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Radiological Implications of Radon Levels on Human Health: Systematic Review in Nigeria

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ABSTRACT

Radon is a colorless, odorless indoor and outdoor air pollutant that is produced by uranium disintegrations (decay). It represents at least half of the typical population's ionizing radiation exposure due to man-made and natural origin. Attention was paid to radon due to its harmful radiological effect on public health. Population have for all time been exposed to radon and its progeny since they are naturally occurred and enter homes through a variety of pathways such as buildings (such as ceiling, walls & floor), Water, Soils and rocks. Radon detection is rarely important because it is not known to exist unless there is a wellbeing distress. The quantity of radon present within water, rock-soils and buildings varies on a number of variables. According to the retrieved studies, indoor radon levels are generally higher during the cold and wet seasons than they are during the summer. This systematic review focuses on the radiological implications arise from high exposure to radon and the elevated probability of happening of wellbeing harms in exposed residents of Nigeria. Previous research on radon concentrations in Nigeria received the most attention. Only a few studies provided evidence supporting the link between outdoor and indoor radon concentrations and radiological implications analyses, such as the evaluation of cancer risk from radon inhalation and ingestion yet within areas of extremely high concentrations. On the other hand, a few studies also revealed a tendency for adverse effects on public health to occur still within circumstances where indoor radon concentrations be lesser. According to data derived from published articles by Nigerian researchers, radon exposure caused some little concern over the association between radon concentration and determinations of radiological impact. Therefore, it is crucial to evaluate the radiological effects of radon, comprehend the dangers of exposure, and determine how inhabitants in Nigeria who are exposed to it may suffer health effects. The best course of action to prevent the harmful consequences of radon gas in an indoor or outdoor environment is to stop its production. Preethi and Jeyanthi offered some methods for radon mitigation in buildings. Depressurization, freshening, and sealing fall under these categories, with related percentage effectiveness ranges of 50–80%, 80–95%, and 50–70%.

Introduction

Radon is an immobile gas that is regularly found within indoor and outdoor environments. World health organization (WHO) stated that radon released during disintegration of uranium (238U). This article makes multiple references to research that demonstrates radon to be a factor in both smokers and nonsmokers developing lung cancer. In fact, several works, generally as of the comparable time period, state that radon ought to be potentially considered as vital source of lung cancer for the wide-ranging population since it causes interior air to turn out to be contaminated through emission of radon from soil, rocks, buildings, and water. The 2nd most reason of lung malignancy was due to radon exposure, which has to do with primary reason of cancer related mortality worldwide, this exposure to radon creates considerable health risks for human beings exposed [1].

Radon posed the greatest threat to human health among the radioisotopes that contribute to ambient background radiation. It is

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responsible for fifty five percent (55%) of the twelve-monthly radon exposure dose expected for wide-ranging populace. Owing to their weight, radon's alpha particles can only travel a short distance. Even though it cannot penetrate skin of human being, it can be inhaled and inhabit in the tissue of lung. Due to highly localized energy accumulation in the tissue of the lung, the hazard of the lung tumor is likely to increase [2]. The most significant indoor air contaminant in buildings is radon, which has negative impacts on the general public's health. Cancer of lung risk is increased through radon inhalation and the short-lived decay products it produces [3]. Radon can move into the indoor air and raise radon concentrations due to geophysical and geological setting as well as the features of the building resources [4].

The fast dissipation of the gas through the open air lead to it build-up inside the building structure, particularly in places where the ground beneath is porous to natural radiation and contains more uranium than it's typical. Consequently, it is important to measure/monitor environmental radon [5]. Inhaled radon and its progeny possibly will be set down on top of the cells facing the airways, airways, wherever the alpha particle released may harm DNA Structures and other potentially dangerous organs and tissues. Ionizing radiation from natural sources is believed to cause a mean standard 2.4 mSv/year worldwide, of which 1.0 mSv is attributable to radon exposure [6,7]. Radon emission is a subject that has received a lot of attention globally. Numerous nations have done case control studies and nationwide radon surveys to examine the link connecting radon exposure and the hazard of increasing cancer. Roughly 55% of all other tumors (cancer) of lung in humans are associated with exposure to radon and its daughters by population [8].

In the United States, airborne radon concentrations are typically calculated in pCi/L (picocuries for each litre) although regions akin to Europe in the West, they make use of the further conventional unit (Bqm-3). As a result of a straightforward calculation, 1pCi is equivalent to 3.7×10^{-2} Becquerel and picocurie per litre is equal to 37 Bq/m3. Experts have shown how important construction materials, ventilation, and meteorological and geological conditions are on behalf of safe society of radon [9]. In line with UNSCEAR, a little raised radon levels originate in the majority of houses is considered unimportant otherwise at slightest not more dangerous than other characteristically good enough dangers deposited by international organization. However, this does not absolve the responsible bodies from duty.

A sizable portion of residences have indoor radon levels that some authorities deemed undesirable [10]. Our homes' construction materials produce some radon, and some types of construction materials are able to be important producers of interior radon. These building materials combine an elevated porosity that allows radon gas to flight with increased Ra-226 levels. Examples include phosphogypsum, Italian tuff, and light-weight concrete constructed with alum shale [11]. When radon that has escaped from the earth comes into contact with the home's negative pressure in relation to the soil, a pressure-driven mechanism is triggered. This pressure difference is brought on by exhaust fans, dryers in the kitchen, bathroom, and laundry room, as well as rising heated air from fireplaces, furnaces, ovens, and stoves, among other things [12].

Additionally, radon enters our homes through the provision of water, flour draw off, hand dug well and linking Pipeline, Secondary Siphon, Base fault, Block joint, Permeable cinder blocks, diffusion from the ground, and equipment used gas, even those that were appropriately vented allowed air drive-force gush into the home, and the supply of water, particularly from personal wells [10,13]. The majority of populace are exposed to elevated level of radon in small structures of buildings than in outsized building structures, as far as to UNSCEAR concerned [14]. The UNSCEAR was established to look by the side of the connection among inhabitants' safety toward the protected way of life of people including contractors working in the buildings engineering company and the ending project yield of any construction [6,7], the healthy status of the building structure was shown to not immediately correlate with the occupants' convenience and safety with regard to their health. in the early hours breakthrough and knowledge of the hazard alerted some countries in the world, like U.S and additional urbanized nations, toward the health danger that this radon creates to individuals and currently they are on the rise justifying measures to maintain exposure levels little; on top of the other hand, the condition is dissimilar in a lot of developing nations, such as Nigeria.

Few people are aware of radon, and little research has been done on the potential health risks it poses in Nigeria. Only recently have numerous initiatives been made to evaluate, examine and decrease the strength of doubt, particularly in our houses. A systematic review of the previous works pointed out that neither radon emission levels in Nigeria at the level of homes or those at workplaces have been adequately documented [15]. About half of the standard yearly effective dose of 2.4 mSv/year for all people globally is absorbed internally by radon inhalation. Since Radium and Uranium are abundant in environmental media such as soils, rocks and water, radioactive radon can escape from its host or material and enter the air. Both indoor and outdoor air contained a significant amount of radon.

It enters the lungs when inhaled and releases harmful particles. When breathed in, radon, a noble gas, is quickly expelled; nevertheless, radon progeny that has been mixed with other air molecules, dust, aerosols, or smoke from inside and outer surface straightforwardly set down in the airways of the lung. The progeny cause damage to the cells lining the airways as they are being deposited there because they release radiation which is ionizing in the type of alpha particles [10,12]. If breathed in radon decomposed daughters (such as solid form of polonium-218 and pol-214), whether free or attached to the outside in aerosols, dust or particles in smoke, turn into extremely wedged in the respiratory organ such as lung, where they can emit radiation and infiltrate the cells of the mucous membranes,

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pulmonary tissue and bronchi [16]. Comparable reports encompass that once taken in radon decays daughters (Pol-218 & Pol-214), must radiate the lung tissue. As previously established, damage due to alpha-particles is what predominantly causes the negative effects of radon exposure. Radioactive radon particles have adequate energy to rise, go through human being tissue, and lead to the cell damage [9].

Research establishes that radon decay daughters can effectively go into the body either via inhalation or through ingesting. According to another research demonstrated that eating poses no risk when there is foodstuff in the abdomen, despite the foodstuff's ingredients. Even a thickness of smaller than 1.5 mm can avoid the greater part of ∝-particles formed by the same radon and its daughter nuclide from disintegrating. The extent and length of exposure were suggested to affect the potential outcome. The most severe consequence of elevated radon exposure is the rise in lung cancer cases currently being documented within some healthcare system [10]. Cancer Association of American estimated that about 8.0 million households in American had radon levels that had sharply increased in 2006 [12]. Additionally, according to the EPA of the U.S, 6 million dwellers exposed to 4.0 pico curie per m3 of radon in buildings [10].

Moreover, it was stated that radon exposure accounts for more than 50% of a person's typical radiation dose. The great volume radon exposures to lungs were due to Polonium-218 and Polonium-214. Although concentrations can vary greatly, radon is always present, according to independent measurement of radon concentrations in buildings and homes. This raises anxiety in the pragmatic increase in lung disorders such as cancer cases surrounded by wide-ranging public could be due to exposure to radon, particularly for persons who spend their time indoor [17]. Additionally, research has shown that radon has the ability to trigger genetic disorders at any concentration [16]. Some Radon progenies (218P0 and 214Po) interact with biological tissue and harm cells, DNA, and chromosomes, leading to a variety of health issues. The level of concentration of radon in the houses be extremely dependent on a wide range of variables, including the area's geology and geophysical orientation, the building materials used, the weather, and the level of outdoor radon, among others. This has significant implications for the small variation noted because of the depreciable levels of concentrations in several houses and inhabited locations mentioned above [6,7]. Using various measurement tools including the Rad7, CR 39, and Pro-3 series detector of radon in houses, places of work, and various campuses in universities, indoor radon and outdoor examinations have been conducted [17,18]. However, there aren't many reports on indoor and outdoor radon implications in Nigeria. This study will review the status of radon in Nigeria and its health implications to environmental residents of Nigeria.

Theoretical Considerations of the Review

The Way that Radon Enters the Atmosphere and Environment

Radon is a radioactive element that was produced when uranium decays and is present in soil, groundwater, the atmosphere, and building materials. Radon is an invisible, tasteless, and odorless radioactive gas. It is created by breaking down radium, a byproduct of the decay of uranium. Radon releases alpha particles in addition to several radioactive forms of radon. Radon poses a lower risk to human health due to its longer half-life than its short-live byproducts such as Po-213 (3 min half-life), 214Pb (27 min half-life), 214Bi (20 min half-life), and 214Po (20min half life). Po-214, the progeny of Bi-214, degrades during a relatively long half-life to generate Pb-210, which is then expelled from the lungs before going through a significant deterioration. The available study focuses more on radon exposure than radon daughters because of radon's quick rates of decay and the fact that its presence alerts the system to be investigated since there's great probability that radon daughters which may pose a serious health danger be present. Figure 1 depicts the radon degradation chain. In the atmosphere, radon and its offspring can be produced in two different forms. Newly produced radioactive elements swiftly interact with trace gases and air vapors after isotope of radon decay to form cluster or unattached radioactive elements smaller than 5 mm, additionally, these radioactive nuclides attach to pre-existing air particles in an open space and produce radioactive aerosols in a matter of seconds. Positively charged and highly kinetic, newly created clusters of decay products are the majority. Due to the Stack Effect, radon penetrates structures through pipes and wires as well as cracks and openings, particularly those near windows and doors (Figure 2).

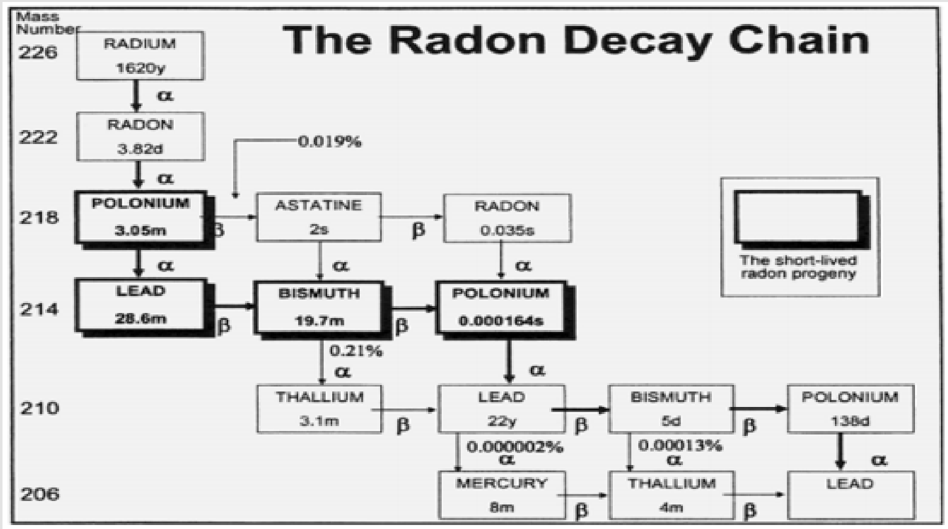

Figure 1: Radon Decay Chain.

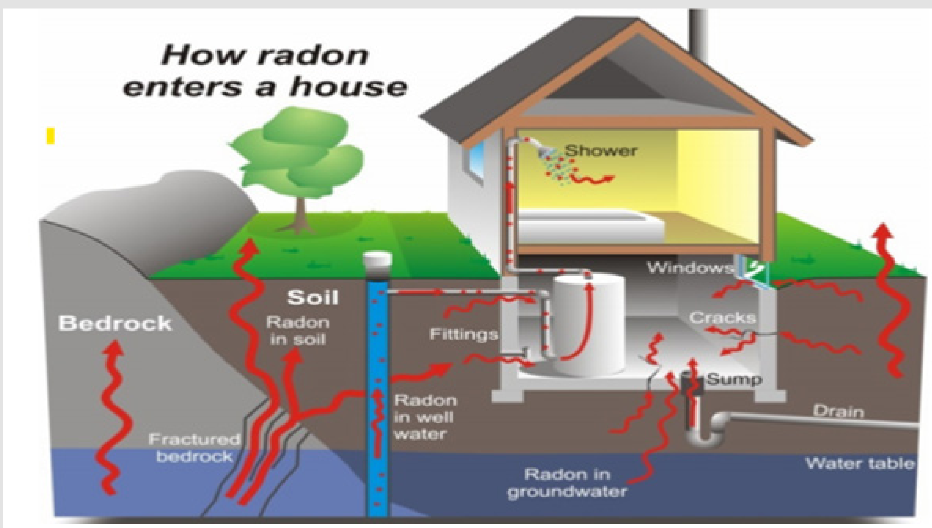

Figure 2: How Radon enters Buildings [19].

Techniques for Detecting Radon Gas

Figure 3 displays the ranges of radon concentrations in ambient samples. Surface waters, particularly ocean waters, have substantially lower radon concentrations than underground groundwater, and different sampling and/or analytical techniques are frequently used. When compared to soil air, radon concentrations in atmospheric air are also typically modest. Three features are used to classify radon measurement methods (Figure 3).

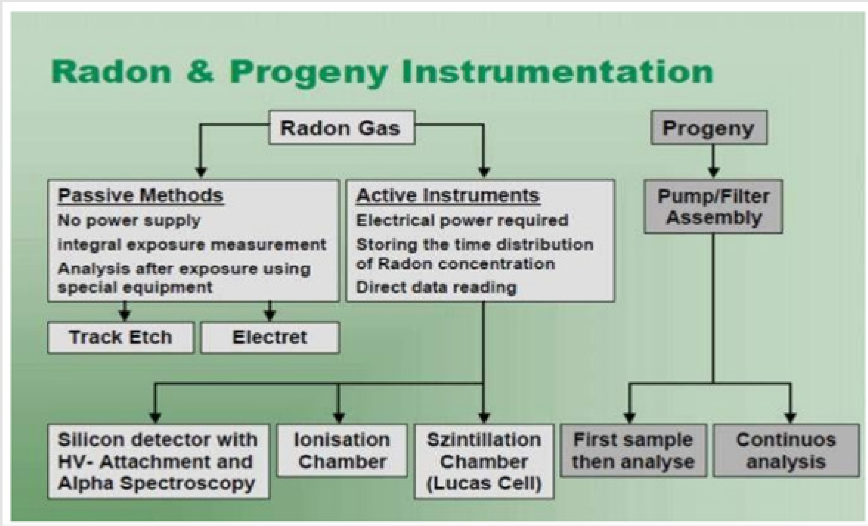

Figure 3: Measurement technique for radon and its daughters [19].

Durridge RAD7 Radon Measurements:

The Durridge RAD7 is a very accurate and adaptable radon measurement tool. The RAD7 is a reliable and durable piece of technology. The RAD7 is an advanced measuring tool that is frequently used in labs and research settings throughout the globe, by radon testers and house inspectors, in mines and deserts, on the ocean and atop volcanoes, and in environments with extreme temperatures (Figure 1). With pre-setups for typical procedures, the RAD7 is also the simplest computer-driven electronic detector to use. It is designed to withstand regular use in the field. The self-contained, self-sufficient detector is housed in a tough, attractive container. Along with a wireless infrared printer, rechargeable batteries, and an integrated air pump, the RAD7 is delivered fully assembled. The detector can gather data as needed and store it for subsequent printing or PC download [19].

Factor Influences Distribution of Radon

The radon concentration inside a building is not constant and is impacted by several factors, such as geographical and metrological factors like seasonal and nocturnal variation, ventilation effect, temperature effect, barometric pressure, and relative humidity, as well as building pattern and location [20].

Diurnal and Seasonal Change: The radon concentration is highest in the morning, drops in the middle of the day, and then rises once more in the evening, according to study on the seasonal and diurnal fluctuations in indoor radon concentration [20]. This is because radon decay is slowed by sunlight, and closing doors and windows from late at night to early in the morning promotes radon buildup by delaying radon dispersion. Studies on the annual variation of Concentration indicated that the wintertime radon concentration was higher than the summer and other seasons for the same low dispersion rate with doors and windows closed. It was found that there was a fall in radon concentration during the monsoon, along with strong southwest winds and heavy rainfall. The reduction in radon levels is caused by several other factors, including monsoon-induced soil water saturation. According to published studies, the openness of doors and windows has a significant impact on indoor radon levels while diurnal and seasonal changes have less effect. Therefore, if the doors are left closed for an extended period, there may be a high concentration of radon indoors. Due to the prevalent nuclear family culture in urban regions, closed dwellings can be observed for indoor radon with acceptable findings in these locations [20] (Figure 4).

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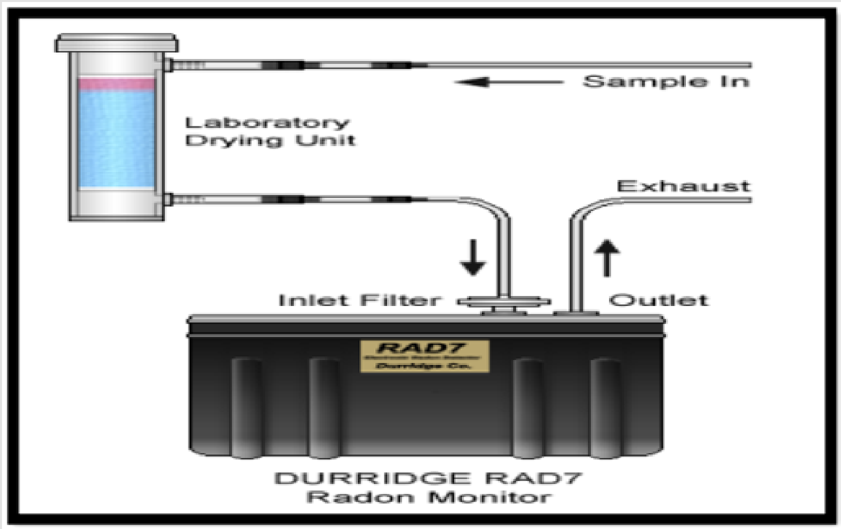

Figure 4: Block diagram of RAD 7 [19].

Effect of Ventilation: Radon concentrations are significantly influenced by ventilation. The ventilation rate is highest in the summer and lowest in the winter. The maximum concentration happens in the winter since there is less ventilation because people keep their windows and doors closed for extended periods of time, which allows radon to build up within the house. To reduce the concentration of radon, the dispersion rate is increased using supplied air; however as wear out air concentrations rises, radon concentration follows suit. It is known from reading the reviews of publications that the ventilation impact is a parameter that may be changed by closing windows and doors open for natural ventilation [20].

Temperature Effect: According to various examinations, the amount of indoor radon increased as the difference between interior and outdoor temperatures widened. Early in the morning, radon levels rise and are at their maximum; however, after increasing early in the morning, radon levels fall and reach their lowest point in the afternoon. Additionally, keep in mind that radon concentrations and temperature are inversely connected [20].

Barometric Pressure and Relative Humidity: When the interior barometric pressure was higher and interior, relative humidity was lower, extremely high indoor radon concentrations developed. When the interior barometric pressure was higher, and the interior relative humidity was lower, extremely high indoor radon concentrations developed. Outdoor wind speeds and outdoor barometric pressure were highly connected, with a correlation value of 0.25. Radon can infiltrate the soil if the barometric pressure is too high and the humidity is too low [20].

Pattern and Location of Buildings: The type of structure will either be a single story or multiple stories. According to past research, factors like the number and size of rooms, the number of occupants of nearby buildings, and the amount of vegetation around the building can affect radon concentration in structures. Examinations revealed that radon concentrations are more influenced by soil in single-storey structures and construction materials in high-rise Florey buildings. Due to the ease of radon infiltration from soil, older buildings with damaged foundations and basements have higher levels of radon exposure. Mud structures had higher radon exhalation rates than concrete buildings, wood buildings, and buildings made of mud. Both radon entrances from the ground and radon diffusion in the indoor environment were well-resisted by wood structures [20].

Health Risks of Radon Exposure for People

Subsequent to smoking, the leading factor in respiratory cancer among the population was radon. It is generally known that radon that radon and the decay product it produces make up a sizeable amount (more than 50%) of the background radiation that individuals are exposed to [2]. The National Academy of Science [NAS] in the US, estimated that approximately 20,000 Americans per year pass away from respiratory tumor caused by radon and its daughters because of lung linkage damage. According to ICRP Publication 66, the two primary divisions of the human respiratory system are the thoracic and extra-thoracic regions. Almost all of the gas inhaled is expelled, but the radon offspring that is breathed accumulates in the lungs' respiratory system. But according to recent epidemiological research, lung cancer can be brought on by radon exposure inside at levels as low as 100.0 Bqm-3. It was previously believed that radon concentrations greater than 400.0 Bq m-3 posed the greatest health hazards. According to recent studies, radon not only causes lung diseases but also has an impact on people's mental health.

Theoretical and empirical studies on how individuals react to biological effect like radon offer a more detailed image of how humans absorbed hazard. Several well-known cognitive biases have an impact on how dangerous we perceive radon to be, which prevents us from behaving in the best interests of the situation. Numerous well-known cognitive predispositions affect how dangerous radon is perceived by us, preventing us from responding in the best interests of the situation [20]. According to the findings of a previous study, the hazard of men infertility and the yearly effective dosage are inversely correlated, and radon levels were higher in most areas where male infertility is prevalent, above all in male with low sperm counts {sperm/ml}. In most research, where radon was estimated as a nonstop variable or when weigh against the greatest to the lowest quartile, the occurrence of down syndrome was higher in locations with high radon levels. Radon exposure at home was linked to an increase in hypertensive problems among the pregnant women in Massachusetts between 2001 and 20015.While second trimester had no statistical significance, the first and third trimesters showed a greater correlation with HDP. When we evaluated the link within each stratum of maternal age, there was found lager consequences in female below the age of 20 than in older female [20].

Material and Method

Search Techniques

The following keywords were used in a systematic search of databases including Goggle Scholar, MPDI, Research Gate, and academia to conduct this study: "Routes of Exposure to Radon," "Risk of Radon Exposure," "Radon concentrations," "Radon in water," "Radon in buildings," and "Annual Effective Dose of Radon in Water." "Radon Effect on Human Health", "Radon Effect on Human Radiation Exposure", and "Radiological Effect of Radon on Human Radiation Exposure", the papers were then picked based on their relevance as the first selection criterion, specifically by considering the largest part pertinent work published in Journal indexed in Scopus, web of Science, Science Direct, Goggle Scholar, and MDPI databases [21]. When "radon" was the only word in the title, abstract, or keywords, 600 publications were discovered in the database. When the search is limited to documents having the term "radon" in the title, the number of publications found is drastically decreases to 440. Because of this discrepancy, the database was always searched for keywords as part of the title/abstract/ Keyword to keep away from rejecting publications that did not have the keywords in the title [22]. The results that were achieved are shown in Table 1.

Table 1: Outcomes of database searching.

S/N	Keywords	Outcomes of Data Bases Searching	Total Number of Articles Removed
1	Routes of Exposure to Radon	50	
2	Hazards of Radon Exposure	40	
3	appraisal of concentrations of radon	25	
4	Water source of radon	100	
5	Buildings as source of radon	78	565
6	yearly effective dose of radon	98	
7	Investigation of radon level and its effect on health	89	
8	Radon effect on human health.	60	
9	Radiological effect of radon on human health	60	
	Total articles retrieved from databases searching	600	
	Total articles included in this review		35

To achieve the goal of the present work, which is to demonstrate and support a relationship between exposures to high indoor radon levels and lung cancer. The figure below indicates the flow chart of the literature retrieved from the databases.

Data Extraction

Locations, Samples, Method, concentrations of radon, effective dose per annum, lifetime Cancer Risk (Inhalation & Ingestion), and References are some of the information that was taken from the articles that were part of this systematic review.

Results and Discussion

Based on the research conducted in Nigeria, radiological implications of cancer due to ingestions and inhalations accounted for 14.28%, and 2.85% respectively (Tables 2 & 3) (Figure 5) [21,23-56].

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Table 2: Summary of the data extracted from the literature.

Location	Sample	Method	Conc	AED	ELCR (Ing)	EL-CR(Inh)	Reference
Ogun State Abeokuta	Soil	RAD7 solid-state detector	1004-19250	-	-	-	Tunde, et al. [23]
Jigawa State	Borehole	liquid scintillation counter & GPS	82.75 Bq/L	0.60mSv/y	2.11	-	Dankawu, et al. [24]
	Dug well Water		94.11Bq/L	0.69 mSv/y	2.37		
Rivers state	House	Digital Radon Detector meter	11.32Bqm^{-3}	2.59	2.45	-	Orlunta, et al. [25]
Borikir	Buildings	pocket sized	12.95	3.26	2.91		
Diobu			8.55	0.784	1.82		
Rebisi							
Ekiti State	HDW	RAD7 radon detector	13.33 Bq/L	-	-	-	Matthew, et al. [26]
Ekiti State University	HPB		27.4 Bq/L				
	MBH		7.40 Bq/L				
	Water						
Kwara State Oyun	Surface water	RAD7Active Electronic detector	35.86 Bq/L	352.20 µSvy^{-1}	-	-	Orosun, et al. [27]
Ogbomosho	Water	RAD 7	1.86 Bq L^{-1}	0.02 mSv /y	-	-	Emmanue & Theophilus [28]
Nigeria	granite & lime-stone Rocks	RAD7 detector	585.16	14.80 mSv/y	-	-	Mustapha, et al. [29]
			237.5	5.99 mSv/y			
Ekiti State	Ground Water	RAD7/RAD H20	78.51Bq/L	0.00157mSv/y	-	-	Akinnagbe, et al. [30]
Ijero Ekit							
Osun State	Granite grey & mica schist	RAD7 electronic radon detector	3.5 kBqm^{-3}	-	-	-	Deborah, et al. [31]
Ile-Ife (OAU)			11.5				
			28.4				
	Bottled	RAD7 detector	0.47 Bq/L	0.00018	-	-	Oni, et al. [32]
	Satchet water		0.25Bq/L	0.00000051			
Nigeria South West	Building	RAD 7 detector	61.74Bq m^{-3}	0.97mSv/y	3.5^{-3}	-	Olowookere, et al. [33]
Rivers State	Azuabie	Digital Radon Detector	10.65 Bq m^{-3}	0.64mSv/y	2.25^{-3}	-	Briggs, et al. [34]
Port Harcourt	Nkpogu		12.25	0.74 mSv/y	2.59^{-3}		
	Amadi		13.32	0.81mSv/y	2.67^{-3}		
Jigawa State	Low		53.3(13.3)	1.469mSv/y	-	-	Mansur, et al. [35]
Radon Prone-zone	Medium		223.3(55.8)	6.157mSv/y			
	High		423.3(105.8)	11.673 mSv/y			
Ondo State	Buildings	Track Test kits	Bqm^{-3}	-	-	-	Asere, et al. [36]
	OkeAgbe	(AT-100)	18.55				
	Ikare		19.78				
	Oka		33.68				
	Isua		59.46				

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Ogun State Ota	Buildings	Durridge RAD 7	19 -160 Bq m^{-3}	-	-	-	Adewoyin, et al. [37]
Nasarawa State Nasarawa	Water		3.91Bq/L	0.000051 (0.985) mSv/yr	0.0001^{-3}	3.45^{-3}	Rilwan, et al. [38]
Ibadan state	House	Durridge RAD7	10.54 Bqm^{-3}	0.48 mSv/yr	-	-	Usikalu, et al. [39]
Egbeda	Buildings		16.9				
Lagelu Ona-Ara			17.95				
Nigeria Iwaraja-If-ewara	G. Water	RAD-7	45.78	59.4 µSv/y	-	0.693^{-3}	Oluwaseun, et al. [40]
Ogun state	Buildings	RAD7 detector	Bqm-3		-	-	Usikalu, et al. [41]
Covenant University	Glass		14.96	0.377mSv/y			
	Brick		10.74	0.271 mSv/y			
	Basement		144.61	3.644 mSv/y			
	Houses						
Nigeria Southwest	G. water	RAD7	35.9 Bq/L	92 µSv/y	-	-	Yinka, et al. [42]
Oyo State Ibadan	School Buildings	CR-39 detectors	176.15Bq/ m^{-3}	1.14 mSv/y	-	-	Obeda, et al. [43]
Bauchi State Gadau	G. water	RAD7 detector	38.3 Bq/L	8.05(0.10) µSv/y	-	-	Hauwa'u Kulu, et al. [44]
Lagos State	G.water	Alpha GUARD monitor	0.138-0.411 Bq/L	2.27-75 µSv/y	-	-	Janet, et al. [45]
Nigeria	FUTA	CR39 detectors	216 Bqm^{-3}	4.0mSv/y	-	-	Oladele, et al. [46]
Western part of Nigeria	EKSU		153	3.0 mSv/y			
	FUOYE		297	5.0mSv/y			
Lagos state	Buildings	CR-39	7.52	-	-	-	Oluwasayoa & Margare [47]
	Wet soil	Detectors	5.66				
	Dry soil		6.98				
Lagos, state	OkeOdo, MRF	CR-39		3.60 Active	-	-	Olaoye, et al. [21]
Dumpsites	Olusosun Solus	Detectors	120.3 Bq m^{-3}	4.53 Dormant			
			257	Dumpsite			
			179.8				
			131.5				
Ilorin	Basement	RAD7	23 Bq m^{-3}	0.0896mSv/y	-	-	Adegun, et al. [48]
Lagos Akure	Work place						
Ekiti and Ondo States	boreholes Wells water	Durridge RAD-7	55.41-104.45	-	-	-	Ebenezer, et al. [49]
	Ponds Streams		61.48-119.71				
			47.31-111.90				
			42.22-88.22 Bq/L				
South-western Nigeria	Buildings	RAD 7	23.08-72.14	0.91-3.27(A)	-	-	Olukunle, et al. [50]
				1.00-3.60(B)			
				1.09-3.94 (C)			

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Kaduna State	Borehole	Trib-carb LSA 1000 Liquid Scintillation Detector	0.35-2.57 Bq/L	0.06-045 (ing)	-	-	Kali, et al. [51]
	Wells water			0.9-6.5(inh)			
Ondo State Akoko area,	Well water	Tri-carb-LSA 1000	17.25 Bq/L	4.10-6.87 (Sm)			Adeola, et al. [52]
Ondo state	Borehole	Liquid Scintillation Counter	28.01Bq/L	0.2	-	-	Oniya, et al. [53]
Akoko	Well water		25.34				
Ogun State	G. water	Alpha GUARD radon detector	1.23-18.11 Bq/L	0.020 - 0.25 mSv/y	-	-	Olusola, et al. [54]
Bauchi State	Buildings	Pro3 radon gas detector, (model HS71512)	19.3-34.2	-	-	-	Likta and Peter [55]
ATBU hostels	Day time		23.0-36.0				
	Night time		Bqm^{-3}				
Kwara State	Surface	Rad7	19.14 Bq/L	237.25 µSv/y	-	-	Ajibola, et al. [56]
Edu-mining site	G.water		24.16				

Table 3: Descriptive analysis of articles used.

S/N		Number of Articles	Number of Articles in percentage (%)
1	Radon in water	17	48.60%
2	Radon In soil	2	5.70%
3	Radon in rocks	2	5.70%
4	Radon in Buildings	12	34.30%
5	Radon in dumpsites	1	2.90%
6	Radon in low- high area	1	2.90%

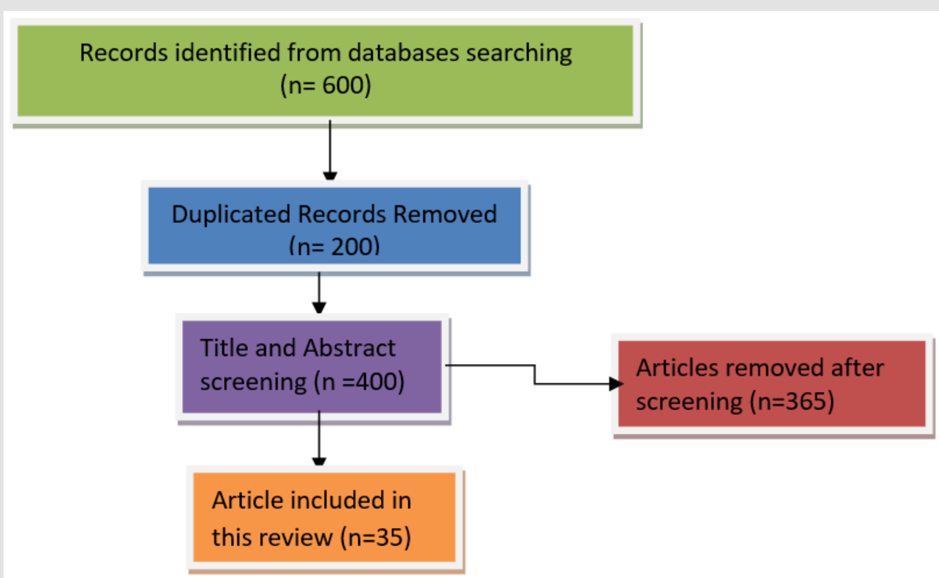

Figure 5: Flow chart diagram of the full literature screening process.

Radon in Water

Due to the concentrations of radon in the rocks that enter into the surface and groundwater, when the bedrock is of the granitic rock type, more radons will contaminate the groundwater. Groundwater picks up radium as it runs past radioactive components in rocks and soils, and this radium is then pumped into the water system. Numerous publications have shown that the concentration of radon in ground water was inversely related to the concentration of radon in soil and is less reliant on other indicators of water quality. The effects of radon on people are studied using a simulation incorporating showers and baths in bathroom. This study found that the quantities of radon and their progenies increase as a shower begins and the water temperature drops. With increasing relative humidity, the concentration of radon daughters in the rain increases to its greatest value. Although numerous areas in Nigeria recorded readings over the limit due to the presence of bedrock types that considerably accelerate the release of radon isotope into groundwater, the WHO and EU counsil state that Maximum radon concentration is only 0.1mSv/y. Furthermore, previous research has demonstrated that other characteristics of water, such as electrical conductivity, hardness, etc., have no impact on the level of radon in groundwater. Indoor radon is less impacted by groundwater than outdoor radon because only 5% of the samples collected from various places throughout Nigeria had radon concentrations over the permissible range.

Using a caliberated Rad7- active electronic detector drurridge, Ajibola, et al. [56] assessed the radiological risk of radon in ground and surface water close to mining site in Kwara State. Radon concentrations ranged from 16.23 Bq/l to 24.72 Bq/l in surface water, whereas they ranged from 21.59 Bq/l to 27.93 Bq/l in ground water, with a mean of 34.16Bq/l. For instance water samples, the mean total annual effective dosage was 187.9 Sv/y for adults, 257.84 Sv/y for kids, and 292.77 Sv/y for neonates, respectively. The dose attributable to intake and breathing was added to determine this dose. Furthermore, the ground water mean effective dose for adults, kids, and newborns were 237.25 Sv/y, 325.44 Sv/y, and 369.53 Sv/y, respectively. The radon levels in all samples were high above recommended limits of 11.1 Bq/l and 100 Sv/y for effective doses from inhalation and ingestion, respectively. Consuming the water in this location poses a grave health hazard as a result because it is not safer for all age groups. It is advised that the water from both site treated before utilization as a result. Similar research was done by Olusola, et al. [54], which used the Aqua KIT and Alpha GUARD radon detectors to measure the levels of radon-222 in ground water from 10 local government areas in Ogun State.

Radon levels ranged from 1.23 to 12.68 to 18.11 Bq/l on average. Although the radon levels in all of the samples were less than the 100 Bq/l guideline limit established by the WHO and the EU, they were all 17% greater than the 11.10Bq/L standards recommended by the EPA. For adults, Children, and babies, the ingestion-related mean annual effective doses ranged from 0.020 - 0.25 mSv/y, 0.041 to 0.509 mSv/year, and 0.024 - 0.279 mSv/year, respectively. Some of the LGAs' mean annual effective doses were greater than the reference dose threshold of 0.1mSv from a year worth of drinking water intake, as advised by the International Commission for Radiological Protection. The levels of radon in groundwater samples from Akoko region of Ondo State were also studied by Oniya et al. in 2021. They also calculated the annual effective dose brought on by consuming water from these sources. Using traditional methods, 17 samples of ground water were collected from diverse location within the research region. The radon amounts in each sample were measured with a Liquid Scintillation Counter. The range of radon activity in sample of water was 12.61-57.50 BqL-1 and 10.30 Bq/L, with average values of 28.01 and 25.34 BqL-1 respectively.

The annual effective doses of radon due to drinking from borehole water were 0.20, 0.40, and1.40 mSv/y for adults, children, and infants respectively. For well water samples, the average values of 0.19, 0.37 and 1.29 mSv/year were found. When the results of the radon activity concentration were compared to 11.10BqL-1 established by the EPA, it was discovered that 94% of the samples exceeded the value. In addition, each annual impact dose estimated exceeded the world health organization limits for radionuclide consumption from water, which is 0.10 mSv/y.

The geology of the study area may have something to do with the observed trend. It is suggested and urged to only use clean water sources. In the Akoko region of Ondo State, southwest Nigeria, Adeola, et al. [52] utilized a scintillation counter to detect the level of radon in water samples taken from hand-dug wells. By using chemical analysis, temperature and physicochemical factors including turbidity and conductivity were evaluated. The range of the radon concentration was 13.42 to 22.47 BqL-1, with average value of 17.25, 2.03 BqL-1. The recommended top limit for pollution by the EPA, 11.1Bq/L, was exceeded in all samples of water. The WHO criterion for radon activity levels in drinking water supplies of less than100Bq/L was also met by all of the samples. The estimated dose to the stomach ranged from 4.10 to 6.87 (nSvy-1) while the estimated dose to the lung ranged from 4.05 to 6.79 (nSv/y), with an average dosage of 5.27 (nSvy-1). The mean of radon in the water from drilled well that could be ascribed to ingestion and breathing ranged from 48.695.72 to 63.43 (nSvy-1) (nSvy-1). The fact that none of the water samples went over the 0.1 mSy-1 individual dose level proves that the well water is safe for consumption. Using a Tri-carb LSA 1000 LSC, Kali, et al. [51] studied the Variation of radon concentration in ground water sources, including borehole and wells in Kaduna State and its environs. People in the three age groups of newborns, children, and adults experienced variable levels of radiation exposure, according to average annual water consumption rates.

The mean radon activity in 16 sample of boreholes and 18 well water samples was 0.57 and 1.8 BqL-1 respectively, while the average

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radon activities ranged from 0.85- 2.57 BqL-1 and 0.35 – 0.85 BqL-1 respectively and were al significantly below the maximum concentrations levels of 11.1 Bq/L set by the EPA. All estimated committed effective doses were found to be well below the level that the WHO & UNSCEAR recommend 1mSv/y, despite being observed to increases with radon concentrations, age and ACRS. The radiation dose rate received by the lung as results of breathing in water borne radon in the air was much larger then when compared to the radiation dose rate received by the stomach walls through ingesting. According to this study, the prevalence of individual organ disorders is rising. The radon content of surface and ground waters collected from near quarries was analyzed.

Ebenezer, et al. [49] using a high-tech durridge Rad7 analyser with a Rad-H2O accessory. The average Concentration of radon for sample of water taken from borehole and wells varied between 55.41 & 104.45 BqL-1 and 61.48 & 119.71 BqL-1 respectively. The average radon activities for ponds and streams, respectively, ranged from 47.31-111.90Bq/L and 42.22 Bq/L respectively. The most of the sources analyzed (82.0%) had average radon concentrations beneath 100Bq/L set as maximum contamination standard by WHO. The UNCE quality recommended range of 4 to 40 Bq/L and EPA maximum contamination limit of 11.1Bq/L were both surpassed in all the water samples. In radon-prone places, there is a potential for radon cancer, and immediate action is required to prevent radon hazards for human health. In a related investigation, Janet et al. measured the amount of 222Rn in ground water from Lagos State, Nigeria (2019). The concentration of radon in water sample ranged from 0.14- 0.41 Bq/L. The mean values were given as 0.12-0.39 Bq/L. These fell beneath the acceptable maximums set forth by international organizations. From 2.27 0.95 to 6.75 2.22 Sv/y, from 4.54 1.91 to 13.50 4.43 Sv.y.1, and from 2.65 -7.87 μSv/y, respectively, were the mean yearly effective doses from drinking water contaminated with radon-222.

The reference dose level, which is 0.1 mSv/y for a year of water drinking, is far lower than the mean effective doses from ingestion for adults, children, and infants, 0.03 -0.10 mSv/BqL-1 was the range of the yearly dose from inhaling radon. The study's results showed that there is very little health risk from exposure to radon-222 in the groundwater under investigation. Ground water might include a non-zero amount of naturally occurring radioactive elements because of its close proximity to rock and soil. However, the area requires ongoing surveillance. Whether it is true that consuming water from deep-bore wells could be seriously hazardous to people's health was examined by Hauwa'u Kulu, et al. [44]. The importance of water in upholding a healthy status makes it imperative to investigate into the biological impact of radioactive radon consumption through groundwater. RAD7 alpha spectrometry was used to analyze a total of ten ground water samples. The range of concentration of radon observed were 4.92 - 82.89 Bq/L (Average means of 38.30 Bq/L), which is greater than reference levels set by EPA of 11.1Bq/L or 300 pCi/L but found to be lower than allowable maximum of 100Bq/L set by WHO and EU for inhalation path way.

It was found that the values derived from the examined medium were often higher than the most of the data examined in the previous work. The mean effective dose per year for ingestions (8.05mSv/y) and inhalation (0.1 mSv/y) of 222Rn in drinking water was discovered to significantly below the action threshold recommended by WHO (0.10 mSv/y) and ICRP (3-10 mSv/y).Remember that a comparison of this kind It should be emphasized that such a contrast might not correctly portray the real scenario given that the projected dose is only 222Rn-contributed. However, the information gathered might serve as a guide for any more radioactive research of the nearby body of water.

Radon and heavy metals have been named as sources of groundwater pollution and probable carcinogens by Yinka, et al.[42]. Most people in southwest Nigeria get their drinking water from underground sources. The purpose of this was to map the distribution of radon in southwestern Nigeria's groundwater and to assess the health effects of radon and heavy metals in drinking water. Using the Rad-7 radon detector, 145 groundwater samples were tested for radon concentrations, while 52 groundwater samples were tested for heavy metal contents. The RAD7 electronic radon detector was used to test the levels of radon in 145 ground water samples, and AAS was used to determine the levels of heavy metals in52 groundwater samples. GIS is used for mapping out the radon distribution. The content of average radon in water samples is 35.9 BqL-1, with a range of 1.6 to 271 Bq/L, while US-suggested EPA's limit of 11.10 BqL-1 was greater than the average groundwater concentration of radon, the recommended limit 100 Bq/L of WHO was lower. For newborns, kids, and adults, the projected average yearly effective radiation doses are 29 Sv/y, 41 Sv/y, and 92 Sv/y, respectively. The study, however, did not cover the consequences of radiological cancer and was restricted to concentrations and yearly dose. Radon in water has been categorized as a global health risk by Oluwaseun, et al. [40]. The most important radioactive carcinogen in water that drives cancer of lung in non-smokers was radon. The geological makeup of the area determines the levels of radon in water. In this research, drinking water from wells in few towns along the Iwara-ifewara geological fault-line in south-western part of Nigeria was sampled.

Twenty (20) water samples were taken at the fault line between 50 and 150 meters. Radon concentration was measured using RAD-7. Radon exposure doses from food and inhalation were calculated, and additional cancer risks were calculated. The average Radon concentration is 45.7885.93 Bq/L, with a range of 5.0 to 400.1 Bq/L. In seventy percent (70%) of the samples, the concentration of radon was greater than the EPA suggested limit 11.10BqL-1. The average total yearly effective dosage obtained was 59.4 Sv/y, which is less than the 100 Sv/y level suggested by the US EPA. The excess lifetime cancer risk from inhaling the water samples were ranged from 75.6 -6053.5 Bq/L, with a mean of 692.9, likewise below the advised limit. As a result, ingesting the water samples from the research regions is safe.

According to Rilwan, et al. [38], water is the primary component of the Earth's oceans, lakes, and streams as well as the fluid used by the majority of living things. On average, it covers 71% of the Earth's surface. All known kinds of life, notably man, depend on it. Therefore, this study uses a liquid scintillation counter to determine whether or not Radon from water sources in Loko of the Nasarawa local government area of Nasarawa State poses a health danger to the general public.

The current research revealed that the mean mean 222Rn concentration in the water samples from Loko was 3.91 0.76 Bq/l on average. It was discovered that the mean yearly dose from ingestion and inhalation were, respectively, 0.000051 mSv/y and 0.985 mSv/yr. Ingestion and inhalation were found to have corresponding extra lifetime cancer risks of 0.00018 x 10-3 mSv/y and 3.45 x 10-3. The findings demonstrated that although underground water samples from wells and boreholes are safe for adults to drink, children should not consume them. It is clear that Loko's natural radionuclide pollution poses a risk to public health. Therefore, it is advised that appropriate radiation monitoring exercises be carried out often in the research area. Oni et al. [32] applied Rad7 detector to conduct monitoring of the environment due to radon levels in some bottle and sachet water sample. The purpose of the study was to ascertain the levels of radon in samples collected at ile-ife market in order to assess any potential health hazards associated with water intake. The findings of this investigation demonstrate that all water samples were safe for consumption and had no radiologically significant effects on health. Water is still the most plentiful and important resource for ensuring the continuation of human life on Earth, according to Dankawu, et al. [24]. It is crucial to ensure that water used for human consumption is clean. In order to determine whether there's any radiological risk to human health, the concentration of radon in drinking water samples taken from 22 different water sources that are used by communities near Dutse Local Government area of Jigawa State, has been measured. Borehole and nearby wells were the origin of the water samples that were collected.

Using LS counter and following industry standards, the r\adon concentration was determined. The concentration of 222Rn in the borehole and well water samples ranged from 31.228 - 273.217 Bq/L and 32.699 – 155. 934, respectively, with mean values of 82.7461 and 94.10771 BqL-1. These readings were discovered to be below the European Commission standard but above the thresholds advised by UNSCEAR and WHO. For the traditional well and borehole water samples, the yearly effective dose owing to inhalation from the corresponding radon concentration varied from 0.082- 0.63mSv/y and 0.078 - 0.68mSv/y, respectively. The average values were determined to be 0.20852 and 0.237151 mSv/y for samples of well and borehole water, respectively. The average yearly effective doses by inhalation were all higher than the WHO suggested limit of 0.1 mSv/year [57]. Additionally, it was discovered that the excess life cancer risk from radon inhalation in the water samples ranged from 2.75×10^{-4} – 2.41×10^{-3} and 2.88×10^{-4} – 2.227×10^{-3}, with the overall meant value for the borehole and traditional well water samples, respectively, being 7.3×10^{-4} and 8.3×10^{-4}.

All of these numbers fell within the EPA's suggested limit of cancer risk. Therefore, it is necessary to examine the water under this study area before using it. Akinnagbe, et al. [30] used the RAD7/RAD H20 driven alpha spectrometry approach to determine the radon concentration in ground water in Ijero, Ekiti State. About forty water from boreholes, wells and stream were collected and evaluated for radon contents. The data were used to determine the effective dose per year in order to assess potential radiological health hazards and to advise essential safety measures. The stream and borehole samples had radon values that ranged from 0.168 – 78.509BqL-1, respectively. 18 of the samples indicated that radon concentrations were greater than permissible limit of 11.10 BqL-1. It was found that none of the samples had concentration of radon values greater than 100Bq/L, which the EU considered to be the maximum limited threshold over which corrective actions is necessary. None of the samples had an annual effective dose that exceeded the upper limit, which are 0.20 mSv/year for Children and 0.1 mSv/y for adults.

The study came to the conclusion that two geological features made of mica-granite and the depth of the source region were the main causes of the elevated concentration of radon and unquestionably contributed to the level found in borehole source of water. There is a degree of health risk associated with the radon's relatively high levels. Though the effective dose appeared to be low, long-term radiation exposure can nevertheless have negative impacts on health and could in the near future have radiological health implications. The quantity of radon and the health effects related with it in drinking water were researched by Emmanuel and Theophilus in 2019. About 30 water samples were analyzed at random in Ogbomosho using Rad-7 detector. Radon levels range from 0.60 to 2.64 Bq/L in the study area, with a mean value of 1.90%. The committed yearly effective dose resulting from ingested substances ranged from 0.00625 - 0.019 mSv/y with mean values of 0.02mSv/y. The levels of radon in Ogbomosho water samples are below the cutoff values established by the European Commission and the EPA, which are 11.0 and 100.0 Bq/L, respectively.

According to Orosun, et al. [27]'s research, mining activities increased the amount of primordial radioactive element in the surroundings, greatly increasing the risk of ionizing radiation exposure of terrestrial origin for people.Therefore, it is thought that the discarded tin and Cassiterite mining site in Oyun, Kawara State, Nigeria, has radiological effect on the local population. Using a Rad-7 detector, the radon content in surface water from the defunct Tin and Cassiterite excavation site was estimated.

Twelve samples of water were examined and used in the assessment of the Yearly effective dose of radon in order to determine the risk or hazard that could be incurred from ingesting such water. The measured concentration of radon was ranged from 44.95 – 21.03

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Bq/L, with an average of 35.86 Bq/L.

The suggested limits of 11.1.Bq/L by the UNSCEARR are far higher than these levels. The estimated total effective dose was determined to be 206.52 and 441.41 μSv/year for adults, 283.30 and 605.47 μSv/year. These readings exceeded the suggested upper limits for adults and children, which are 100 and 200 μSvy, respectively. Concerns concerning the probability cumulative impact on the consumers of such water should also be highlighted if consumption is prolonged. In a similar line, according to Matthew, et al. [26], radon is the heaviest radioactive nuclide among the noble gase in the periodic table is found naturally in soils, oils, and water. It has attracted a lot of study attention recently because of its crucial function in the development of cancer. The radon detector and Rad-7 accessories from durridge and co. were used in this investigation together a total of 68 ground water for analysis. For drilled wells, hand pumped boreholes, and motorized boreholes, the measured concentrations of radon were ranged 0.6 – 36.2 BqL-1 with mean 23.30 Bq/L, 13.33 Bq/L, 7.4 Bq/L respectively. In the HDW, HPB, and MBH, about 54, 86, and 15% of the samples exceeded parametric reference level 0f 11.10 Bq/L, which was proposed by EPA, but was below the allowable limit of 100.0 BqL-1 suggested by WHO and E.U. The mean yearly effective dose of radon from drinking water that are obtained for three groundwater sources are below the limit advised by ICRP and WHO. The information from this study can be compared to similar studies that have been done in Nigeria and other countries, as described in the literature. However, it is advised for the research region that radon levels in drinking water and the indoor environment be continuously monitored.

Radon in Buildings

Every building material created from mineral raw materials or natural rock contains uranium and radium naturally, depending on the geological origin. If uranium and radium decay, radon is formed and released into the building along with it's by products. As of recent, radon exposure in houses to hold responsible for 5% of cancer of lung cases in the German Populace. Radon is therefore one of the major cause of cancer of lung. Building materials like concrete bricks are often composed of aggregate elements like sand, gravel, clay, lime, concrete, or similar materials. If industrial waste items, which contain more uranium and radium and are utilized as aggregate materials, such as slag from metal smelting or sludge from water treatment, the amount of radon that enters a building may increase. Sandstone, Concrete, unfired bricks & burned; granite and marble are the most popular construction supplies used in houses and decoration. They regarded as the 2nd largest indoor radon emitter, behind soil. Depending on its geology, every building material made from mineral raw material or natural rocks contains anutral amount of radium and uranium. As they break down, radon and its daughters are discharged into buildings. Inhaled alpha particles from solid radon daughters have a propensity to deposit on the bronchial epithelium of the respiratory system, where they irradiate the lung [46].

This irradiation can damage lung tissue. Studies indicate that in addition to the lung, human also inhale, consume and deposit radon and its metabolite on their skin and other body organs. The kidney, bone marrow, stomach and skin are among this organ [46]. The WHO in 2009 suggested that national reference levels between 100 and 300 Bq/m3, where EPA advised limit of 4 pCi/m3 (148Bq/m3) due to risk presented by radon [3]. As indicated in Table 2, the findings showed that radon levels are greater at night than they are during the day. This provided evidence that radon levels are influenced by ventilation. The building had no ventilation at night and all the doors and windows were locked during the day, preventing radon gas from escaping into the space outside. 222Rn is major risk factor for lung cancer after smoking according to Asere, et al. [36]. This makes determining the concentration of radon activity inside of dwellings an important health concern. The study examined the radon levels in residences in specific regions of Ondo State in southwest Nigeria using alpha track detectors. Detectors were placed outside for 90 days. Radon levels were affected by the age of the buildings, the ventilation situation, the types of heating, and the type of building materials. The radiological health indices underwent the same procedure. The results showed that older cement-block buildings with appropriate ventilation had lower levels of radon than more contemporary mud-block buildings. House using natural gas showed greater radon concentrations than houses using charcoal and fire wood for cooking. Average yearly effective dose and estimated radiological indices did not exceed the suggested levels. This demonstrated that the majority of the local homes were suitable for habitation.

Adegun, et al. [48] research has similarly shown that basement workplace are cramped areas with poor indoor air quality, particularly when it comes to toxins with a soil gas origin. Radon a has similarly shown that basement workplaces are cramped areas with poor indoor air quality, especially when it comes to toxins with a soil gas origin. Radon infiltrates and builds up indoor natural ventilation, where it can become deadly. The radon levels in the basement of Illorin and Akure were sampled for this research. The investigation conducted to measured radon concentration in the basement of the buildings was provided. The majority of workers in the basement are unaware that a radon level exists, and there is little published research in Nigeria on the health dangers it poses. The survey's parameters included radon levels, floor heights, geographic regions, and the effects of atmospheric conditions. Temperature meters, a prologues wireless weather station, a continues, digital radon monitor and a corentium monitor were all used in the experiment.

Indoor radon concentrations and effective doses in the occupied basement had yearly mean values of 23.0 Bq/m3 and 0.089mSv/year respectively. The south-western region of Nigeria's federal University of Technology Akure, Ekiti State university and Federal University Oye-Ekiti are the three campuses where Oladele, et al. [46] did another indoor radon study employing CR-39 detectors in the offices. The mean indoor radon activity concentration in the examined offices on

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all three university campuses was determined to be 222.44 Bq/m3, which was less than the reference criteria of 300 Bq/m3 established by the ICRP.115. Depending on the age of exposure, the chance of acquiring lung cancer at age 70 for the three institutions ranged from 1.06×10-7- 6.24×10-5. The estimated mortality rate from exposure to radon activity concentrations between 7 and 1358 Bq/m3 was calculated to range from 0- 44 fatalities for a population of 10,000 persons.

According to obeda, et al. [43] a radon survey was carried out in a few pre-school and elementary schools in Ibadan. The passive diffusion cup and CR-39 detectors were used to estimate the radon concentrations. The mean radon concentration in the study region was 176.16 Bq/m3, and mean annual effective dose to the respiratory organ was found to be 1.14 mSv/y. These mean radon levels are regarded as safe when compared to the action levels set by ICRP for work places, the upper reference level of 1000 Bq/m3 (ICRP, 2014). Olowookere, et al. [33] conducted radon study and measured its quantities using an active detector in the basement of a complex of buildings housing the Science faculty of a higher institution in south western Nigeria. Using the mathematical models and Rad-7 detector, the average for all the buildings studied was 61.74 and 58.48. The average was lower than the 100Bq/m3 average for the world. The mean effective dose of 0.022mSv/year was received by the student of engineering lab, 0.0209 mSv/y received by residents of hostels and lastly workers received an average of 2.036 mSv/y. However, if the basement is used as a living space, students and staff who work there may experience health problems due to the high radon concentration in Room I-R. The calculated excess life cancer risks (ELCRs) for students and homeowners, respectively, range between (0.64-5.82) x 10^{-3} and (1.16 -10.58) x 10^{-3}. The average readings for the two participants are less than the maximum danger of 3.5 x 10^{-3}.

In the cities of Borikiri (BT), Diobu (DR), and Rebisi (RB) in Port Harcourt, Rivers State, Nigeria, Orlunta, et al. [25] examined indoor radon concentration levels and related health risk factors using a portable Corentium Arthings digital radon detection meter. A handheld GPS was used to record the geographic coordinates for each of the various sample locations. For a total of 30 sample locations among the three villages, ten residences from each municipality were measured. The statistics show that Borikiri town's concentration level ranged from 30.7100 to 19.9800 Bq/m, with an average of 11.32 to 2.59 B/qm. The yearly absorbed dosage ranged from 7.7478 to 1.1202 mSv/yr with a mean value of 2.59 0.65 mSv/yr, whereas the annual equivalent dose rate ranged from 0.829 to 0.336 mSv/yr with an average of 0.690.16 mSv/yr. Over a 70-year period, the increased risk of developing cancer varied from 6.510 to 0.941, with an average of 2.45 to 1.71.

This is the mean value for the results of the indoor concentration level for the town of Diobu, which ranged from 37.74 5.9200 Bqm to 12.95 2.91 Bqm. The increased lifetime cancer risk predicted for seventy years varied from 8,000 1.725 with a mean of 2,91 0,61, while the yearly absorbed dose for the area ranged from 9.5214 1.1494 with an average of 3.26 0.73 mSv/yr. The annual equivalent dose rate varied from 0.694 0.359 with a mean of 0.78. The indoor concentration level in Rebisi town varied from 12.9500 to 4.0700 Bqm3 with an average of 8.55, the annual absorbed dose from 3.2671 to 1.0268 mSv/yr, the annual equivalent dose rate from 0.784 to 0.269 with an average of 0.52, and the excess lifetime cancer risk from 2.745 to 0.863 with an average of 1.82. The indoor concentration levels, the annual absorbed dosage, and the annual effective dose rate are all within the ICRP safe limit. The excess lifetime cancer risk values are all higher than the ICRP tolerable recommendation limit of 0.029 ×10-3, nevertheless.

Usikalu, et al. [39] measured the radon levels in a sample of households in three local government areas of Ibadan using a calibrated portable continuous radon monitor type (RAD7) manufactured by Durridge firm. The distance between homes was maintained at all areas between 100 and 200 cm. The living room door was closed throughout the measurements. The mean radon levels at Egbeda, Lagelu, and Ona-Ara were 10.54 1.30 Bq/m, 16.90 6.31 Bq/m, and 17.95 1.72 Bq/m respectively. The mean annual absorbed dose and annual effective dose for the locations within the three local government regions were 0.19 mSvy-1 and 0.48 mSvy-1, respectively. Radon levels at location 10 in the Ono-Ara local government were higher than recommended. However, it was found that the average indoor radon concentration for the three local governments was lower than the 40 Bq/m3 global norms. As a result, there is a need for thorough education on the dangers of radon development in houses. In a related study, Usikalu, et al. [41] monitored the levels of radon in several building types, such as glass houses, brick buildings, and basement residences, using a radon detector (RAD7) equipment.

The mean radon concentrations in a glass home, brick house, and basement house are 14.96, 10.74, and 144.61 Bq/m3, respectively. Glass houses can have radon values between 11.03 and 17.46 Bqm3. For houses made of brick, the radon levels that were tested ranged from 6.62 to 20.85 Bqm3. Basement buildings can contain anywhere from 15.75 and 614.52 Bqm3 of radon. The analysis found that the basement structure's average radon concentration was four times the recommended limit. The estimated yearly effective doses for homes made of glass, brick, and concrete are 0.377, 0.271, and 3.644 mSvy, respectively. The study came to the conclusion that subterranean constructions with limited ventilation provide a greater health risk than glass and brick homes with adequate access to natural ventilation outlets. Therefore, it is suggested that residences with basements incorporate proper ventilation.

Adewoyin, et al. [37] conducted research on the radon levels in various workplaces of a pharmaceutical firm in Ota, Ogun State, in 2019. Durridge RAD 7 equipment was used to measure the amount of radon inside. Four different offices in the business's main administrative building received an 8-day radon concentration measurement (one office on the ground floor and three on the first floor). Although the results at the four locations varied from 19 to 160 Bq/m3, they were still under the 200 Bq/m3 global limit set by the International Commission on Radiological Protection. However, the office on the ground floor had the highest radon-222 reading, at 160 Bq/m3. The highest concentration of radon-222 discovered in this study is therefore below the global standard limit, indicating that the inhabitants of the offices taken into account for this analysis are safe. Briggs, et al. [34] evaluated indoor radon levels and associated health risk factors in three communities in Port Harcourt, Rivers State, Nigeria, including Azuabie, Trans-Amadi, and Nkpogu towns. A portable Corentium Arthings digital radon detection meter was used to measure the indoor radon levels. The geographic coordinates were recorded using a handheld GPS for each of the sample locations.

A total of 30 sample points were evaluated, with 10 sample points assigned to each municipality. The town of Azuabie (AZ) had a concentration level that ranged from 6.660 Bq/m3 to 13.690 Bq/m3, with an average of 10.65 Bq/m3, according to the results of the concentration levels. In the town of Nkpogu (NK), the indoor concentration level ranged from 7.030 Bq/m3 to 20.350 Bq/m3, with an average of 12.25 Bq/m3. The concentration levels measured outside ranged from 9.250 Bq/m3 to 18.870 Bq/m3, with a mean of 13.32 Bq/m3. For Azuabie, Trans-Amadi, and Nkpogu, respectively, the annual absorbed dose varied from 1.680 mSvy-1 to 3.921 mSvy-1, 2.334 mSvy-1 to 47610 mSvy-1, and 1.774 mSvy-2 to 5.134 mSvy-1. For the three towns, the yearly effect dose rate ranged from 0.403 mSvy-1 to 0.941 mSvy-1, 0.560 mSvy-1 to 1.143 mSv/y, and 0.426 mSvy-1 to 1.143 mSvy-1. Over the course of a person's lifetime, the increased cancer risk varied from 1.4117 to 3.294, 1.9607 to 3.999, and 1.4901 to 3.999, respectively. The annual indoor concentration levels, annual effective dose rate, and absorbed dosage all fall within the ICRP safe limit. However, all of the data for the increased lifetime cancer risk are over the ICRP acceptable threshold level of 0.029 ×10-3. Radon levels have been found to be greater in buildings that use more granite as decorative elements and slabs than other styles of architecture. According to a review of past studies on the topic, building materials leak radon into the indoor environment if they contain a radioactive source. This holds true whether or not substitute raw materials are used in the manufacturing of construction materials. Therefore, in order to have a healthy interior environment, researchers advised that building materials be tested for radon emissions prior to being put on the market.

Radon in Rocks/Soils

The growing interest in employing mineral rocks and soils for construction and interior building decoration has been a significant source of radiological concern because doing so produces radioactive gaseous components that are dangerous to human health. This review assessed the concentrations of radon, yearly effective dose, and lifetime cancer risk in order to investigate of various rocks and soils in Nigeria on human health.

Based on this, Mansur, et al. [35] conducted a study to assess whether Jigawa State, Nigeria, was a radon-prone site with a low, medium, or high potential. They used a ten-point radon potential scale. A detailed study into the cause of the upsurge in lung cancer among nonsmokers in Nigeria was required. According to the study's findings, Jigawa State has no high radon potential locations and a low radon potential in 72.76% of its land and a medium radon potential in 27.24% of its land. The total yearly effective dose was determined to be between 0.276 mSvy- and 2.758 mSvy-1, 3.033 mSvy-1to 9.927 mSvy-1, and 10.204 mSvy-1to 13.789 mSvy-1, respectively, for areas with low, medium, and high radon potential. The International Commission for Radiation Protection has set a maximum permissible dose for those people with high radon potential levels (ICRP). The findings of this study show that the level of radon exposure experienced by Jigawa State people is safe. In residential buildings with varied wall, ceiling, and floor covering materials, Olukunle, et al. [50] assessed the tracheobronchial effective dosage from radon inhalation. Using various dosimetric lung models, 180 residential buildings in some cities in south-western Nigeria with the most frequent combinations of covering materials were investigated using a RAD 7 active electronic radon gas detector. The average mean concentration of radon were ranged form 23.08 Bq/m^3 – 72.14Bq/m^3 for all the inhabited building tested.

Building with C-grade roofing materials have the greatest radon levels. The findings showed that the average indoor levels were generally determined to be lower than the action levels of 200Bq/m3 and reference levels of 100Bq/ m3suggested by ICRP and WHO respectively. The tracheobronchial effective dose ranged from 0.91mSv/y for combination (A), 1.0 mSv -3.60 mSv for combination (B) and 1.09 mSv -3.94 mSv for C-combination. The more recent model was found to have a superior value for the yearly effective dose of tracheobronchial medication. It was discovered that only the James model's yearly tracheobronchial effective doses showed values within the recommended range (3-10 mSv) for the ICRP. The tracheobronchial effective dose estimates reported by other models were below the ICRP's recommended intervention levels. All residential buildings and residential buildings and various combination casing materials investigated in this paper are not expected to provide a radioactive hazard to their occupants, according to these indications. Olaoye, et al. [17] claim to have used CR-39 detectors to look into the radon levels in both active and inactive dumpsites. For a total of three months, detectors were installed in 50 randomly selected homes that were between 0 and 100 meters from the dumpsites.

They were then gathered and etched for three hours in a water bath at 90°C with a 6M NaOH solution. The semi-automatic counting of tracks was accomplished by mounting a DCE camera atop a microscope and connecting it to a PC. For OkeOdo, MRF, and Olusosun Solus, the mean radon concentrations were 120.3 Bq/m3, 257.0 Bq/m3, 179.8 Bq/m3, and 131.5 Bq/m3, respectively. 3.60 mSv (8.97 per million) and 4.53 mSv (12.47 per million) were the annual effective dosage and cancer risk, respectively. According to this study, some dwellings next to abandoned landfills had greater radon concentrations than those close to active landfills. One should avoid doing this because it presents a major risk to their health. Oluwasayo and Margaret [47] measured radon concentrations and estimated exhalation rates in soil near houses in Lagos State in order to determine the contribution of the soil to indoor radon concentrations and the effect of soil wetness on exhalation rates. A total of 54 samples were randomly selected, and to account for moisture content, 27 were measured as wet samples and 27 as dry samples. A passive measuring technique was adopted, utilizing the cover cup approach and the CR-39 solid state nuclear track detectors.

Results

The amounts of radon released from the soil samples and those discovered indoors only seldom correlated. Data gathered showed that moist soil produced less radon than dry soil, demonstrating the significance of moisture. The results also demonstrate that samples of both wet and dry soil, as well as the highest mean and lowest value, all originated from the same environment, suggesting that the soil there has peculiar petrophysical features. It can be assumed that soil samples with more moisture may have lower radon concentrations since radon concentrations in wet soil are higher than in dry soil. Both the surface exhalation rates and the bulk exhalation rates agree with the findings for the radon concentrations released from wet and dry soil samples.

According to data Deborah, et al. [31] released, the main factor contributing to the radiation dosage from natural sources was exposure to radon in the environment. Since radon is produced by uranium-bearing bedrocks and overburden, the study measured the amount of radon in each of the three lithological units that the residential areas of the Obafemi Awolowo University Campus, Ile-Ife (OAU) were built upon. At a constant depth of 0.80 m, measurements of the soil gas radon concentration were taken using a RAD7 electronic radon detector across the three lithologies (such as granite gneiss, grey gneiss, and mica schist). Radon levels in soil were measured in-situ 138 times in total. The average soil radon concentration was 14 kBq/m3, although it varied across lithologies from 0.04 kBq/m3 to 190 kBq/m3. The mean values of Rn-222 concentration were, respectively, 3.5–5.9kBq/m3, 11.5-25.8, and 28.4–37.4kBq/m3 for granite gneiss, grey gneiss, and mica schist. The three lithologies had considerably different average radon-222 concentrations (p 0.001) from one another. The mica schist lithology has been given a medium radon index, but the granite gneiss and grey gneiss lithologies have been given a low radon index. According to Swedish risk criteria, 34% of the evaluated regions had high radon risk, demanding protective measures.

Mustapha, et al. [29] tested the radon concentrations in a study on several types of rocks using a RAD7 detector. The study's conclusions showed that granite and limestone rock types had higher radon concentrations and exhalation rates than other rock samples analyzed. The radon concentration is tolerable for rocks formed of granite and limestone. Therefore, every effort should be made to ensure that any building that uses these types of rocks as decorative architectural elements has proper ventilation. The findings can serve as a springboard for more investigation into the different types of rocks that can be found elsewhere. In a different investigation, Tunde, et al. [23] measured the levels of soil gas in-situ radon-222 at 28 locations throughout Abeokuta, Nigeria, using a RAD7 solid-state detector. The size of the six selected geological formations for each cell, with a minimum distance of 3 km between them, was used to identify the locations for the measurements. The measurement sites' geographical coordinates were established using a GPS compass. The measured soil gas radon concentration and soil-air permeability were used to compute the geogenic radon potential. The soil has a radon activity of 1004 to 19250 Bq/m3. As a result of this conclusion, locals can be in danger. It is vital that corrective action be taken [57-64].

Technique to Prevent Radon from Entering Buildings

The best course of action for radon gas is to be stopped to prevent its harmful effects indoors.

Conclusion

According to study published in Nigeria, the main sources of radon are soil, groundwater, and buildings structures, with water and buildings accounting for the highest percentages of radon exposures at 48.6% and 34.3%, respectively. It was discovered that the concentration of radon in Nigeria relies on a number of variables, including seasonal change, ventilation, temperature, relative pressure, and barometric pressure. Previous studies were not completely capture individual level radon exposure because radon levels fluctuate based on geographical setting of a place and kind of building structures. Few studies conducted within Nigeria found connections between radon concentrations and its radiological implications such as cancer due to ingestion and inhalations of radon. Based on the research conducted in Nigeria, radiological implications of cancer due to ingestions and inhalations of radon accounted for 14.28%, and 2.85% respectively. Future research is required because of the limitations of the already available literature research currently in circulation on radiological effects of radon within Nigeria. Stopping radon is the best corrective action to avoid the negative effects of radon gas in an indoor/outdoor setting. Some techniques were suggested by Preethi and Jeyanthi [20] for radon reduction in buildings setting. These include; depressurization, freshening and Sealing with percentage effectiveness ranged from 50-80%, 80-95% and 50-70% respectively.

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Competing of Interest

No competing of interest

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