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Measurement of Radon and potentially toxic elements concentrations in groundwater around Ota, Ogun State, Nigeria

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Abstract
This study investigated the concentrations of radon and some potentially toxic elements in drinking water in Ota; an industrial hub of south-western Nigeria. RAD-7; an active electronic device produced by the Durridge Company in the USA was used for measurement of radon concentration and Atomic Absorption Spectrometer for potentially toxic elements. Twenty (20) water samples were collected for this study. Radon concentration in the samples varied from 2.3 to 34.5 Bq L^{-1}, with a mean of 7.7 Bq L^{-1}. The committed annual effective doses due to the ingestion of radon varied from 0.017 to 0.252 mSv y^{-1} with a mean of 0.056 mSv y^{-1}. It was observed that 15% of the samples have radon concentration above the 11.1 BqL^{-1}; the action level recommended by the United States Environmental Protection Agency. The mean concentration of potentially toxic elements in the water samples were 0.02, 0.014, 0.048, 0.010 and 0.003 mgL^{-1} for Cd, Pb, Se, Cr and As, respectively. The concentrations of Pb, Se and As were higher than the WHO permissible limit. This study revealed high concentration of some potentially toxicelementsin water in the study areas which may have some delirious effects on the consumers.

Keywords
radon, water, toxicelements, industrial area, residential area

Introduction

The World Health Organization has identified radon as a carcinogenic agent in human beings (WHO, 2009). It is the second leading cause of lung cancer after smoking (IARC, 1998). The total valuation of health risk posed by radon is roughly 16% per Bq/m^3 (Darby *et al.,* 2005). Radon is a harmful element accommodated by rock water and due to its solubility properties, diffuses into the atmosphere (Ahmad *et al.*, 2015). Out of the radon isotopes, radon-222 is of serious concern to human being. Inhalation and ingestion are the ways in which humans are exposed to radiation from radon. The deformation of DNA occurs when alpha particles released from the radioactive decay of radon interact with the lung cells (WHO, 2009). Some radon concentration measurements in water have been carried out in South Western. Nigeria (Oni *et al.,* 2014; 2019). Aside, Radon, potentially toxic elements such as Cadmium, Lead, Chromium, Arsenic, and Selenium are distributed in wáter through several natural processes such as tectonic activity, erosion, and through

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anthropogenic activities which include fossil fuel combustion, industrial processes (Engwa et al., 2019). Even at low conentration, these toxic elements through generation of free radicals which can cause oxidative stress, damage of DNA and biological molecules (Bradl, 2002).

In most African countries including Nigeria, the urban settlement is commonly faced with problem of portable water due to human activities and industrialization. This problem may lead to pollution and scarcity of quality water. Leachate from domestic and industrial wastes may also pose high risk to underground water.

Therefore, this study is designed to evaluate the radiological risk due radon inhalation and ingestion of some water samples from Ota industrial area. The study will also evaluate the concentration of some potentially toxic elements in the water samples. This study will also serve as basis for further research and policy making on Rn-222 and leachate concentration in groundwater in Nigeria.

Materials and Methods

The study area

The study area is located in Sango-Ota between latitude 6°40´ 00´´ N and longitude 3° 13´ 00´´E (Figure 1). According to the 2006 census, the estimated population of Ota in Ogun state was about 163,783. The total land area of Ota is about 878km^2 with its headquarter located at Ado-Odo/Ota local government area. The third largest concentration of industries in Nigeria is Ota as at 1999 (Salako, 1999). Some of the industries include but not limited to the following: Pharmaceutical, Chemical and paints, Brewery/distillery, Polymer/Plastic, food, cosmetics, gas manufacturing companies, paper, honda vehicle parts amufacturing and other metallurgical companies. The sampling site includes several industries and residential areas. The study area is situated precisely on the international road connecting Nigeria to the Republic of Benin.The sites were selected based on its importance and proximity to the municipal and industrial settlement to determine the impact of their activities and its effect on human health.

Geology of the study area

The geology of the study area is found within the sedimentary rock sequence of Dahomey Basin of southwestern Nigeria; which span through the continental margin of the Gulf of Guinea. The Dahomey Basin consists of Ogun River and Owena basin. The tectonic structure of the basin is simple and forming a monocline extending from the eastern part of Ghana through Togo and Benin Republic to the western margin of the Niger Delta. The study area is extensively a coastal plain sand with only little evidence of geological faults(Ufoegbune et al, 2016).

As part of Ogun state, Ota has the same geological features like many other parts of the state, it falls within the eastern Dahomey (or Benin) Basin of southwestern Nigeria which stretches along the continental margin of the Gulf of Guinea (Joel et al., 2017). It posseses the basement complex rock and the pre-Cambrian age, consisting of the older and younger granites in the northern part of the state as well as the younger and older sedimentary rock in the tertiary and secondary ages in the southern parts (Ufoegbune et al, 2016). The study area is characterized by a typical tropical rain forest climate with two major climatic conditions; the rainy season lasting for a period of six to seven months and usually run between April and October with a month break in August and the dry season which span through November to February. The region is very hot and wet due to its closeness to the equator with an average temperature of not less than 18° C for all the months throughout the year.

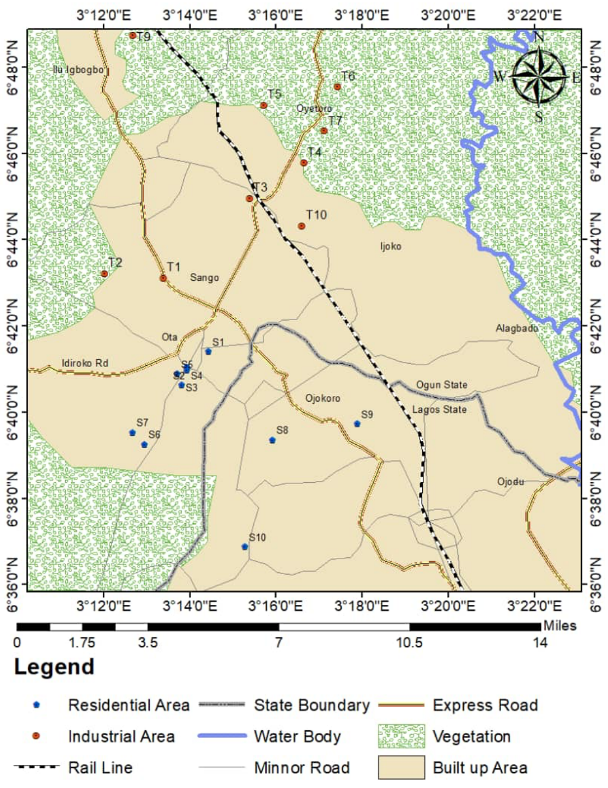

Figure 1. *Location Map of the study area.*

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Sample Collection
Twenty (20) water samples (ten each at residential (S1-S10), and industrial (T1-T10) areas respectively) were randomly collected. Ten samples of 0.5L of well-water from each area was collected in a clean bottle and sealed with masking tape to prevent escape of radon from the water. The samples were conveyed to the laboratory where radon concentration was measured in each sample.

Methodology

Radon analysis using RAD-7
The procedure used in this study for the measurement of radon concentration was a close loop technique, by which the air volume and water were constant but not depended on the flow rate (Hamzeh *et al*., 2012). Radon was extracted as air flows continuously through the water until a steady equilibrium was attained. For a reliable result from the sampling and measurement technique, each of the water samples were analyzed in more than one cycle, after which the mean value for the radon concentration in water was deduced. The RAD-7 device used has model number 3093 and it is manufactured by the Durridge Company, in the United States of America. The device used was calibrated and has a high degree of accuracy and sensitivity (Inacio, 2017). The choice of this device was made due to its capability to determine radon concentration just within 30 minutes of measurement which is way lower than the half-life of radon itself.

Committed Effective Dose
The annual effective dose by ingestion was assessed based on the intake of water by the populace of the study area (Todorovic et al, 2012). The annual effective dose was calculated based on Equation [1].

$$E_{ing} = Rn^{222}con.(BqL^{-1})\ x\ K\ x\ KM\ x\ t \qquad [1]$$

where, = the committed effective dose from ingestion [30]; K = the ingesting dose conversion factor of radon (10^{-8}Sv Bq for adult); KM= the average water consumption per day (2 litre /day); and t = the duration of consumption (365 days). For the dose estimation, a conservative consumption of 2 litres per day for standard adult drinking the same water and directly from the source point was assumed (UNSCEAR, 1993).
The annual effective radon dose due to inhalation of radon from water is obtained from Equation [2]

$$E_{inh}\ (\mu Svy^{-1}) = Rn^{222}con.(BqL^{-1}) \times R_{aw} \times F \times O \times DCF_{inh} \qquad [2]$$

where, E_{inh} is the effective dose of inhalation (µSvy^{-1}), R_{aw} is the ratio of radon in air to radon in water (10^{-4}), F is the equilibrium factor between radon and its decay products (0.4), O is the average indoor occupancy time per person (7000hy^{-1}) and DCF_{inh} is the inhalation dose conversion factor (9nSv h^{-1} (Bq/m^3)$^{-1}$) (UNSCEAR, 2000).

Figure 2. *The RAD-7 experimental set-up for radon in water measurement.*

Potentially toxic elementsanalysis using AAS
This is a highly sensitive because atomic absorption lines are extremely narrow (0.02-0.5A) with transition energies which are unique for each of the element.
The Spectrometry method was used with Atomic Absorption Spectrometer (AAS Buck Scientific Model 211 VGP) to examine concentration of Cadmium, Lead, Chromium, Arsenic, and Selenium in the water samples.

Results and Discussion

The concentration of radon gases are predominantly higher in areas underlain by granites, which are rich in uranium and radium. The radon concentration in granite- hosted ground waters generally increases with an increase in the uranium content of the soil and bedrock but is highly variable, depending on aquifer characteristics, bedrock geology, and water chemistry (Jobbágy et al., 2017).
The results of radon concentration in water samples and the geographical location of the sampling sites are presented in Table 1. The radon concentration in the

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water samples varied from 2.3 0 to 34.5 0 with mean of 7.914.1 BqL^{-1} in residential areas and from 2.3 ± 1.2 to 34.5 ± 4.5 BqL^{-1} in the industrial area with mean of 7.449.13. The peak-recorded value was found in Ile-ogbo area with 34.5 ± 4.5 BqL^{-1}, while the minimum value was found in Nepa area with 2.3 ± 1.2 BqL^{-1}.

The annual effective doses due to intake of radon were estimated and the values ranged from 0.0168 to 0.252 mSv y^{-1} with a mean value of 0.056 mSvy^{-1}. Due to intake of water, the effective dose from radon is presented in Table 1. High doses of 0.118mSvy^{-1}for sample S3 (Unity area; which is a residential region) and 0.252mSvy^{-1}sample T3 (Singer area, which is an industrial region) were recorded around the study sites. The water samples around both regions are above the recommended limit of 0.1 mSvy^{-1} (Somlai *et al.*, 2007).

Table 1.*Result of radon concentration and Annual Effective dose (AED) in water samples*

Samples ID	Locations	Geographical coordinates		Radon Concentration (BqL^{-1})	AED (ingestion) ($mSvy^{-1}$)	AED (inhalation) (μSvy^{-1})
S1	AMODU GIWA	6.690123^{0}N	3.240607^{0}E	9.9 ± 1.7	0.0723	0.24948
S2	ABEBI	6.683998^{0}N	3.232208^{0}E	10.2 ± 1.8	0.0745	0.25704
S3	UNITY ROAD	6.677175^{0}N	3.230240^{0}E	16.2 ± 2.2	0.1180	0.40824
S4	ANJORIN	6.682862^{0}N	3.232377^{0}E	6.6 ± 1.4	0.0482	0.16632
S5	OKE-OLA	6.681524^{0}N	3.228670^{0}E	13.1 ± 2.1	0.0956	0.33012
S6	ADEYEMO	6.654223^{0}N	3.215778^{0}E	5.8 ± 1.6	0.0423	0.14616
S7	OYEBANJI	6.658823^{0}N	3.211367^{0}E	5.5 ± 1.4	0.0402	0.1386
S8	OYEYEMI	6.655911^{0}N	3.265312^{0}E	3.7 ± 1.2	0.0270	0.09324
S9	OYEWO	6.662186^{0}N	3.298162^{0}E	2.7 ± 1.0	0.0197	0.06804
S10	ILE-OGBO	6.614656^{0}N	3.254709^{0}E	5.4 ±1.4	0.0394	0.24948
Mean				**7.9 ± 1.6**	0.0577	0.199332
T1	JOJU	6.718475^{0}N	3.223402^{0}E	5.0 ± 1.8	0.0365	0.12600
T2	ALI-ISHIBA	6.720153^{0}N	3.200621^{0}E	4.7 ± 1.7	0.0343	0.11844
T3	SINGER	6.749326^{0}N	3.256887^{0}E	34.5 ± 4.5	0.2520	0.86940
T4	NEPA	6.762929^{0}N	3.277821^{0}E	2.3 ± 1.2	0.0168	0.05796
T5	OYEDE	6.785329^{0}N	3.262345^{0}E	5.2 ± 1.7	0.0380	0.13104
T6	MAYEGUN	6.792312^{0}N	3.290678^{0}E	3.2 ± 1.3	0.0234	0.08064
T7	SUGAR	6.775445^{0}N	3.285756^{0}E	4.1 ± 1.5	0.0300	0.10332
T8	EWUPE	6.911317^{0}N	3.229989^{0}E	2.4 ± 1.3	0.0175	0.06048
T9	AKOSHILE	6.812196^{0}N	3.211609^{0}E	6.9 ± 1.9	0.0504	0.17388
T10	IGBEHINADUN	6.738624^{0}N	3.276922^{0}E	6.1 ± 1.8	0.0445	0.15372
Mean				**7.4 ± 1.9**	0.0543	0.18748

Drinking of water is not the only source of waterborne radon but inhalation of the radon escaping from water is an addendum to the radiological hazard. The annual effective dose due to inhalation varied from 0.06804 to 0.33012 for the resident area (S1–S10) and 0.05796 to 0.8694 for the industrial area (T1–T10). The mean values for the annual effective dose due to inhalation for the residential and industrial area of Ota were 0.199332 and 0.18748 , respectively. At the industrial area, the mean annual effective dose from ingestion of radon is 0.0577$mSvy^{-1}$, while at the residential area it was calculated to be 0.0543$mSvy^{-1}$. Likewise, the annual effective radon dose by inhalation in both the industrial and residential areas was found to be 0.199332 and 0.18748 respectively. About 15% of the samples collected have radon concentration above

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the permissible limit of 11.1 BqL^{-1} (USEPA, 1999). Therefore, the radon in Ota, Ogun State is comparatively moderate, since the Maximum Recommended Level (MCL) of United States Environmental and Protection Agency (USEPA) is 11 Bq L^{-1}. The variation in radon level could be ascribed to the differences in the lithological units and depths at which the aquifers are located. An additional feature that may contribute to the variation of radon level in water is time of storage (El-Taher, 2012).

Table 2. *Concentration of Potentially toxic elements in the water samples (mgL^{-1})*

SAMPLE CODES	Cd	Pb	Se	Cr	As
S1	ND	0.004	0.066	0.005	ND
S2	ND	0.003	0.068	0.003	ND
23	ND	0.005	0.065	0.004	ND
S4	ND	0.002	0.064	0.007	ND
S5	ND	0.006	0.069	0.006	ND
S6	0.002	0.026	0.047	0.024	0.005
S7	0.001	0.024	0.048	0.026	0.003
S8	0.002	0.027	0.045	0.023	0.007
S9	0.002	0.025	0.049	0.022	0.006
S10	0.003	0.028	0.046	0.025	0.004
Mean	**0.002**	**0.015**	**0.057**	**0.015**	**0.005**
T1	ND	0.005	0.044	0.003	0.001
T2	ND	0.007	0.046	0.001	ND
T3	ND	0.006	0.043	0.004	0.001
T4	ND	0.003	0.042	0.005	0.001
T5	ND	0.004	0.045	0.002	0.002
T6	ND	0.022	0.036	0.007	0.003
T7	ND	0.024	0.034	0.006	0.001
T8	ND	0.023	0.035	0.008	0.002
T9	ND	0.020	0.038	0.005	0.005
T10	ND	0.021	0.037	0.009	0.004
Mean	-	**0.014**	**0.041**	**0.005**	**0.002**
WHO Permissible Limit	0.003	0.01	0.01	0.05	0.000010

Table 2 shows the concentrations of the potentially toxic elements in the two areas studied. The result showed that Cadmium (Cd) was not detected in five of the ten sites sampled in residential area and was not detected in all the sites in the industrial area.

In the five sites in residential area, low concentration of 0.002mgL^{-1} was detected. Arsenic was not detected in five of the ten sampling sites in the residential area but was detected in low concentration (0.003mgL^{-1}) in the industrial area. Lead concentration ranged from 0.004mgL^{-1} to 0.026mgL^{-1} across the study area with mean of 0.015 mgL^{-1} while Selenium had the highest concentration range between 0.036mgL^{-1} to 0.066 mgL^{-1} with mean of 0.057 mgL^{-1} in residential area and 0.041 mgL^{-1} in industrial area. Chromium (Cr) has the highest concentration of 0.024mgL^{-1} in the industrial area but lower concentration was estimated in the industrial area. Lead, Arsenic and Selenium have concentrations higher than the permissible limit (WHO, 2009) which may be due chemicals used by the industries in the study area.

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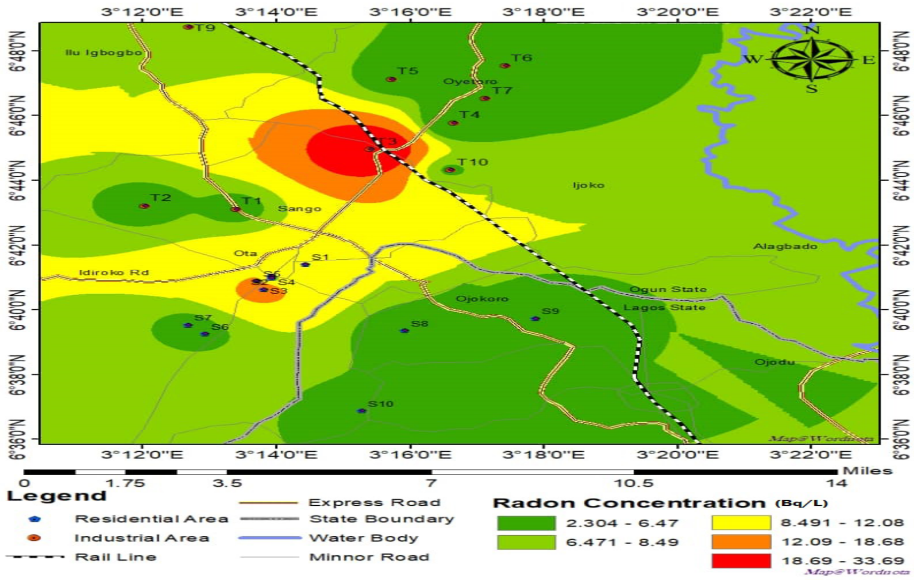

Figure 3. *Map of the study area showing the spatial distribution of radon concentration in groundwater.*

Conclusion

From the result of this research, it is appropriate to infer that no significant attention has been given to the concentration of radon in water for drinking and other domestic purposes in Nigeria. Consequently, to enhance the safety of the public from the radiological threats associated with exposure to radon and its progenies, it is essential to carry out broad work on radon measurements in air, soil and water through various geological and geo-political zones in Nigeria, in order to create enough records for policy and improved radon program, using data from few works and also this study as benchmark.

Conversely, the probable hazard caused by industrial and residential activities in most of the study sites to the environment (human, plants and animals) is averagely minimal at present but may become prominent and risky on long term. Therefore, it is imperative to monitor their accumulation potentially toxic elementsin water samples.

From the outcome of the study, we recommend to the indigenous applicable authorities to properly sensitize the inhabitants and as well monitor the level of radon and potentially toxic elementsin the water system in all cities.

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Misurazioni delle concentrazioni di radon e metalli pesanti nelle acque sotterranee intorno a Ota, Stato di Ogun, Nigeria

Riassunto

Questo studio ha esaminato le concentrazioni di radon e alcuni metalli pesanti nell'acqua potabile di Ota; un polo industriale della Nigeria sudoccidentale. RAD-7; per la misura della concentrazione di radon e dello spettrometro ad assorbimento atomico per metalli pesanti è stato utilizzato un dispositivo elettronico attivo prodotto dalla Durridge Company negli USA. Per questo studio sono stati raccolti venti (20) campioni d'acqua. La concentrazione di radon nei campioni variava da 2.3 a 34.5 BqL^{-1}, con una media di 7.7 BqL^{-1}. Le dosi efficaci annuali impegnate dovute all'ingestione di radon variavano da 0.017 a 0.252 mSv y^{-1} con una media di 0.056 mSv y^{-1}. È stato osservato che il 15% dei campioni ha una concentrazione di radon superiore a 11.1 BqL^{-1}; il livello di azione raccomandato dalla United States Environmental Protection Agency. La concentrazione media di metalli pesanti nei campioni di acqua era 0.02, 0.014, 0.048, 0.010 e 0.003 mgL^{-1} per Cd, Pb, Se, Cr e As, rispettivamente. Le concentrazioni di Pb, Se e As erano superiori al limite consentito dall'OMS. Questo studio ha rivelato un'elevata concentrazione di alcuni metalli pesanti nell'acqua nelle aree di studio che possono avere alcuni effetti deliranti sui consumatori.

Parole chiave: *radon, acqua, metalli pesanti, zona industriale, zona residenziale*

Mesure des concentrations de radon et de métaux lourds dans les eaux souterraines autour d'Ota, État d'Ogun, Nigéria

Résumé

Cette étude a examiné les concentrations de radon et de certains métaux lourds dans l'eau potable à Ota; un pôle industriel du sud-ouest du Nigéria. RAD-7; un dispositif électronique actif produit par la société Durridge aux États-Unis a été utilisé pour mesurer la concentration de radon et un spectromètre d'absorption atomique pour les métaux lourds. Vingt (20) échantillons d'eau ont été prélevés pour cette étude. La concentration de radon dans les échantillons variait de 2.3 à 34.5 BqL^{-1}, avec une moyenne de 7.7 BqL^{-1}. Les doses efficaces annuelles engagées en raison de l'ingestion de radon variaient de 0.017 à 0.252 mSv y^{-1} avec une moyenne de 0.056 mSv y^{-1}. Il a été observé que 15% des échantillons ont une concentration de radon supérieure à 11.1 BqL-1; le niveau d'action recommandé par l'Agence américaine de protection de l'environnement. La concentration moyenne de métaux lourds dans les échantillons d'eau était de 0.02, 0.014, 0.048, 0.010 et 0.003 mgL^{-1} pour Cd, Pb, Se, Cr et As, respectivement. Les concentrations de Pb, Se et As étaient supérieures à la limite autorisée par l'OMS. Cette étude a révélé une forte concentration de certains métaux lourds dans l'eau dans les zones d'étude, ce qui peut avoir des effets délirants sur les consommateurs.

Mots clés: *radon, eau, métaux lourds, zone industrielle, zone résidentielle*