IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 11, Issue 5 Ser. I (Sep. – Oct. 2019), PP 73-79
www.iosrjournals.org

NORM (^{222}Rn) Level and Its Associated Effective Dose in Selected Carbonated Drinks Sold in Lagos Traffic, Southwestern Nigeria.

[*1]Abiola O. ILORI, [2]Edward E. CHIKWELU, [3]Gilbert A. IBITOLA and [4]Olanrewaju AJANAKU

[1,3,4]Department of Physical Sciences, Ondo State University of Science and Technology, Okitipupa, Nigeria.
[2]Department of Physics Education, Federal College of Education (Technical), Umunze, Anambra State, Nigeria.

Abstract: *The aim of this study was to measure radon (^{222}Rn)concentrations, a decay product of long-lived naturally occurring radioactive elements, in different carbonated drinks sold in Lagos-traffic, Nigeria and to calculate the annual effective dose. Radon concentration in the studied samples was measured using RAD7 detector, an electric radon detector. The lowest radon concentrations in the carbonated drink samples ranged from 0.037 ±0.016 $Bq.l^{-1}$to 0.092 ± 0.009 $Bq.l^{-1}$, with an average value of 0.071 ± 0.012 $Bq.l^{-1}$; this contributed an annual effective dose of 0.015 ± 0.0013 $mSv.y^{-1}$to 0.038 ± 0.0025 $mSv.y^{-1}$, with an average value of 0.029 ± 0.0016 $mSv.y^{-1}$. The highest radon concentrations in the carbonated drink samples ranged from 0.167 ±0.009 $Bq.l^{-1}$to 0.190 ± 0.013 $Bq.l^{-1}$, with an average value of 0.182 ± 0.009 $Bq.l^{-1}$; this contributed an annual effective dose of 0.069 ± 0.0011 $mSv.y^{-1}$to 0.078 ± 0.0009 $mSv.y^{-1}$, with an average value of 0.075 ± 0.0011 $mSv.y^{-1}$. The results of this study revealed that the presence of radon in the studied samples were less than the permitted maximum radon concentration level set as standard according to the World Health Organization and other radiation protection regulatory bodies. It can thus be argued that there is no significant radiological risk to the teeming population of Lagos from radon ingestion by consuming carbonated drinks in the studied locations.*

Keywords: *annual effective dose, carbonated drinks, Lagos traffic, radon, RAD7.*

Date of Submission: 19-09-2019 Date of Acceptance: 07-10-2019

I. Introduction

The presence of naturally occurring radioactive materials (NORM) has been recognized over the years with a concentration higher than the radiological reference assigned by the United Nations Scientific Committee on the Effects of Atomic Radiation to be hazardous to the living organism [UNSCEAR, 2000b]. The whole environment we live constitutes of these radionuclides of natural origin, thus naturally occurring radiations are present in the soil, water, air, floors/walls of our homes, food consumed by animals/human and drinks [IAEA, 1989]. Long-lived radioactive elements such as uranium, thorium potassium and any of their decay products, such as radium and radon are examples of these naturally occurring radioactive materials.

The term NORM exists to distinguish natural radioactive materials from anthropogenic sources of radioactive material, such as those produced by nuclear power and used in nuclear medicine, where incidentally the radioactive properties of the material may be what makes it useful [USNRC, 2015]. However, from the perspective of radiation doses to human, such a distinction is completely arbitrary. Radium-226 is the fifth decay product of uranium-238 that decays into radon-222 which is the heaviest gaseous element in the natural decay series of uranium, thorium and actinium [USEPA, 2016]. Radon is a radioactive, colorless, odorless, tastelessnoble gas which results from natural radioactive decay of uranium, radium and thorium that exist everywhere in the trace of the rocks and soils of the earth's crust [Gillmore and Jabarivasal, 2010]. It is represented with symbol Rn and atomic number 86.

Radon occurs in nature as an intermediate step in the normal radioactive decay chains through which thorium and uranium slowly decay into lead and other short-lived radioactive elements; radon itself is the immediate decay product of radium, characterized by naturally emitting alpha particles [USEPA, 2016]. Naturally occurring isotopes of radon are radon (^{222}Rn) which is produced from the decay of ^{238}U having natural abundance of about 99.3% of the total uranium within the Earth's crust, thoron (^{220}Rn) which is produced in nature during the decay of ^{232}Th and actinon (^{219}Rn) which is formed during the decay of ^{235}U [Gillmore *et al.*, 2010].The most stable and abundant isotope of radon is (^{222}Rn) which has a half-life $Rn(T_{1/2}) = 3.82\ days$. It decays by emitting an (α) particle of 5.49 MeV and creates radioactive daughters [Khattak *et al.*, 2011]. The following natural nuclear decays are noticeably valid in this respect:

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$ (1)
$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + ^{0}_{-1}e$ (2)
$^{234}_{91}Pa \rightarrow ^{234}_{92}U + ^{0}_{-1}e$ (3)
$^{234}_{92}U \rightarrow ^{230}_{90}Th + ^{4}_{2}He$ (4)
$^{230}_{90}Th \rightarrow ^{226}_{88}Ra + ^{4}_{2}He$ (5)
$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$ (6)
$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}He$ (7)

As it can be seen from equation (1) to (7), the natural decay series consists of radioactive isotopes and isobars, with the emissions of energetic alpha- and beta-particles to the environment or living tissue.

Radon can be dissolved and transported into the water by pores in rock and soil. The activity concentration of ^{226}Ra in carbonated drinks can vary considerably since it depends on the origin of the water used in the production of the drinks among other chemical factors [Palomo *et al*., 2007]. The associated health hazard gives rise to a radiation dose which results from either inhalation or ingestion. Thus, radon gas can be transmitted from water to the air, and when inhaled, this leads to the exposure of the lungs to radiation risk and ingestion of water containing radon is considered to directly impact the stomach [Khursheed, 2000].

Under normal conditions and considering the gaseous nature of radon, it is easily inhaled, therefore, considered a health hazard [USEPA, 2016]. It is often the single largest contributor to an individual's background radiationdose, but due to local differences in geology [Kusky, 2003].Radon is the second most frequent cause of lung cancer, after cigarette smoking, causing 21,000 lung cancer deaths per year in the United States [USEPA, 2003; USEPA, 2012]. While radon is the second most frequent cause of lung cancer, it is the number one cause among non-smokers, according to the United States Environmental Protection Agency's estimates [USEPA, 2012].

It has been reported that Nigeria is the fourth market in the world with the biggest consumers of carbonated drinks in the world coming after the United State of America, China and Mexico [Euromonitor International, 2017]. It was also reported that Nigeria's fast-growing population brings with it a continuing demand for carbonated drinks, especially as the climate is quite hot. It was also reported that 86.5% of Nigerians consumes carbonated soft drink [NBS, 2010]. Lagos State, being a port city and the most populous city in Nigeria and on the African continent, is leading with the consumption rate of carbonated drink by its populace in Nigeria and Africa at large. Lagos surpassed Cairo in size in 2012 to become the largest city of Africa [Campbell, 2012].

A study has shown nearly 16% of children in Ibadan, a popular town in Southwestern Nigeria, aged 6-18 months were given soft drinks at least once per day as a weaning drink [Bankole *et al*., 2006]. Thus, the aim of this present research work is to measure radon concentrations in different types of carbonated drinks that are sold in Lagos-traffic, southwestern, Nigeria and calculate the annual effective dose in all samples collected.

II. Theory

For $N(t)$ ^{222}Rn nuclei at time t, the number of ^{222}Rn which decay in time t is:

$$\frac{dN(t)}{dt} = -\lambda . N(t) = -\frac{1}{\tau} N(t) \quad (8)$$

where:
$\tau = \frac{1}{\lambda}$ = lifetime of sample of ^{222}Rn nuclei;
$\lambda =$ decay or disintegration constant;
$N(t)$ = number of nuclei at time t.

Also, $N(t) = N(0)e^{-\lambda t} = N_0 e^{-t/\tau}$ (9)

where:
$N(0) = N_0$ = number of radioactive nuclei at time $t = 0$ (i.e., initially)

Further, we have:

$$N(t) = N_0 e^{-\lambda T_{1/2}} \quad (10)$$

$T_{1/2}$ = half-life of ^{222}Rn = $\frac{ln\left(\frac{1}{2}\right)}{-\lambda} = \frac{ln(2)}{\lambda} = 0.693/\lambda = 0.693\tau(s)$ (11)

The strength or activity $c(t)$ of ^{222}Rn source is the number of decays that take place per second. That is,

$$c(t) = \frac{-dN}{dt} = \lambda N = \lambda N_0 e^{-\lambda t} \quad (12)$$

The units of $c(t)$ are:
$Curie = Ci = 3.7 \text{ x } 10^{10}\ decays/s$

$$Becquerel\ (S.I.) = Bq = 1\ decay/s.$$

The concentration of ^{222}Rn (C_{Rn}) is given by:

$$C_{Rn} = \frac{\text{Activity } of\ ^{222}Rn\ sample}{Volume\ of\ ^{222}Rn\ sample} = \frac{c(t)}{V} \quad (13)$$

where:

$$c(t) = activity;$$
$$V = volume\ (in\ litre\ L\ or\ m^3).$$

Hence, the unit of concentration of ^{222}Rn to be measured are $Bq.l^{-1}$ or $Bq.m^{-3}$.
The Radiation Dose (D) is defined as:

$$D = \frac{energy\ absorbed\ (J)}{mass\ of\ absorber\ (living\ /non-living\ )\ (Kg)} = \frac{E}{M} \quad (14)$$

The SI unit of D is $gray\ (Gy), 1\ Gy = 1\ J/Kg.$
The quality factor (Q) of the alpha particles from the ^{222}Rn radiation is given by:

$$Q = \frac{biological\ effect\ of\ 1\ Gy\ o\ ^{222}Rn\ radiation}{biological\ effect\ of\ 1\ Gy\ of\ 200-KeV\ X-rays} \quad (15)$$

It has been observed that Q is proportional to D_0 (the Dose Conversion Factor).
The effective dose (H) is the radiation dose that can cause radiation damage to living tissue. The SI unit of H is the Sievert (Sv). H is defined as:

$$H = Q \text{ x } D \quad (16)$$

The corresponding rates are:

$$\frac{dH}{dt} = Q \text{ x } \frac{dD}{dt}, \quad (17)$$

where:
$\frac{dH}{dt}$ = effective dose rate = annual effective dose (or monthly or weekly or daily effective dose);
$\frac{dD}{dt}$ = dose rate = annual dose (or monthly or weekly or daily dose).
The unit of $\frac{dH}{dt}$ are: $(i) Sv.yr^{-1};\ (ii) mSv.yr^{-1};\ (iii)\ mSv.hr^{-1}; etc.$

III. Materials, Method and Measurements

3.1 The Study Area

Lagos was chosen in this study due to its highly industrialized and population nature. Lagos is a state in Southwestern Nigeria with geographical coordinates of $6^0 27.244' North$ and $3^0 23.68' East$. Located near the equator, Lagos has only a slight seasonal temperature variation, with high temperatures ranging $28.3 - 32.9^0 C$ [NOAA, 1990].Lagos has a population estimated at 21 million in 2016, which makes it the largest city in Africa [World Population Review, 2019].

Fig 1: Map of Lagos State

★An indicator of samples collection metropolis (Ikeja, Ojodu and Yaba in Lagos).

3.2 Samples Collection

Forty-two samples of carbonated drinks (14 different brands, 3 samples each) were purchased from various locations in Lagos-traffic at Ikeja, Ojodu and Yaba metropolis in February 2019. Commonly purchased and consumed carbonated drinks in the city of Lagos were carefully selected as samples for this study.

3.3 Samples Preparation and Measurement

Radon concentration in the samples for this study was measured using RAD7 radon detector (Durridge Co., USA), an electric radon detector that is connected to RAD H_2O accessory for a period of one month [Durridge, 2010]. RAD H_2O simply means radon in water with the setup shown in figure 2.

Fig 2: Arrangement of apparatus for measuring radon content in the carbonated drinks.

The RAD7 detector is truly versatile radon and thoron detector used by research scientists and professionals worldwide. It comes complete with a built-in air pump, rechargeable batteries, and a detachable wireless printer. The radon detector was used to measure the concentrations of radon in the carbonated drinks by connecting the detector to a bubbling kit, this is to enable gas to be released from the samples under study into the air existing in a closed loop. 250mL of each carbonated drink was taken into a radon-tight bottle connected to a glass bulb, this will ensure absorption of available moisture because it contains calcium, it will also ensure a firm connection to the detection chamber. The detection chamber (radon monitor) acts as a scintillator to detect alpha particles. The air was then circulated in the closed circuit for a period of 10 minutes to ensure uniformity in the mixture of radon with the air, the resulting alpha was then recorded [Durridge, 2010].

3.4 Annual Effective Dose Estimation

The annual effective dose (D_{AE}) to an individual from the intake of ^{222}Rn radionuclide through the intake of carbonated drinks is calculated using the relation [UNSCEAR, 2000a]:

$$D_{AE}(mSv.y^{-1}) = C_{Ra}(Bq.l^{-1}) \text{ x } I_{CD}(I.yr^{-1}) \text{x } D_c \quad (18)$$

Where D_{AE} is the annual effective dose due to ingestion of radionuclide from consumption of carbonated drink; C_{Ra} is the concentration of ^{222}Rn in the carbonated drink; I_{CD} is the annual ingestion of carbonated drink and D_c is the dose conversion factor for intake of ^{222}Rn given as 0.005 mSv [UNSCEAR, 1999].The net annual consumption of carbonated drinks over nearly two hundred (200) nations is said to be 552 billion litres, this amounts to 82.5 litres of carbonated drinks consumption per person annually [Zenith International, 2008]. The detection limit of the device used was $0.004\ Bq.l^{-1}$; hence, BDL simply means below the detection limit.

IV. Results and Discussions

The results of the measured radon concentration were reported in $Bq.l^{-1}$ and $Bq.m^{-3}$ as shown in Table 1; the annual effective dose values in the selected carbonated drink samples are shown in Table 2.

Table 1: Concentrations of radon in carbonated drink samples for the present study

Samples Code	Trade Name	Flavour	Radon Concentration ($Bq.l^{-1}$)				Radon Concentration ($Bq.m^{-3}$)			
			S1	**S2**	**S3**	**Average**	**S1**	**S2**	**S3**	**Average**
S1	Mirinda	Orange	0.092±0.009	0.084±0.013	0.037±0.016	0.071±0.012	92.00±9.45	84.00±13.30	37.00±16.91	71.00±12.67
S2	Fanta	Orange	0.063±0.015	0.081±0.080	0.077±0.011	0.074±0.036	63.00±15.03	81.00±80.16	77.00±11.30	73.67±36.15
S3	Fanta	Apple	0.168±0.013	0.019±0.010	0.149±0.009	0.112±0.010	168.00±13.32	19.00±10.41	149.00±10.33	112.00±10.13
S4	Savanna	Lemon	BDL	BDL	BDL	-	BDL	BDL	BDL	-
S5	Savanna	Orange	0.213±0.007	0.146±0.012	0.174±0.010	0.178±0.009	213.00±7.90	146.00±12.90	174.00±10.61	177.67±9.51
S6	La Casera	Apple	0.160±0.014	0.215±0.012	0.163±0.006	0.179±0.010	160.00±14.21	215.00±12.07	163.00±6.09	179.33±10.94
S7	Pepsi	Cola	0.133±0.007	0.116±0.013	0.125±0.010	0.125±0.009	133.00±7.05	116.00±13.74	125.00±10.82	124.67±9.33
S8	Sprite	Lemon-lime	0.125±0.002	0.119±0.010	0.123±0.011	0.122±0.007	125.00±2.98	119.00±10.32	123.00±11.72	122.33±7.16
S9	CocaCola	Cola	0.081±0.010	0.073±0.016	0.076±0.008	0.077±0.012	81.00±10.01	73.00±16.64	76.00±8.24	76.67±12.42
S10	CocaCola	Zero-sugar	0.097±0.018	0.106±0.013	0.084±0.011	0.096±0.013	97.00±18.32	106.00±13.01	84.00±11.21	95.67±13.58
S11	Smoov	Chapman	0.201±0.011	0.113±0.006	0.172±0.014	0.162±0.009	201.00±11.85	113.00±6.82	172.00±14.52	162.00±9.29
S12	Seven Up	Lemon-lime	0.167±0.009	0.190±0.013	0.188±0.013	0.182±0.009	167.00±9.07	190.00±13.45	188.00±13.80	181.67±8.35
S13	Bigi	Cola	0.107±0.016	0.110±0.002	0.110±0.016	0.109±0.008	107.00±16.39	110.00±2.72	110.00±16.49	109.00±8.14
S14	Bigi	Lemon-lime	BDL	BDL	BDL	-	BDL	BDL	BDL	-
		Mean	**0.125**	**0.105**	**0.114**	**0.115**	**125.00**	**105.17**	**114.00**	**114.72**

*BDL – Below Detection Limit

Table 2: Annual effective dose due to the concentration of radon in studied samples

Samples Code	Trade Name	Flavour	Annual Effective Dose Estimation ($mSv.y^{-1}$)			
			S1	S2	S3	Average
S1	Mirinda	Orange	0.038±0.0025	0.035±0.0017	0.015±0.0013	0.029±0.0016
S2	Fanta	Orange	0.026±0.0042	0.033±0.0021	0.032±0.0020	0.030±0.0031
S3	Fanta	Apple	0.069±0.0035	0.008±0.0009	0.061±0.0017	0.046±0.0022
S4	Savanna	Lemon	-	-	-	-
S5	Savanna	Orange	0.088±0.0015	0.060±0.0021	0.072±0.0021	0.073±0.0018
S6	La Casera	Apple	0.066±0.0062	0.089±0.0038	0.067±0.0029	0.074±0.0041
S7	Pepsi	Cola	0.055±0.0027	0.048±0.0021	0.052±0.0032	0.051±0.0025
S8	Sprite	Lemon-lime	0.052±0.0036	0.049±0.0048	0.051±0.0028	0.050±0.0034
S9	CocaCola	Cola	0.033±0.0061	0.030±0.0026	0.031±0.0021	0.032±0.0042
S10	CocaCola	Zero-sugar	0.040±0.0046	0.044±0.0031	0.035±0.0035	0.039±0.0036
S11	Smoov	Chapman	0.083±0.0029	0.047±0.0052	0.071±0.0026	0.067±0.0038
S12	Seven Up	Lemon-lime	0.069±0.0011	0.078±0.0009	0.0780.001319	0.075±0.0011
S13	Bigi	Cola	0.044±0.0038	0.045±0.0032	0.045±0.0054	0.045±0.0040
S14	Bigi	Lemon-lime	-	-	-	-
		Mean	**0.052**	**0.043**	**0.047**	**0.047**

The lowest radon concentrations in the carbonated drink samples collected were recorded in samples S1 (Mirinda, orange flavour) whiranged from 0.037 ±0.016 $Bq.l^{-1}$to 0.092 ± 0.009 $Bq.l^{-1}$, with an average value of 0.071 ± 0.012 $Bq.l^{-1}$; this contributed an annual effective dose of 0.015 ± 0.0013 $mSv.y^{-1}$to 0.038 ± 0.0025 $mSv.y^{-1}$, with an average value of 0.029 ± 0.0016 $mSv.y^{-1}$.

The highest radon concentrations in the carbonated drink samples collected were recorded in samples S12 (seven-up, lemon-lime flavour) which ranged from 0.167 ±0.009 $Bq.l^{-1}$to 0.190 ± 0.013 $Bq.l^{-1}$, with an average value of 0.182 ± 0.009 $Bq.l^{-1}$, this contributed an annual effective dose of 0.069 ± 0.0011 $mSv.y^{-1}$to 0.078 ± 0.0009 $mSv.y^{-1}$, with an average value of 0.075 ± 0.0011 $mSv.y^{-1}$.

Varying concentrations of radon were in all samples of carbonated drink collected (*see Tables 1 and 2*) except for samples S4 (savanna, lemon flavour) and S14 (Bigi, lemon-lime flavour) which were not detected by the detector.

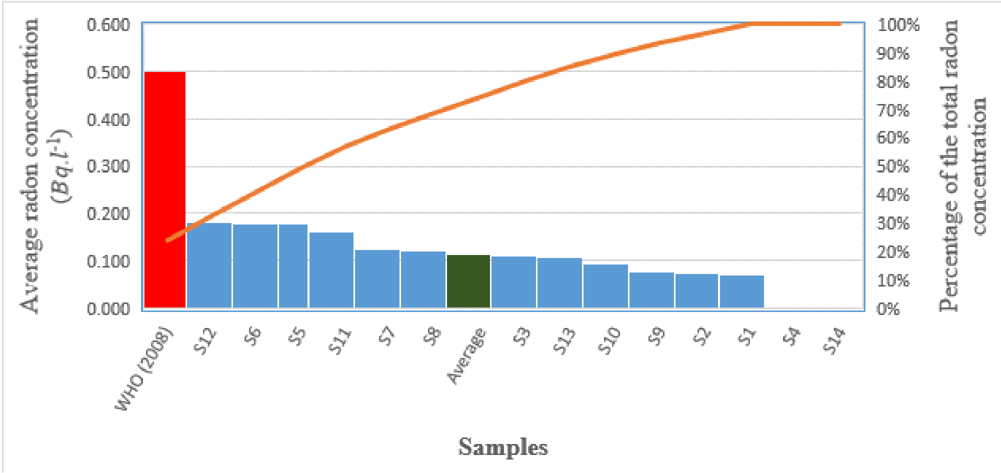

Figure 3: Pareto chart of the distribution of radon concentrations in the studied carbonated drinks in descending order of frequency, with a cumulative line on a secondary axis as a percentage of the total radon concentrations.

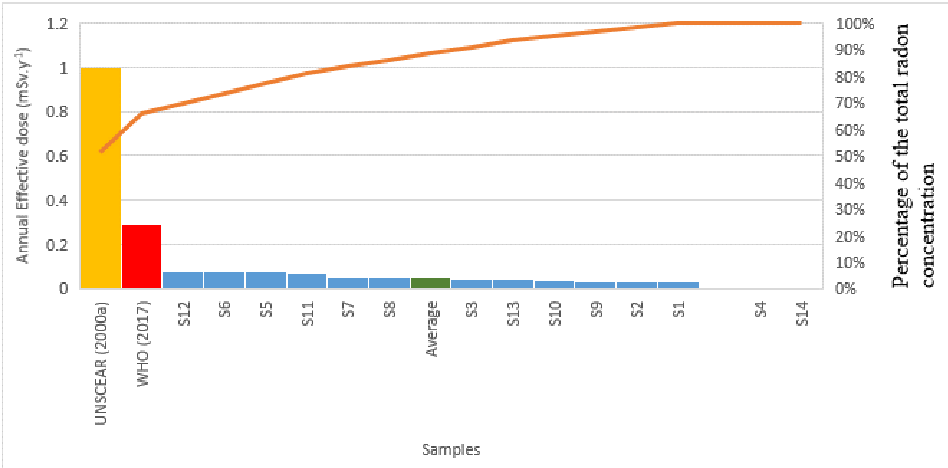

Figure 4: Pareto chart of the annual effective dose due to ingestion radon via consumption of studied carbonated drinks in descending order of frequency, with a cumulative line on a secondary axis as a percentage of the total annual effective dose.

V. Conclusion

The values obtained for the concentration of radon in the present study showed that radon is present in all studied samples except for samples S4 (savanna, lemon flavour) and S14 (Bigi, lemon-lime flavour) which were not detected by the detector. However, the presence of radon in the studied samples were less than the permitted maximum concentration level set as standard according to the World Health Organization and other radiation protection regulatory bodies. The values reported for radon concentrations in carbonated drink samples for the present study were lower than the maximum allowed concentration standard of 0.5 $Bq.l^{-1}$for carbonated drinks [WHO, 2008]. Also, the results of the annual effective dose due to ingestion of radon from the consumption of carbonated drinks in studied samples were lower than the estimated world average of 1 $mSv.y^{-1}$ [UNSCEAR, 2000a] and lower than the reported mean annual effective dose of 0.29 $mSv.y^{-1}$ [WHO, 2017]. The average annual effective dose reported for the studied samples is 4.7% of the estimated World average value. Hence, in conclusion, it can be argued that there is no significant radiological risk to the teeming population of Lagos from radon ingestion by consuming carbonated drinks in the studied locations.

References

[1]. Bankole, O. O., Aderinokum, G. A., Odenloye, O. and Adeyemi, A. T. (2006). Weaning Practices among some Nigerian Women: Implication on Oral Health. *Odontostomatologie Tropicale* 29(113):15–21.
[2]. Campbell John (2012). "This Is Africa's New Biggest City: Lagos, Nigeria, Population 21 Million". *The Atlantic*, Washington DC. Retrieved March 27, 2019.
[3]. Durridge Co. USA (2010), RAD7, *RAD H_2O Accessory Owner's Manual*. Available at
[4]. https://durridge.com/documentation/RAD7%20Manual.pdf.

[5]. Euromonitor International (2017). Soft Drinks Global Overview: Key Trends in 2017. *Reports during Strategy Briefing on Global Soft Drinks Market Analysis*. available at https://www.euromonitor.com/soft-drinks-global-overview-key-trends-in-2017/report. Retrieved on April 5, 2019.

[6]. Gillmore, G.K. & Jabarivasal N. (2010). A Reconnaissance Study of Radon Concentrations in Hamadan City, Iran. *Natural Hazards and Earth System Sciences* 10, 857–863.

[7]. IAEA (1989). Measurements of Radionuclides in Food and the Environment in *Report of the International Atomic Energy Agency*, Technical Report Series No. 295, Vienna.

[8]. Khattak N.U., Khan M.A., Shah M.T. and Javed M.W. (2011). Radon Concentration in Drinking Water Sources of the Main Campus of the University of Peshawar and Surrounding Areas, Khyber Pakhtunkhwa, Pakistan. *Journal of Radioanalytical and Nuclear Chemistry*, 290: 493-505.

[9]. Khursheed A (2000). Doses to Systemic Tissues from Radon Gas. *Radiation Protection Dosimetry* 88 (2), 171–181.

[10]. Kusky Timothy M (2003). Geological Hazards: A Sourcebook. Greenwood Press. pp. 236–239. ISBN 9781573564694.

[11]. NBS (2010). Consumption Pattern in Nigeria, 2009/2010 *Report of Survey of the National Bureau of Statistics*, Nigeria.

[12]. NOAA (1990). Lagos Climate Normals 1961–1990". *Publication of the National Oceanic and Atmospheric Administration, American Scientific Agency of United States Department of Commerce*. Retrieved March 26, 2019.

[13]. Palomo M., Penalver A., Borull F. and Aguilar C. (2007). Measurement of radioactivity in bottled drinking water in Spain. *Appl. Radiat. Isot.*, **65:** 1165- 1172.

[14]. UNSCEAR (1999). Exposures from natural radiations sources. United Nations General Assembly 48th Session of UNSCEAR. New York: United Nations.

[15]. UNSCEAR (2000a). Dose Assessment Methodologies in Report of Sources and Effects of Ionizing Radiation. Report to the General Assembly, with Scientific Annexes, Volume 1: Sources. New York: United Nations.

[16]. UNSCEAR (2000b). United Nations Scientific Committee on Sources and Effects of Ionizing Radiation, *Report on Effects of Atomic Radiation submitted to the General Congress* by United Nations Scientific Committee, Volume II, 12-15.

[17]. USEPA (2003). Assessment of Risks from Radon in Homes. *Report of the Office of Radiation and Indoor Air, United States Environmental Protection Agency*. Available at

[18]. https://www.epa.gov/sites/production/files/2015-05/documents/402-r-03-003.pdf

[19]. USEPA (2012). A Citizen's Guide to Radon".*Publication of the United States Environmental Protection Agency*. Retrieved 6th April, 2019.

[20]. USEPA (2016). A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon. *Publication of the United States Environmental Protection Agency*. Retrieved 4th April, 2019.

[21]. USNRC (2015). Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities 2015: *Forty-Eighth Annual Reportof theUnited States Nuclear Regulatory Commission*, NUREG-0713, Volume 37.

[22]. WHO (2008). Guidelines for Drinking Water Quality: Radiological Aspects, 3rd ed., Vol. 1. Available at

[23]. https://apps.who.int/iris/bitstream/handle/10665/204411/9789241547611_eng.pdf;jsessionid=2363F6DB8826B0FAA93F8B031B2785E4?sequence=1.

[24]. WHO (2017)., Guidelines for Drinking Water Quality: Radiological Aspects, 4th Edition, available at

[25]. https://www.who.int/water_sanitation_health/publications/2011/9789241548151_ch09.pdf.

[26]. World Population Review (2019). "Lagos Population Data", *Publication of the latest review on UN World Urbanization Prospects*. Available at http://worldpopulationreview.com/world-cities/lagos-population/. Retrieved on April 10, 2019.

[27]. Zenith International (2008). Global Soft Drinks Report. Reports of Zenith International Limited. Available online at http://www.zenithinternational.com [accessed on March 22, 2019].

Abiola O. ILORI." NORM (^{222}Rn) Level and Its Associated Effective Dose in Selected Carbonated Drinks Sold in Lagos Traffic, Southwestern Nigeria." IOSR Journal of Applied Physics (IOSR-JAP) , vol. 11, no. 5, 2019, pp. 73-79.