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Assessment of Radon Concentration of Ground Water in Ijero Ekiti

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ABSTRACT

Assessment of radon concentration in ground water in Ijero, Ekiti State, was carried out using the RAD7/RAD H_20 driven alpha spectrometry technique. The results were used to estimate the annual effective committed doses in order to establish possible radiological health hazards and to suggest necessary safety measures Forty water samples from boreholes, wells, and streams were collected and analyzed for the radon concentration. The minimum and maximum radon concentrations in the samples were 0.168 Bq/L and 78.509 Bq/L from stream and borehole samples, respectively. Out of the samples, 18 had radon concentration exceeding 11.1 Bq/L, the maximum permissible limit. It was observed that none of the samples has radon concentration value up to 100 Bq/L, which is recommended by the European Union to be the upper bound value, above which remedial action is required. No particular trend was observed, and no relationship can be inferred to exist between the mean radon concentration, temperature, and PH of the samples. None of the samples had an annual effective dose higher than the maximum permissible limit of 0.2 mSv/y if consumed by children and 0.1 mSv/y if consumed by adults.

We concluded that two-mica-granite geological structures and the depth of the source area predominant factor for high radon concentration and definitely contributed to the level observed in the borehole sources. The relatively high levels of radon indicate a certain level of health risk. Though the effective dose seemed low, effects of prolonged exposure to radiation is still possible.

Keywords: RAD7/RAD H_2O, ground water, alphayspectrometry, radon concentration, radiological health hazard, annual effective committededos

INTRODUCTION

Radon, a chemical element of atomic number 86, was discovered by Friedrich Ernest Dorn in 1900 while studying radium's decay chain. There are 39 known isotopes of radon from ^{193}Rn to ^{228}Rn (Audi et al., 2003; Sonzogni, 2008). This study focused mainly on radon-222 because it is the most stable of all the isotopes that originate from the radioactive decay chain of ^{226}Ra and ^{238}U (United States Environmental Protection Agency [USEPA], 1990, 2010). Radon-222 is a radioactive, colurless, odurless, and tasteless noble gas with a half-life of 3.82 day occurring naturally as an indirect decay product of thorium and muranium. Since uranium is essentially ubiquitous in the earth crust, ^{226}Ra and ^{222}Rn are present in almost all rocks, soil, and even water (USEPA, 2003; Giammanco et al., 2009). Radon has been described to be the second most frequent cause of lung cancer after cigarette smoking, causing 21,000 lung cancer deaths per year in the United States. Epidemiological studies have shown a clear link between a high concentration of radon and incidence of lung cancer (BEIR, 1999).

When radon-222 decays in air, it forms a number of short-lived radioactive decay products (radon progeny), which include polonium-218, polonium-214, polonium-210, bismuth-214, and bismuth-21,with half lives of 3.05 min, 1.5×10^{-4}, 190 day, 20 min, and 5 days respectively (Sonzogni, 200; Dowdallet al., 2013). Radon itself does not contribute much dose since it is immediately exhaled from the lungs before decaying (Hulburt, 1989; ICRP, 1993, 2010). But radon daughters, being basically solids, sometimes are electrically charged and can stick to the surfaces of our bronchial tubes just like dust particles in air (Brooks, 1988). In spite of the low penetrating power of alpha particles, they transfer a huge fraction of their energy to biological cells they pass through or interact with. This large release of energy to a single cell is just what is needed to initiate cancer (Zapecza et al., 1986). As a result, an alpha particle is a hundred times more likely to cause cancer than other types of radiation (Christensen et al., 2014; ICRP, 1993, 2010; IARC, 1988).

After radon is produced as a result of radioactive decay of radium in unsaturated soils and rocks, it is transported throughout the soil; this process in called emanation. Emanation is the process by which radon is transported from a solid to a gas or liquid (Shiroma et al., 2015).Diffusion and convection facilitate the transportation of radon throughout soil and within pores. The escaped radon is carried away from the origin to other areas; this makes radon the most important natural radio nuclide contributing to radioactivity in air and water. Radon is sparingly soluble in water; hence, radon is dissolved in ground water sources as it is transported through pores across the saturated zone of the earth crust (Shiroma et al.,2015). The rate of radon transfer from water to air increases with temperature, agitation, mixing, and surface area. In household water usage, showers, baths, dishwashers, laundries, and toilets also provide adequate aeration to release a high percentage of the waters' radon content into the household air, hence increasing the radon concentration in air (Prichard et al., 1975). Aeration is the process where a volatile gas such as radon-222, which is mildly soluble in air, tends to escape from water on contact with air. This is similar to carbonated soda drinks where carbon dioxide is dissolved in the soda and is released when you open the bottle. When radon-rich ground water is used as drinking water, people are exposed both through water consumption and inhalation (UNSCEAR, 200; Dowdall et al., 2013).

Inadequate water supply is one of the major problems facing most developing nations especially Africa. Due to the inadequate public treated water supply, the populace relies majorly, if not totally, on ground water for municipal and agricultural activities (Orosun et al., 2016).Ground water, particularly from areas underlain by granites and similar uranium-bearing rocks, have been reported to contain high radon concentration (UNSEAR, 2006; Knutson & Olofsson, 2002; Badhan et al., 2010; Oni et al., 2014). A geological survey indicated that pegmatite rock type is the predominant rock type in Ijero Ekiti and environs. A uranium concentration of greater than 500 ppm has been reported in the residual soils in Ekiti State (Obajeet al., 2014; Arisekola et al., 2007).

Considering the cancer risk due to ingestion, primarily cancer of the stomach and other digestive organs and increased incidence of radon-induced lung cancer as a result of radon exposure, this work seeks to investigate the radon contaminant level of ground water in Ijero Ekit, and also to assess the exposure level in order to establish possible radiological health hazards and suggest necessary safety measures.

MATERIALS AND METHODS

Study Area

The study area is within the southwestern part of the Nigerian Precambrian basement complex and within latitude 7°42.0611' N and longitude 5°17.009' E with the elevation ranging between 1218 m and 1469 m above sea level and an average elevation of 1343 m (Olumide, 2014).Pegmatite has been identified as the major rock type in Ijero (Okunlol & Akinlola, 2010; Obaje et al., 2014; Ale et al., 2014).It occurs as ridges and lowland located in about 50 km northwest of Ado-Ekiti with the coordinates 7°49'N and 5°5'E and is wholly crystalline mineralized igneous rock (Ale e.al., 2014). Minerals mined from Ijero include emigmatite, Gneiss,quartz, schist, muscovite mica), feldspar, and gemstone (Okunlola & Akinlola, 2010; Ale et al., 2014). The geological map of the study area is presented in the Figure 1 below.

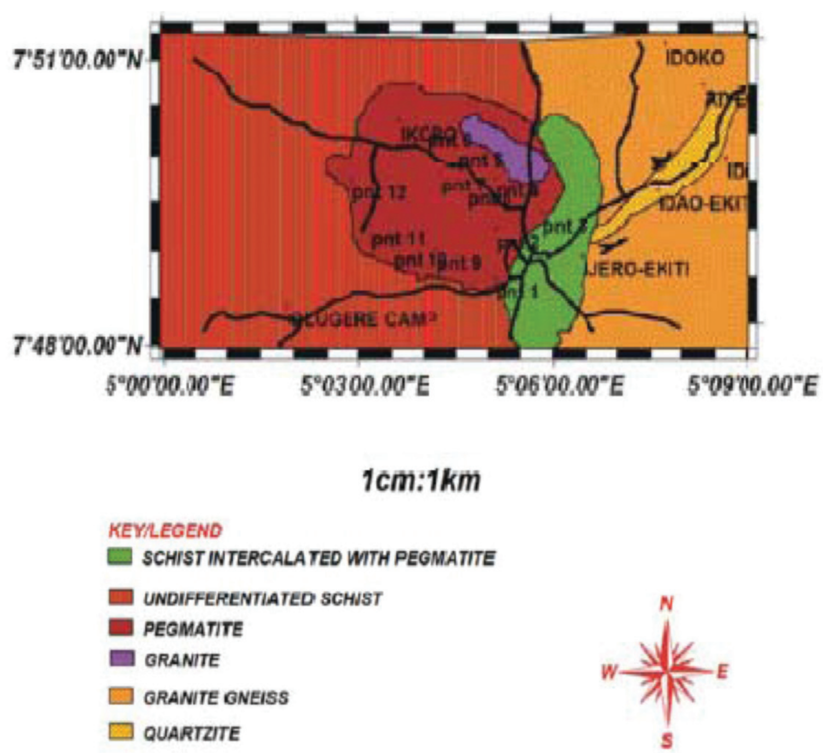

Figure 1: Geological map of the study area (Ale e.al., 2014).

Sample Preparation

A total number of 40 water samples from boreholes, wells, and streams were collected and analyzed for radon concentration. Samples of 500 mL were collected in precleaned plastic pet bottles and then capped. In addition, the bottles had been prewashed with distilled water and with dilute acid (0.1M HC∫, and were allowed to dry before collection procedures. For borehole sources, the samples were collected after turning on and allowing runoff for about —10 min. This was to allow the water temperature to stabilize and also for purging of trapped air. Also, the stream of flow was reduced to about 1/8 inch in diameter, bringing air bubbling to a minimum. Samples previously stored in tanks were not collected. The well samples were collected with the aid of bailers. For the stream samples, the bottles were carefully dipped to collect the samples. The bottles were filled to the brim to prevent the formation of air pockets. The samples were marked and carefully labeled to reflect the time of collection and location. The analysis of the samples for ^{222}Rn does not need any preservation. Since the maximum holding time is just 3 days, the samples were taken to the laboratory almost immediately in order to reduce the decay coefficient. Since the samples would give up radon readily at higher temperatures, they were transported to the laboratory in a bag containing ice in order to ensure the low temperature condition of the samples.

Samples Analysis

The samples were analyzed using the Durridge Inc. RAD7. It is a sophisticated, active radon detector that uses a computer-driven electronic detector with preprogrammed setups. The real-time monitoring device uses the alpha spectrometric technique. To analyze radon in water, an accessory, RAD H_2O, is connected to RAD7as shown in Figure 2. The analysis result is obtained in about 30 min, making it a relatively fast technique. The RAD7/RAD H_2O system is well documented (Durridge, 2013).

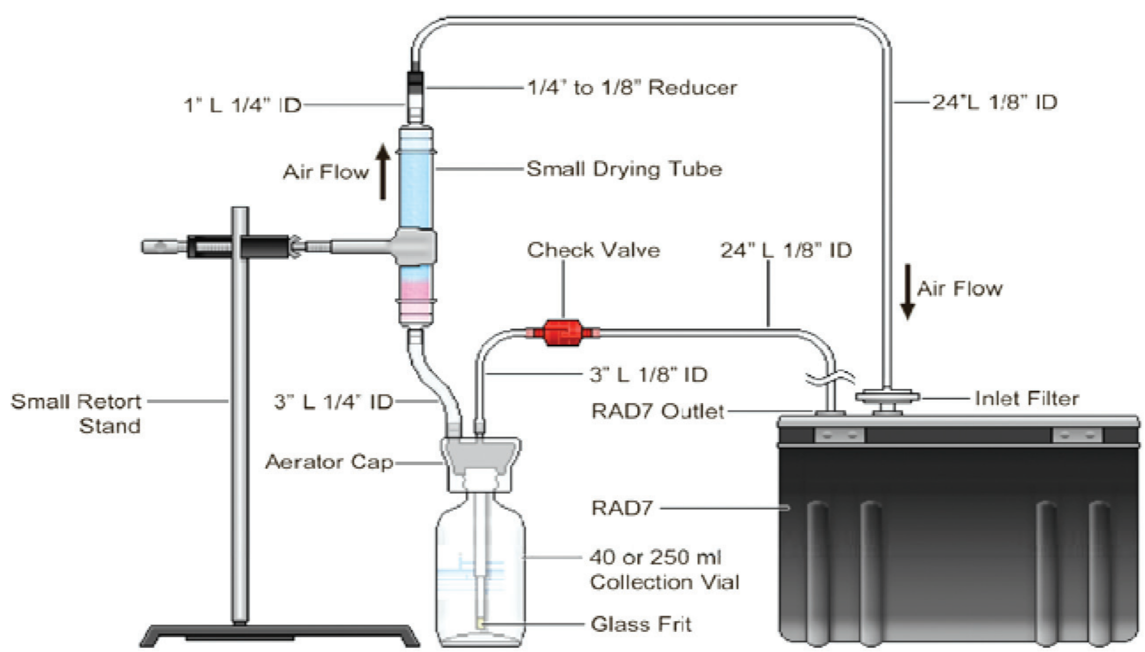

Figure 2: GRad H_20 schematic.

The collection, sealing, and counting of the samples took 28 h. This led to the reduction of the radon concentration in the samples due to radioactive decay. To account for this reduction, the measured concentrations were corrected using the decay correction factor (DCF), from the time of sampling to the time of counting. DCF, a simple exponential function of a time constant (TC) is given by (Durridge, 2013)

$$\text{Time constant} = \frac{3.825 \text{ days (half-life of 222Rn)} * 24 \text{ (h/day)}}{\text{In } 2} = 132.4 \text{ h}$$

$$\text{DCF} = \exp\ (T/132.4 \text{ h}) \qquad (1)$$

where T = decay time in hours

The readings of each sample were taken once, and a(DC) was used. DCF is a simple exponential function with a time constant (Durridge, 2013). The results were corrected back to the sampling time by multiplying with the decay correction coefficient.

Committed Annual Effective Dose

Radon assessment of drinking water is extremely important because of the recognized health risks, primarily as a cause of lung and stomach cancer (Hulburt, 1989; IARC, 1988). Committed annual effective dose from ingestion was calculated using equation 2 according to Somlai et al.(200), Ali et al.(2013), and El-Tahe (2012).

$$E = K \times G \times C \times t \qquad (2)$$

where E = committed effective dose from ingestion (Sv)
K = ingesting dose conversion factor of ^{222}Rn (Sv Bq^{-1})
G = water consumption, 2L per day (World Health Organization [WHO], 2008)
C = concentration of ^{222}Rn (BqL^{-1})
T = duration of consumption, 1 year (WHO, 2008)

For dose calculations, it was assumed that an adult drinks directly from the source and consumes an average of 2 L of water per day and children take an average of 1 L per day (UNSCEAR, 1993; Tayeb et al., 1998; WHO, 2008; Ali et al., 2013). For adults, committed effective dose per unit intake from the ingestion of radon in water (K) is 10^{-8} $SvBq^{-1}$, and for children, it is 2×10^{-8} $SvBq^{-1}$ (UNSCEAR, 1993; Binesh et al., 2007; Ali et al., 2013).

RESULTS AND DISCUSSION

The minimum and maximum radon concentrations in samples are 0.168 Bq/L and 78.509 Bq/L from stream and borehole samples, respectively. It was observed that none of the samples has a radon concentration value up to 100 Bq/L, which is recommended by the European Union to be the upper bound value above which remedial action is required (Oni et al., 2016; Oni et al., 2014; WHO, 2008). No particular trend was observed, and no relationship can be inferred to exist between the mean radon concentration, temperature, and pH of the samples (Sharma et al., 2017). Irrespective of the sources, 18 out of the 40 (45%) samples had a radon concentration higher than the maximum permissible limit of 11.1 Bq/L (USEPA, 1991), and all the samples had values higher than the maximum permissible limit of 0.1 Bq/L set by the Nigerian Standard for Drinking Water Quality (NIS, 2007). The distribution of radon concentration in all the samples is presented in Table 1.

Table 1. Distribution of ^{222}Rn Concentrations in Samples

Sample Type	No. of Samples	<5 Bq/L	5–11.1 Bq/L	11.1–20 Bq/L	20–100 Bq/L	<100 Bq/L
Stream	5	3 (60%)	2 (40%)	—	—	—
Well	20	6 (30%)	7 (35%)	7 (35%)	—	—
Borehole	15	1 (6.7%)	3 (20%)	4 (26.7%)	7 (46.7%)	—

Radon Concentration in Streams

The radon concentration in the five samples collected from streams ranged from 0.168 Bq/L to 10.237 Bq/L. However, two out of the samples have a considerably high radon concentration (10.237 and 8.442 Bq/L) when compared with samples from other streams. This observation is at variance with the reported works that have indicated surface water to generally contain a very low concentration of radon-222 because of the diffusional losses to the atmosphere (Binesh et al., 2010). Due to aeration, streams are expected to have low radon concentration, typically ranging from 0.001–0.5 Bq/L (WHO, 2011). The radon concentrations observed in the two samples in question are very close to the maximum permissible limit, 11.1 Bq/L(USEPA, 1991). The two samples with the high radon concentration values are from the streams traversing the binary or peraluminuous granite terrain, which are among those aquifer materials that have high radon risks. The two-mica or binary granite is the major type of granite in Ijero, and such a binary granite area has been reported to be with very high radon concentration in water (Kosh et al.,1988; Lachassagne et al., 2001). Although uranium concentration in two-mica granite is low, uranium within this type of granite is labile; hence, they get dissolved in ground water during weathering. The radon concentrations observed in the two samples in question are very close to the maximum permissible limit, 11.1 Bq/L. A significant number of the populace in IjeroEkiti relies heavily on streams particularly in the rainy season resulting in exposure and possible impact.

Radon Concentration in Wells

The radon concentration of the 20 samples collected from the wells ranged from 4.511 Bq/L to 26.542 Bq/L. Seven out of these samples had a radon concentration greater than the maximum permissible limit of 11.1 Bq/L (USEPA, 1991). It was observed that some samples have an unusually high concentration of radon, especially with the very shallow nature of the wells. The sampled wells have depths ranging from 1 to 3 m and are observed to contain shiny materials at the base, which are identified to be mica. This observation is consistent with radon concentration in wells from areas with high background radiation in southwestern Nigeria (Oni et al., 2014).

Radon Concentration in Boreholes

For borehole samples, 11 out of the 15 (73.33%) samples analyzed had radon concentrations greater than 11.1 Bq/L with the lowest and highest concentrations recorded to be 2.698 Bq/L and 78.501 Bq/L, respectively. The arithmetic mean radon concentration of borehole samples was 23.036 Bq/L. This observation showed a similar trend when compared with earlier studies that have reported high radon concentrations in borehole sources (Oni et al.,2014) reported that borehole source has the highest concentration of radon when compared with those from wells from high background radiation areas in southwestern Nigeria. The reason for the high radon concentration could be a function of the geological structure of the areas. It has been reported that the geological structure of an area is a predominant factor for high radon concentration. The saturated zone of the earth crust has been reported to contain a high amount of radon (WHO, 2011). This implies that the depth of the source is also a predominant factor for high radon concentration. The two-mica-granite structure of the study area may have contributed to the high radon concentrations observed in borehole sources.

Annual Effective Dose Assessment

The result of the annual effective dose from ingestion of radon-222 in water by both adults and children calculated using equation 2 is presented in Table 2. The minimum and maximum annual effective doses in samples are 3×10^{-6} and 1570×10^{-6} mSv/y for adults and 7×10^{-6} and 3140×10^{-6} mSv/y for children, respectively. The arithmetic mean of the annual effective dose for adults is 282×10^{-6} and 563×10^{-6} mSv/y for children. It was observed that none of these sources had an annual effective dose higher than the maximum permissible limit of 0.2 mSv/y if consumed by children and 0.1 mSv/y if consumed by adults (WHO, 2008). It was also observed that the dose receivable by children is quite low relative to the dose receivable by adults.

Artisanal mining of minerals is still the major type of mining in Ijero. Cottage or full-scale industrial mining activities, without adequate planning to take care of all possible impacts, would result in an increased level of radionuclides and radon in ground water. Technologically enhanced naturally occurring radionuclides would get leached into the ground water, increasing the risk to radiation exposure. There is therefore the need to pay urgent attention to this situation in order to protect the populace from further radiological hazards that might arise from the ingestion and inhalation of radon.

CONCLUSION

Radon concentration of ground water in Ijero, Ekiti State, Nigeria was investigated. Data obtained for ^{222}Rn concentrations from the study ranged from 0.168 to 78.509 Bq/L. The results showed that 45% of radon concentration in the ground water samples has values higher than the maximum permissible

Table 2. Summary of the Annual Possible Effective Dose From Ingestion of 222Rn in Water

Sample Type	No. of Samples	Adults			Children		
		Minimum (mSv/y)	Maximum (mSv/y)	>0.1 mSv/y	Minimum (mSv/y)	Maximum (mSv/y)	>0.2 mSv/y
Borehole	15	0.000054	0.001570	—	0.000108	0.003140	—
Well	20	0.000024	0.000531	—	0.000048	0.001062	—
Stream	5	0.000003	0.000205	—	0.000007	0.000409	—
Total	40						

limit set by USEPA and comparable to the work of Oni et al. (2016),which has radon concentration values in underground water in Ado Ekiti, Nigeria,ranging from 3.09 to 32.03 Bq/L. There is a need for immediate action for radon reduction as all the water is not safe for domestic purposes and consumption in that all the samples had higher values when compared to the maximum permissible limit of 0.1 Bq/L set by the Nigerian Standard for Drinking Water Quality (NIS, 2007). Hence, investigation of radon concentrations in air, soils, and indoor radiation of houses in the study area is recommended for further studies, as it would provide more complimentary data to work with.

Furthermore, radon concentration in ground water should be investigated across all geopolitical zones in Nigeria. This will help in investigating radon risk areas and seeking for ways to protect her citizens from risks associated with the inhalation and ingestion of radon. Inhalation and ingestion of radon have been associated with the incidence of stomach and lung cancer. There is a need to carry out epidemiological studies to investigate the incidence of lung and stomach cancer in the study area and other areas in Nigeria where high radon concentration is observed.

Finally, the public water system should also be revisited, and efforts should be made to educate and enlighten the public on radon, its health effects, and remedial actions necessary to reduce radon concentration in water.

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