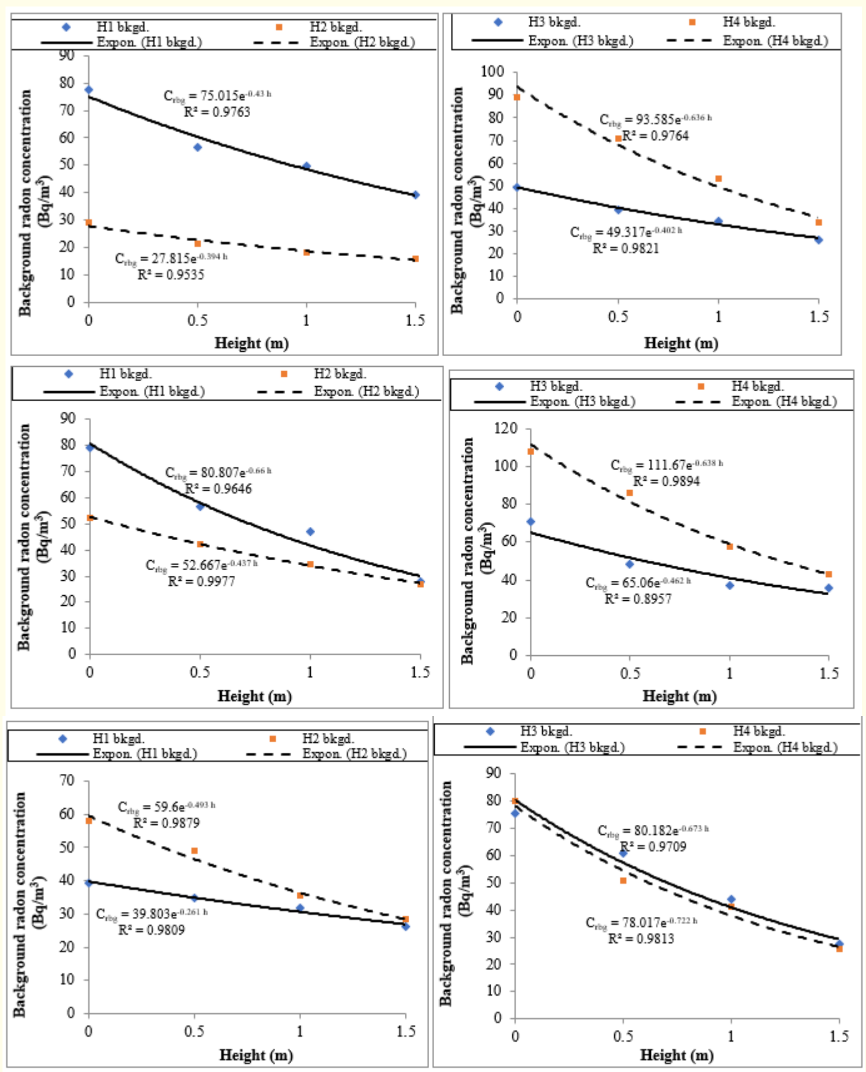

Figure 5: Background radon concentration variation with height shown for houses of the three zones (Crbg represents background radon concentration (Bq/m3) and, h represents the height (m) from the floor level).

The low concentration of radon in house number four (H4) of Sidama zone seems to be due to bamboo floor cover or due the effect of ventilation (Table 3). The very high floor level concentration of Wolayta house number two (H2) could possibly be due to lack of any crack in the walls, which could have facilitated air entrance into the house. The floor covers in Siltie zone did not bring much difference with the uncovered ones in terms of radon concentration. This means, floor covering with cow dung cannot serve the purpose of preventing emission of radon gas from the ground like bamboo floor cover.

Knowing the pattern of background concentration of radon variation with height is important for comparison with the corresponding indoor concentrations. Figure 5 shows the variations of background radon concentrations with height.

As observed in the figures, variations of background radon concentration with height follows exponential trend, with R^2 ranging from 0.8957 to 0.9977, which shows very good correlation. Some background concentrations show relatively large reduction with height (e.g. around H1 and H4 of Siltie zone, H1 and H4 of Wolayta zone and H2 – H4 of Sidama zone). Such large variations may be indicative of calm atmosphere. For the other locations the changes are subdued. The small changes are indicative of uniformity of radon concentration with height, perhaps due to instant mixing with air. Such mixing occurs when the ground surface is warm and there is upward convection such that the radon gas moves up with other air molecules.

The exponential decays of the background concentrations and the increase in radon concentration on the floor compared to the points above the floor indicate soil as the major source of this gas. Besides, in the absence of convective circulation in the room, the radon gas tends to remain close to the ground due to its heaviness and its density (7.5 times heavier than air and also has a density of 9.73 g/L). The variability of radon concentration with height can also be observed in high-rise buildings in which the upper floors have contributions only from the building materials and thus have concentrations ranging from 10-20 Bq/m^3 [10]. The wall materials have their own contributions since construction materials have various amounts of natural radionuclides [10]. The R^2 values indicate that radon concentration can be easily explained by exponential functions even though the coefficients and the powers vary.

In general, the background concentrations measured at ground level where the effect of wind is very low (because of surface friction) can be compared with the indoor concentration of the same level. On windy days, at elevated heights (1 and 1.5 m), the radon gas may be swept sideways resulting in instant dilution rather than moving upwards. Dose., *et al.* [18] also mention the partial loss of radon when measured in open space.

Radon concentration variability among zones and houses of the same zone

A one-way ANOVA was used to compare radiation levels among the different houses and among zones, separately. Comparisons among the houses were made using data of ground level concentrations. The result showed no significant differences among the houses of the same zone. The mean values and the standard deviations of each house are shown in Table 4.

Zone	House	Mean	SD
	H1	77.8	18.4
Z1	H2	79.8	26.0
	H3	77.0	25.7
	H4	69.8	26.7
	H1	73.3	17.6
Z2	H2	110.3	61.9
	H3	64.0	20.1
	H4	47.8	22.6
	H1	76.0	20.3
Z3	H2	69.3	19.6
	H3	74.5	22.9
	H4	77.3	13.6

Table 4: The mean values and the standard deviations of each house of each zone.

As observed in Table 4, house H2 of Wolayta zone exhibited the highest mean value and also the highest variability. House H4 of the same zone showed the least mean concentration. On the other hand, house H4 of Sidama zone exhibited the least variability. The least variability of this house could be due to its floor cover and its ventilation, which distributes the gas within the house and causes dilution effect.

The lack of significant difference among the houses is mainly attributed to the inability to find identical houses within each zone and thus variations in the amount of ventilation, floor cover and the structure of the walls have contributed to the relatively high variability among the houses. These must have acted as extraneous variables and confounded the differences.

Comparison among the three zones also shows no significant difference among the zones. Table 5 shows the averages and the standard deviations of the radon concentrations of the houses of each zone.

Zone	Mean	SD
Z1	76	4
Z2	74	26
Z3	74	4

Table 5: Average values and standard deviations among houses and zones

SD = standard deviation.

From among houses of the three zones, the least mean value was observed in Wolayta and Sidama Zones but the least variability were observed in Siltie and Sidama zones. The low standard deviations indicate uniformity in the materials of the houses and also of the soils.

Wolayta zone houses on the other hand, are all unvented and three of the four houses have uncovered floors. The floor cover of the first house of this zone did not reduce the radon emission significantly since two of the houses (H3 and H4) with uncovered floors had lower floor-level concentrations than the first house. This can be due to the inadequacy of the floor cover to prevent radon emission. Floors with cow dung cover have pore spaces through which radon gas can pass. Besides, when it ages (perhaps in weeks), it has a tendency to peel off and exposes the bare soil. Thus, in order to be effective, it has to be recoated on certain time intervals.

Radon concentrations in Sidama houses are primarily assumed to be from floor emissions since the walls are from bamboo whose contributions to radon emission are insignificant. However, even if the major source of radiation from wood is from ^{40}K there are also trace amounts of ^{226}Ra in woods [19]. For instance, Aamidalddin., *et al*. [19] in their research with building materials in Saudi Arabia found ^{226}Ra emission from woods ranging from 3.35 to 23.73 Bq/kg. They found dose rate of 0.56 mSv/y from wood, which is actually next to granite and ceramic in rank. This quantity may be substantial when the quantity of wood used in the construction is large. The other reason may be the limitations in the amount of ventilation in the houses. Even if bamboo houses seem to be well ventilated, this can only be true during their early years of construction. Overtime, the small openings of these houses are gradually filled with soot and other particulate emissions that are released with smoke during cooking processes. This gradually closes the tiny openings of the walls and reduces the capability of ventilation of the houses and hence, it can be the other reason for the slightly higher mean radon concentration compared to Siltie houses.

Overall, it is not uncommon to find radon concentrations of the magnitude observed in this study. Average radon concentration for individual countries range from 9 – 184 Bq/m^3 (UNSCEAR, 2010). For instance, Salih., *et al.* [14] found radon concentrations in the range of 71 – 292 Bq/m^3 or average of 154 ± 38 Bq/m^3 in 50 shops of building materials in Sudan. The values obtained in this study are close to the lower value obtained in their studies. Besides, except five houses, for all the other houses the radon concentration level is either comparable to the background level or less (Table 6).

Radon concentration of vented versus unvented houses

Radon build up in a house is large when the floor is uncovered and there is limited ventilation, particularly at night, when the doors are closed. Ventilations are assumed to partially prevent radon emission in houses. Since measurements in this study were carried out during early morning hours, the concentrations reflect night time concentrations which are assumed to be higher than day time concentrations. During day times, when people are inside the doors remain open and allow more air into the house that dilutes the radon concentration. Figure 6 shows the differences in the mean values (a) and the standard deviations (b) of radon concentrations of vented and unvented houses

As seen in Figure 6, the unvented houses exhibited both higher mean values and standard deviations. Ventilated houses showed a reduction of 36 Bq/m^3 (27.9%) mean radon concentration as compared to the unventilated houses, at floor level. The mean values and the standard deviations of the vented and unvented houses showed similar trends (i.e., exponential decay) with height, similar to indoor and background radon concentrations.

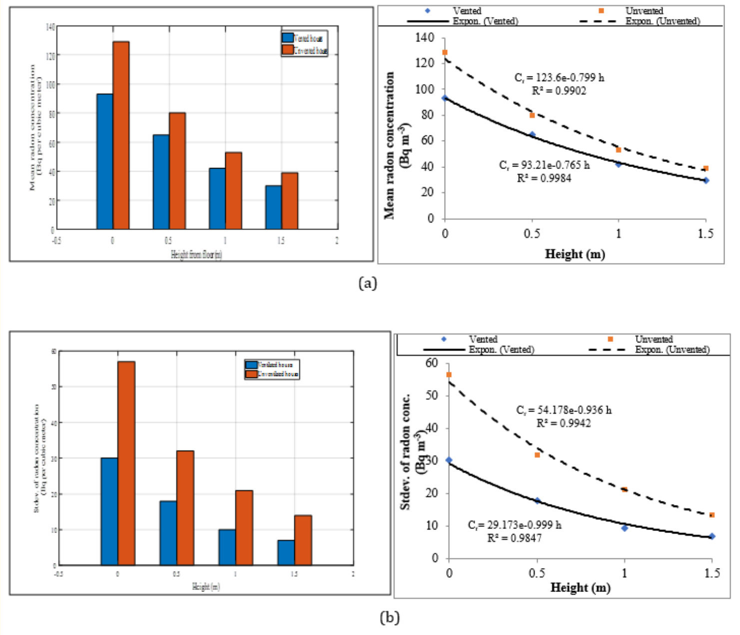

Figure 6: Differences in (a) the mean values and (b) the standard deviations of radon concentrations of vented and unvented houses at different heights from the floor.

At night both doors and windows are closed because of security and also to keep the house warm. Therefore at night times the difference between ventilated and unventilated houses is not much. The only ventilations in houses at night times are through small openings between doors and walls, windows (if any) and walls and between the walls and the roofs. Since closed rooms with poor ventilation increase indoor radon concentration [14], at night time the concentration tends to be higher even for houses that have windows. Poor ventilation also increases the exhalation rate of radon. In their work, Salih., *et al.* [14] did not find significant differences between the unventilated (123 Bq/m^3) and the poorly ventilated (126 Bq/m^3) rooms. Abdallah., *et al.* [20] also mention about the dependence of radon level on the ventilation level of rooms.

Radon concentration in houses with covered and uncovered floors

Floor coverage is one of the mechanisms by which radon emanating from the soil is stopped or minimized. But this depends on the type of floor cover. If the floor cover is porous, the likelihood of radon passing through the pores is high and the benefit of the floor cover, as far as blocking radon emission is concerned, is minimized. In the study, two types of floor covers were observed. The first type of floor cover is the slurry of cow dung applied to the floor and left to dry. Its main purpose is to minimize dust in the house. The other one used in one of the Sidama houses is bamboo sticks. Figure 7 shows the differences between houses whose floors are covered and the uncovered ones. The right hand side plots are shown to see the exact variation with height since they include equations. The values considered are the mean values of all the houses in the categories considered. In the figure, height dependence is also considered. The standard deviations are shown in order to see how the values of each group varied.

As observed in Figure 7, houses with covered floors generally showed lower mean radon concentrations than houses with uncovered floors. It indicates that, even porous floor covers such as the one with cow dung can slightly minimize the emission of radon gases from the floor. Houses with floor cover showed a reduction of 46 Bq/m^3 (33.6%) radon concentration at floor level compared to the houses with uncovered floors. The mean values and the standard deviations exponentially decayed with height. However, the mean values and the standard deviations of the houses with covered-floors showed slightly lower exponential decay with increase of height from the floor as compared to the ones with uncovered floors.

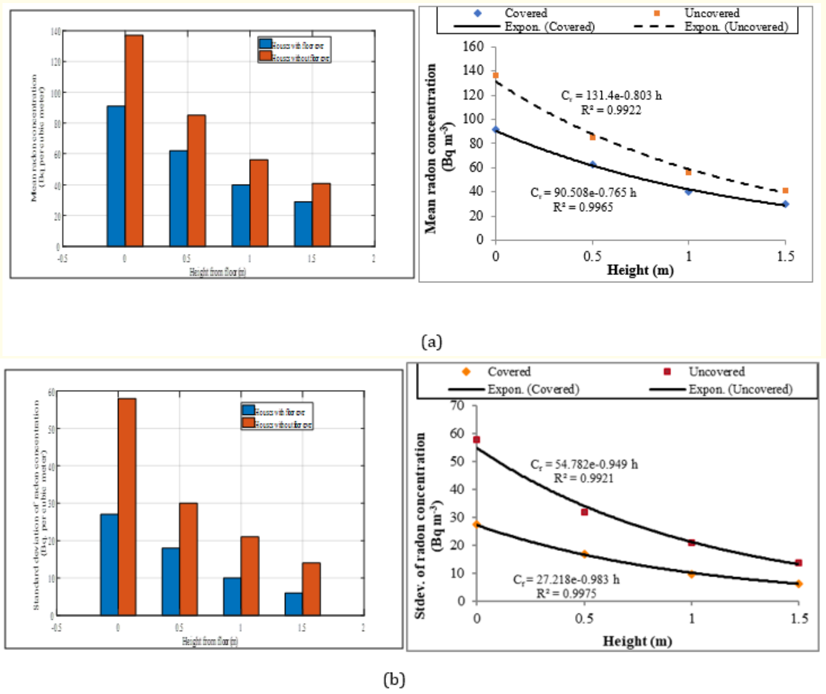

Figure 7: Differences in (a) mean values and (b) standard deviations of radon concentrations of houses with covered and uncovered floors.

Radon risk levels in all the houses

The fundamental need for this study was to assess the risk levels for people living in the different types of houses at the three locations. The risks can be associated with the soil type (especially for soils emitting high levels of radon concentrations) or it can be linked to the types of houses (materials from which they were built, covered/uncovered floors or the presence and lack of ventilations). The overall radon risk levels of the houses at floor levels are summarized in Table 6. The risk levels were evaluated based on the IAEA limit of 200 Bq/m^3.

Location	House	Concentration (Bq/m^3)*	IAEA limit (Bq/m^3)	Difference (Bq/m^3)	Risky (R) or not risky (NR)
	H1	71.3	200	-128.8	NR
Z1	H2	133.8	200	-66.3	NR
	H3	105	200	-95.0	NR
	H4	98.2	200	-101.8	NR
	H1	82.3	200	-117.7	NR
Z2	H2	225.0	200	25.0	R
	H3	79.7	200	-120.3	NR
	H4	86.0	200	-114.0	NR
	H1	106.5	200	-93.5	NR
Z3	H2	182.5	200	-17.5	NR
	H3	140.3	200	-59.7	NR
	H4	56.5	200	-143.5	NR

Table 6: Radon risk levels of each house compared with the IAEA limit.

Based on Table 6, only one house (H2 of Wolayta zone) showed slightly higher radon risk; whereas the others showed no risk. Even the other houses which have shown concentrations closer to the limit may not be considered as totally safe because the concentration could be higher before the doors are opened. For people sleeping on the floor the risk level is generally higher. Assuming that most people sleep in beds of heights of 0.5 m – 1 m and spend most of their times sleeping at night, it is necessary to consider the risk levels at these two heights. Table 7 summarizes this result.

Location	House	Height from floor (m)	Concentration (Bq m^{-3})	IAEA limit (Bq m^{-3})	Difference (Bq m^{-3})	Risk (R) or No risk (NR)
	H1	0.5	53.8	200	-146.2	NR
Z1		1	39.5	200	-160.5	NR
	H2	0.5	78.5	200	-121.5	NR
		1	40.5	200	-159.5	NR
	H3	0.5	85.3	200	-114.7	NR
		1	52.3	200	-147.7	NR
	H4	0.5	64.5	200	-135.5	NR
		1	50.5	200	-149.5	NR
	H1	0.5	50.7	200	-149.3	NR
Z2		1	31.0	200	-169.0	NR
	H2	0.5	87.0	200	-113.0	NR
		1	60.0	200	-140.0	NR
	H3	0.5	43.0	200	-157.0	NR
		1	27.7	200	-172.3	NR
	H4	0.5	59.7	200	-140.3	NR
		1	40.3	200	-159.7	NR
	H1	0.5	77.8	200	-122.2	NR
Z3		1	53.3	200	-146.7	NR
	H2	0.5	128.0	200	-72.0	NR
		1	83.8	200	-116.2	NR
	H3	0.5	112.8	200	-87.2	NR
		1	73.8	200	-126.2	NR
	H4	0.5	41.5	200	-158.5	NR
		1	28.5	200	-171.5	NR

Table 7: Radon risk levels of each house compared with the IAEA limit at heights of 0.5 and 1 m.

Risk evaluation at the two heights reveals no risk, for all the houses. Compared to the height of 0.5 m, the 1.0 m level is better in terms of minimizing the exposure level.

Radon can be a problem in homes of all types, old homes, new homes, drafty homes, insulated homes, homes with basements and homes without basements. Local geology, construction materials and how the home was built are among the factures that can affect radon levels in homes [21]. Radon gas can penetrate houses from many sources in many fashions [22]. The measurement of soil radon gas concentration is based on the detection of the radioactive decay effects of radon and its decay products. Since radon and its decay products in principle, are emitting alpha and/or beta particles as well as photons, the use of whole spectrum of detectors is needed for measurement in combination with a suitable sampling technique [11].

The most important contributor to indoor radon is the soil from which radon can be drawn through gaps in house floors, walls and foundation. Houses that are in direct contact with the ground will have higher radon levels than houses with an air space under the dwelling. The concentration of radon in the home should be measured and appropriate action taken if the level is found to be greater than 200 Bq/m^3 [7]. When carrying out radon measurement, the first step is to determine whether to measure radon itself or its progeny. In each case, alpha, beta and gamma radioactivity are the detectable phenomenon [17].

The risk levels in houses are not dependent on distant from the walls. Lust and Realo [9] found very small dose rate variation of 10 - 15% with distance from the wall. They also suggested the middle of the room as a good approximation to consider the average dose rate in the room. Amente., *et al.* [23] found variations in net radiations within a room depending on the types and materials of the walls. But in general they found slightly lower radiation level in the middle of the room. The other point is the dimensions of the room (house), which have relatively small effect in the dose rate of the room [9]. To the contrary, Markkanen [7] mentions about the influence of the dimensions of the house (surface to volume ratio) on the concentration of indoor radon.

Conclusion

The study was conducted to compare radon concentrations emitted from different types of houses, some with covered floors and some vented, while the others are not. The aim was to assess the risk level for people living in the different types of houses at three locations of Southern Ethiopia.

The study showed exponential decay of radon concentration with height from the floor. The concentration reduces by more than half as the height is increased from zero to 1.5 m, and this illustrates the floor as a major source of radon. Similar patterns were also observed with background radiations of the three zones. ANOVA tests did not show significant differences among houses of the same zone or among the zones. Both floor cover and ventilation reduce the amount of radon concentration in a house. The dose, except one house from among the twelve houses show radiation level below the limit set by IAEA for indoor radiation, at floor level. For people sleeping in beds of heights of 0.5 m – 1 m there is no radon risk at all. Proper ventilation habit and proper floor cover are the two ways to minimize radon emission in houses.

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