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Measurement of Radon Concentration in Water within Ojo Axis of Lagos State, Nigeria

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Abstract: Background: The problem of radon (Radon-222) in water is one of the daily health hazards faced by those in Ojo Axis, Nigeria. Therefore, continuous monitoring of radon contamination in different types of water is essential. In the present work, sixteen groundwater and surface-water samples (wells, boreholes, and sachets) were collected from six different locations within the Ojo Local Government area in Nigeria. The water samples collected were stored in 75 cl bottles that were already sterilized with distilled water to avoid contamination. Water samples were then taken to the laboratory for the analysis of radon levels using a RAD7, an active electronic device produced by the Durridge Company in the USA. The radon level in the water is higher than the safe limits of 11.1 Bq/L, as per EPA regulations, except for two sample points from the studied areas. The total annual effective doses from ingestion and inhalation for drinking and groundwater were higher than the safe limit of 0.1 mSv y^{-1} that is recommended by the World Health Organization and the European Union Commission. Conclusions: The obtained results underline the importance of the development and/or updating of databases regarding radon levels in drinking and groundwater in the Ojo Local Government area in Nigeria.

Keywords: radon; radon in water; RAD7; water contamination

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Citation: Mostafa, M.; Olaoye, M.A.; Ademola, A.K.; Jegede, O.A.; Saka, A.A.; Khalaf, H. Measurement of Radon Concentration in Water within Ojo Axis of Lagos State, Nigeria. *Analytica* **2022**, *3*, 325–334. https://doi.org/10.3390/analytica3030023

Academic Editors: Roberto Mandrioli, Victoria Samanidou, Thomas W. Bocklitz and Marcello Locatelli

Received: 22 July 2022
Accepted: 30 August 2022
Published: 2 September 2022

1. Introduction

Water is a natural resource without which people, crops, and living creatures cannot survive (either directly or indirectly) [1–3]. It is one of the planet's fundamental and crucial natural resources on which most life depends. Furthermore, it plays a major role in the environment, the ecosystem, and human health. However, once contaminated, it can cause major health issues to humans and degradation of the natural environment, as well as the ecosystem in general. The solubility of several chemicals, minerals, and radioactive elements cause the groundwater to be more radioactive than the surface water. The flow of water through rock and soil formations also contributes to groundwater being more radioactive than surface water [4–9].

Various studies on naturally occurring radionuclides, including radon, radium, uranium, thorium, and actinium isotopes, are predominantly reported in groundwater, drinking water, and freshwater [9,10]. However, their quantities are highly variable because the levels depend on the type of aquifer and the local lithology [11,12]. Furthermore, the presence of uranium radionuclides series in water, such as ^{226}Ra and ^{222}Rn, can be harmful to human health. As a result, exposure to these radionuclides through consumption poses a concerning health risk to humans [13–17].

Radon, as one of the naturally occurring radionuclides, is emitted by rocks and soil and has a half-life of 3.8 days. It tends to accumulate in enclosed spaces, such as underground mines and indoor spaces. The radioactive daughters of ^{222}Rn, ^{214}Po, and ^{218}Po decay through alpha emissions and account for approximately 90% of the total radiation dose received by humans due to radon exposure [18–25].

Radon and its decay products are contained not only in soil and air but also in water. The solubility of radon in water is one of its most important properties; therefore, it can be transported large distances through soil [26–28]. The concentration of radon in water depends on the original source of that water. Rainwater washes out radon and its decay products from the air, while radon from the core of the earth diffuses into the groundwater.

About half of the world's drinking water comes from underground waters. Underground water predominately moves through rocks that contain natural uranium. Uranium, by its decay, releases radon into the area's water. In this way, radon can be dissolved and deposited in underground springs. Therefore, a significant contribution to the general exposure to radon and its decay products comes from ingesting drinking water from underground sources via excavated and drilled wells [26,27,29–32]. Drinking water that has been enriched with radon can be harmful to your health in two different ways: by inhaling it, after the radon has been transferred from the water to the air inside your home, and by ingesting it [9].

Recent studies have indicated that the annual effective dose from ^{222}Rn is 1.3 mSv y^{-1}, contributing to a total natural exposure of 2.40 mSv y^{-1} (more than 50%) [33,34]. According to a previous study [35], the World Health Organization (WHO) states that "1–7% of all lung cancer deaths are caused by radon levels in water, while 10–15% of total indoor radon may be attributed directly to outgassing from tap water" [36]. The maximum contamination level for radon in drinking water is 11.1 Bq/L, according to USEPA (the Environmental Protection Agency in the United States) regulations [36–40]. The European Union Commission and the World Health Organization have proposed that the standard limit of concentrations of ^{222}Rn in drinking water should be set at 100 Bq/L [36,39]. In general, groundwater resources, rather than surface water, have much higher concentrations of radioactive materials such as ^{222}Rn [30–32,37,40–42].

Several researchers and international scientific organizations have rated radon as carcinogenic and as a serious health issue [43–46]. Long-term exposure of the public to elevated amounts of radon and its progeny produces numerous detrimental consequences, such as alterations to respiratory function and the growth of lung cancer [47,48].

Most of these studies have concluded that there are strong correlations between the concentration of radon and the geology of the surrounding environment. The consumption of water containing enhanced activity concentrations of ^{222}Rn could elevate the effective dose received by humans and raise the cancer risk [46]. The behavior of radon in Lagos' coastal plains and alluvial aquifers is being investigated, demonstrating the influence of the parent deposit radionuclide.

In most countries of Africa, such as Nigeria, urban regions are regularly affected by the problem of potable water availability, caused by human activities and industrialization. This problem may lead to pollution and a lowering of water quality. Leachate from domestic and industrial wastes also poses a high risk to the quality of underground water. As reported in numerous studies on the health risks linked to radon in water, it is, therefore, crucial to assess radon concentrations from the perspective of radiation [49,50].

The assessment of radon concentrations is essential from the perspective of radiation safety and health, as reported in numerous studies on the health risks linked to radon in water [51–53]. Therefore, this study aimed to measure radon activity and estimate the radiological risk due to radon inhalation and ingestion, using water samples from the Ojo Local Government area in Nigeria. The findings of this inquiry will contribute to the radon database and supply information to inform the relevant policies.

2. Materials and Methods

Sixteen groundwater and surface-water samples (wells, boreholes, and sachets) were collected from six different locations within the Ojo Local Government area in Nigeria. The collection sites are presented in Figure 1. Ojo's sedimentary geology is clearly demonstrated.

Most of the coastal plain sands, lagoon sediments, and littoral sands are made up of alluvial deposits. The land on the state's northern border has topographically low-lying soils that do not rise very high above sea level [54].

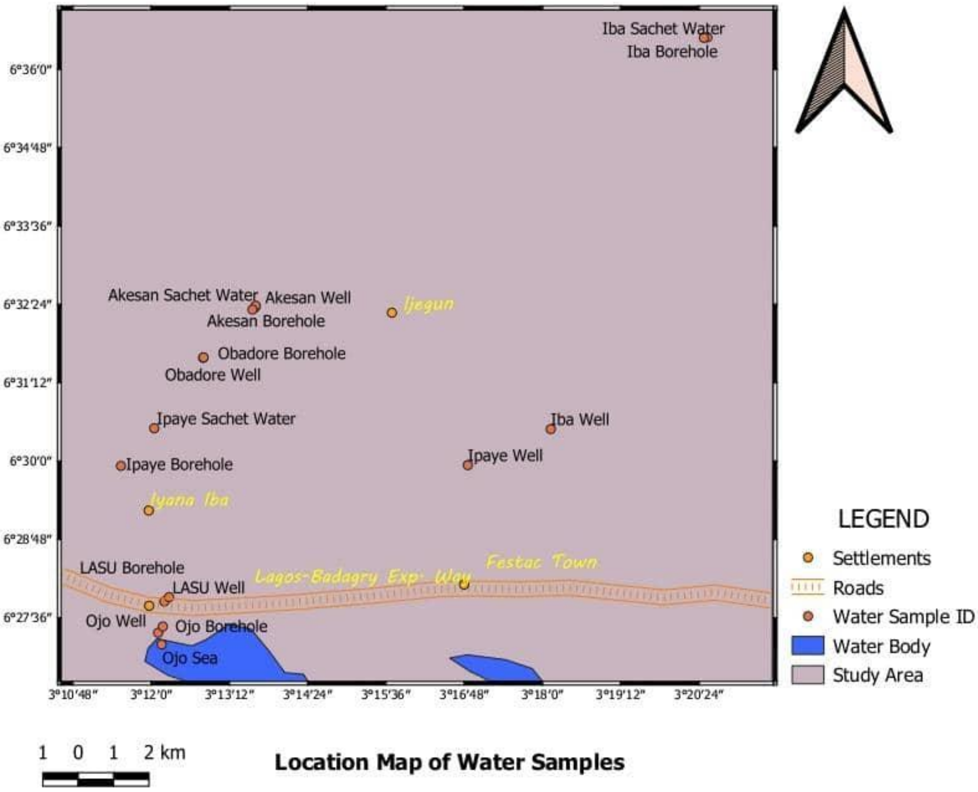

Figure 1. Map of sites of water collection from Ojo Local Government area in Nigeria.

Radon Measurement

The radon detector (RAD7) manufactured by the Durridge Company, Inc., in the USA, is a portable radon detector offering fast measurement that is widely used to measure the radon concentration in water samples. Its lower limit detection (LLD) is less than 0.37 Bq/L.

Using a RAD7, H_2O samples yield results after 30 min of analysis, with a sensitivity that matches or exceeds that of liquid scintillation methods (RAD7, RAD H_2O). The setup of a RAD7 being used to measure ^{222}Rn activity in water samples is shown in Figure 2. The accuracy of radon sampling in water measurement when utilizing a RAD7 is affected by numerous factors, such as the technique used for sampling, sample size, counting time, temperature, relative humidity, and background effects. The water sample is representative of the water being tested, in the sense that it has never been in contact with the air. In the standard sampling method, a 250 mL vial is filled with water and taken for radon concentration measurement. Radon concentrations of less than 100 Bq/L are observed; for radon concentrations higher than 100 Bq/L, a 40 mL vial is used.

Since, in this investigation, the radon concentration in water was unknown, samples of both sizes were taken. When sampling tap water, the water was left to run for 10 min before taking the sample, to let out the water from the possibly stagnant pipe section. The sampling vial (volume 250 mL) was placed in the bottom of the bowl, and the tube end was put into the vial. The water was allowed to flow for a while, keeping the vial full and flushing it with fresh water. The vial cap was put on while still under the water.

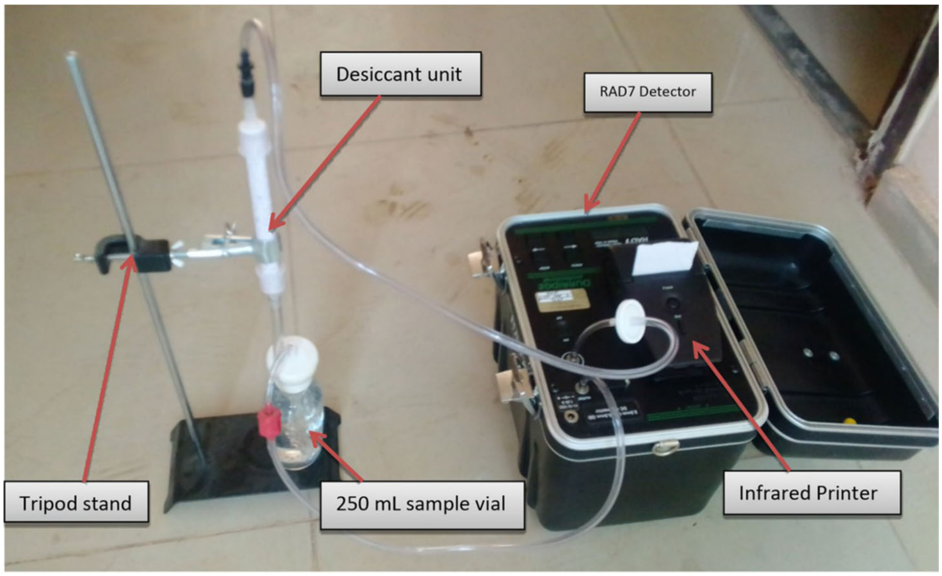

Figure 2. The setup of the RAD7 detector used to measure Rn-222 activity in water samples.

Due to the impact of relative humidity on measurements, the RAD7 counter should be dried out thoroughly before taking measurements. High humidity reduces the efficiency of collection of the ^{218}Po atoms, the first decay state of radon, inside the chamber. However, the ^{218}Po half-life of 3.05 min means that almost all the decays that are counted come from the mode as posited.

The annual effective dose due to the ingestion of radon from underground water, $E_{(ing)}$, was calculated using Equation (1) [55,56]:

$$E_{(ing)} = CRn\ (Bq/L) \times DCF \times Crw \tag{1}$$

where C_{Rn} = the mean radon (^{222}Rn) activity concentration in water, DCF = dose conversion factor = 3.5 nSv/Bq, and C_{rw} = annual consumption rate of water = 730 L/y [56].

The annual effective dose of inhalation $E_{(inh)}$ of radon from water can be obtained from Equation (2) (UNSCEAR, 2000) [56,57]:

$$E_{(inh)} = C_{Rn}\ (Bq/L) \times R \times D \times F \times T \tag{2}$$

where C_{Rn} is the mean radon (^{222}Rn) activity concentration in water, R is the ratio of radon in air to radon in water (10^{-4}), D is the dose conversion factor of radon (9 $nSvh^{-1}(Bq/m^3))^{-1}$, F is the indoor equilibrium factor between radon and its progeny (0.4), and T is the time indoors (7000 hy^{-1}) [56,58]. This equation is applied because the water under study is pumped through public water pipelines.

3. Results

The mean radon activity concentrations of the sixteen samples of water, taken from six different locations within the Ojo Local Government area in Nigeria and measured with a RAD7 counter, are presented in Figure 3. The radon activity concentrations were above the 11.10 Bq/L (the action level recommended by the United States Environmental Protection Agency) [40], except for two samples (7 and 8), which were lower than this limit at 10.80 and 6.04 BqL^{-1}, respectively. None of the water samples has a radon activity concentration value of up to 100 Bq/L, the value recommended by the European Union Commission to be the upper bound value at which remedial action is required [39]. A normal distribution histogram of the measured radon activity concentrations for the sixteen samples is presented in Figure 4.

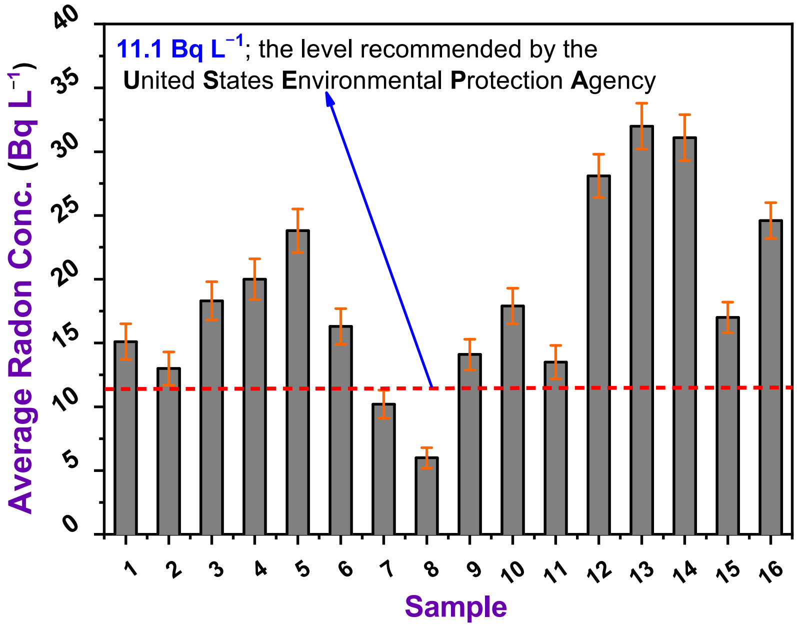

Figure 3. Variations of the mean radon activity concentrations for the sixteen water samples, compared to the USEPA parametric value.

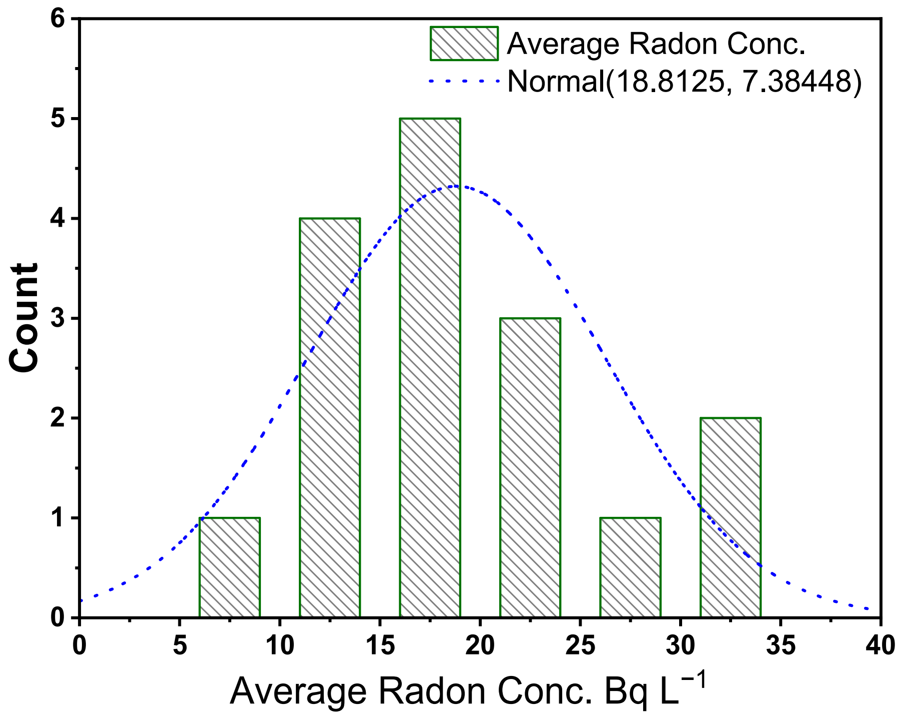

Figure 4. Normal distribution histogram of the measured radon activity concentrations for the sixteen samples.

The mean value for all samples is 18.80 ± 7.40 Bq/L (Figure 4). The value of error (7.40) in the mean value, around 40% of the activity concentration, is due to the difference in the activity concentration from site to site. Therefore, for each site, the average activity concentrations of radon, independent of the source (sea, well, borehole, and sachet water), are shown in Figure 5. The maximum average is found at the Akesan site (30.40 ± 2.04 Bq/L). which is more than the recommended level of 11.10 Bq/L reported by [29], and the minimum average value is found at the Ipaye site (10.80 ± 5.18 Bq/L), which is nearly equal to the recommended level of 11.10 reported by [29]. The obtained results are comparable to those in the works of Oni et al. [59,60], which report radon concentration values in underground water in Nigeria at a range of 3.09 to 32.03 Bq/L. There is a need for a radon reduction action plan as all the water samples had higher values when compared to the maximum permissible limit of 0.10 Bq/L that has been set by the Nigerian Standards for Drinking Water Quality [61].

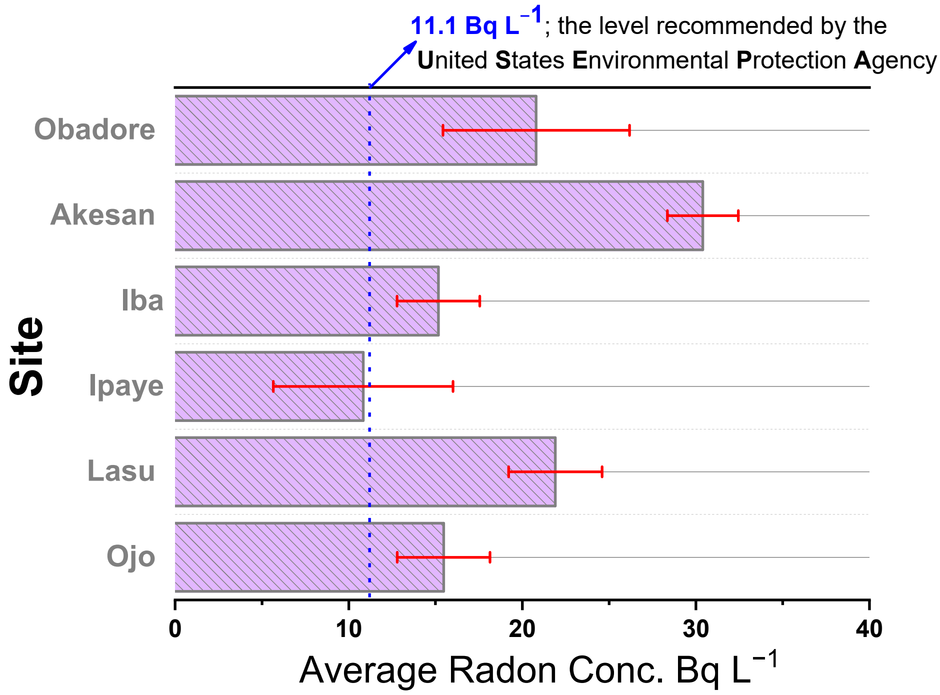

Figure 5. The average activity concentrations of radon, independent of the source (sea, well, borehole, and sachet water).

Based on the results of the activity concentrations of radon in the tested water samples, the annual effective dose due to exposure by ingestion or by inhalation from water is estimated and presented in Figure 6.

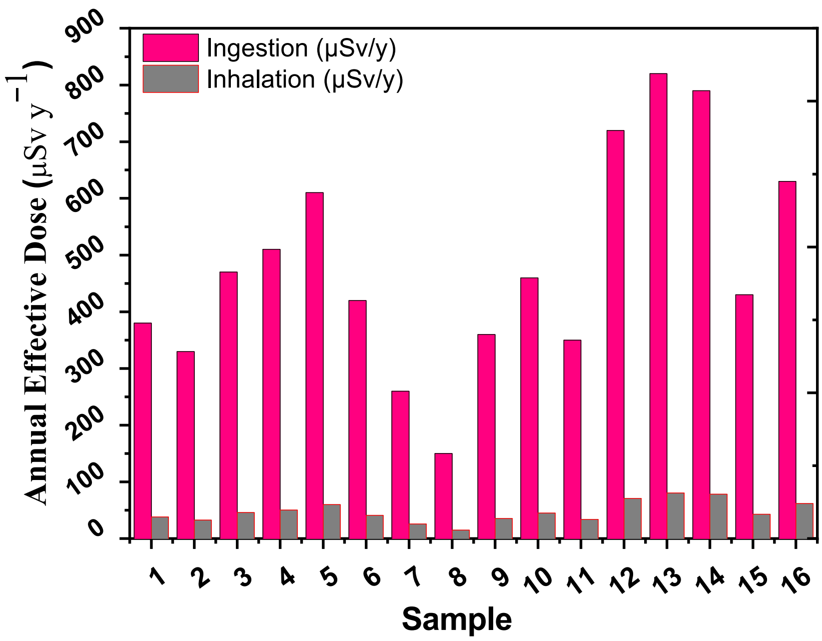

Figure 6. The annual effective dose with ingestion and inhalation for the sixteen water samples.

The samples have an annual effective dose from ingestion and inhalation of drinking and groundwater that is higher than the maximum permissible limit of 0.2 mSv/y if consumed by children and the maximum limit of 0.1 mSv/y if consumed by adults that is recommended by the WHO and the European Union Commission [36,39].

The annual effective dose ranges, with their mean and distribution, comprising ingestion and inhalation are shown in Figure 7. A strong Pearson correlation (0.93) between the annual ingestion and inhalation effective dose is observed, as presented in Table 1. With a value of 0.936, a strong Pearson correlation also exists between the annual effective ingestion dose and radon activity concentration for the measured water samples. This agrees with the WHO report, which says that "a higher radon dose is received from inhaling radon compared with ingestion".

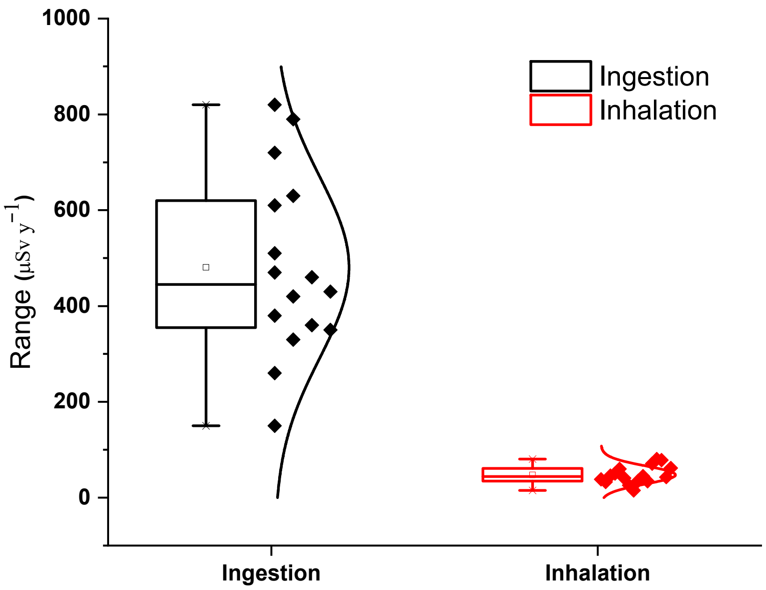

Figure 7. The annual effective dose range, with means, due to ingestion and inhalation, for the sixteen water samples.

Table 1. Pearson correlations between ingestion and inhalation of the annual effective doses, with radon concentrations.

		Average Radon Conc.	Ingestion	Inhalation
Average Radon Conc.	Pearson Corr.	1		
Ingestion	Pearson Corr.	0.93618	1	
Inhalation	Pearson Corr.	0.99985	0.93416	1

4. Conclusions

The aim of this research is to measure the activity and estimate the radiological risk due to radon inhalation and ingestion, as tested in water samples from the Ojo Local Government area in Nigeria. The radon activity levels in the drinking and groundwater were analyzed for 16 samples from 6 different locations within the Ojo Local Government area in Nigeria. The radon level in water is higher than the safe limits of 11.1 Bq/L set by the EPA regulations, except at two sample points in Ipaye. All the water samples had higher values when compared to the maximum permissible limit of 0.1 Bq/L that is set by the Nigerian Standards for Drinking Water Quality. The weighted mean of the total annual effective doses from ingestion and inhalation for drinking and groundwater is higher than the safe limit of 0.1 mSv/y recommended by the WHO and the EU Commission. The results demonstrate that the drinking and groundwater in selected locations in the Ojo Local Government area in Nigeria need frequent monitoring and evaluation with regard to radon values. Radon reduction action plans are required and recommended for drinking and consumable water in the studied locations, to reduce the potential risks.

The public water distribution system should also be revisited, and efforts should be made to educate and enlighten the public on the risks of radon, its negative health effects, and the remedial actions necessary to reduce radon concentrations in water.

The obtained results promote the development and the update of databases recording radon levels in drinking and groundwater in the Ojo Local Government area, which will help in policy- and decision-making concerning radon within the country. Furthermore, the radon concentration in groundwater should be investigated across all geopolitical zones in Nigeria. This will help in investigating radon risk areas and in seeking ways to protect the population from the risks associated with radon ingestion and inhalation, which have been associated with the incidence of stomach and lung cancers. There is also a need to carry out epidemiological studies to investigate the incidence of lung and stomach cancer in the study area and in other areas in Nigeria where high radon concentrations have been observed.

Author Contributions: M.M.: Resources, writing—review and editing, and conceptualization; M.A.O.: investigation and formal analysis; A.K.A.: project administration; O.A.J.: supervision and visualization; A.A.S.: methodology and data curation; H.K.: validation and writing—original draft. All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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