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Annual effective dose due to ^{222}Rn in spring and some surface waters of Johor State, Malaysia

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Abstract: *Ubiquitous nature, along with the detrimental health impact of radon (^{222}R), has led to the investigation of its activity concentration in various environmental medium, including bodies of water. This work was conducted to estimate the annual effective dose of inhalation due to ^{222}Rn in spring and some surface waters in Johor state, Malaysia. ^{222}Rn activity concentration was measured using the RAD7 alpha detector. The annual effective dose for inhalation was evaluated using the measured ^{222}Rn activity concentration in water. The activity concentration of ^{222}Rn in water varies from 80 ± 110 to 5400 ± 1100 mBq l^{-1} in surface and spring water, respectively. The measured activity concentrations in the samples were found to be below the EPA and WHO maximum permissible limit for ^{222}Rn in Water of 1100 mBq l^{-1} and 10^5 mBq $l^{-1,}$ respectively. The highest value of ^{222}Rn activity concentration was measured in spring water discharging from the granitic rock Aquifer. While the lowest value was measured in surface waters. The values of an annual effective dose of inhalation, due to ^{222}Rn in spring water, were found to range from 0.998 to 5.139 µS y^{-1} with a mean value of 2.15 µS y^{-1}, while in the surface waters, the values range from 0.076 to 1.140 µS y^{-1} with a mean value of 0.423 µS y^{-1}. The inhalation doses estimated were found to be well below the recommended limit set by UNSCEAR of 1260 µ Sv y^{-1}.*

Keywords: *Radon in water; spring water; surface water; type of aquifer*

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1.0 Introduction

Radon is an inert radioactive gas that is ubiquitous within our environment and exists in various quantities. Radon (^{222}Rn) that emerges from the ^{238}U decay series is considered the most significant isotope due to its long half-life (3.82 days) in comparison to other isotopes of radon (Eddy et al., 2025). The dissolved ^{222}Rn in water mainly originates from ^{226}Ra that either dissolves in water or is localised in a porous and permeable rock aquifer or soil materials in contact with water (Auwal et al., 2025). When ^{222}Rn atoms are produced in soil or rocks, they have the potency to be expelled from the soil grain by alpha-recoil and transported to groundwater or void air and seep through the atmosphere (Abdallah et al., 2007; Somlai et al., 2007; Tabar and Yakut, 2014; Marques et al., 2004).

^{222}Rn concentration in groundwater varies according to the geological formation of a given aquifer (Abdallah et al., 2007; Duggal et al., 2013; Salih et al., 2002; Jobbágy et al., 2010; Przylibski and Gorecka, 2014). The movement and concentration level of ^{222}Rn within a bedrock is anisotropic, which mainly relies on the type of rock, physical condition as well as geochemistry of the rock aquifer (Michel, 1990; Durrani, 1999; Zhuo et al., 2001; De Oliveira et al., 2001; Aleissa et al., 2012). Numerous studies were conducted to investigate the relationship between ^{222}Rn activity concentration in water and the geological environment. Elevated ^{222}Rn levels are commonly found in ground and spring waters discharging from metamorphic and granitic rocks (Michel, 1990; Durrani, 1999; Weise et al., 2001; Aleissa et al., 2012; Freiler et al., 2016). Moreno et al. (Moreno et al., 2014), reported that Felsic granites contain an excessive concentration of the parent element of the ^{222}Rn decay series (^{238}U).

The radiological risk of lung cancer due to inhalation of ^{222}Rn and its progeny is well recognised (WHO, 2009). ^{222}Rn undergoes alpha decay, with the emission of two daughters (^{214}Po and ^{218}Po) that contribute to more than 90% of the radiation dose due to ^{222}Rn exposure (Marques et al., 2004). Exposure to ^{222}Rn accounts for more than 50% (1.26 mSv/y) of the average annual exposure due to natural sources (UNSCEAR, 2008). The associated hazard of ^{222}Rn ingestion is less than that of inhalation of ^{222}Rn that exhale into the air from the same water (Crawford-Brown, 1990); DURRIDGE Cmpanu Inc., 2011; Duggal et al., 2020). Therefore estimation of inhalation dose due to ^{222}Rn in water is considered in this research

Intrusive igneous rocks of granitic origin cover 27 % of the total land area in Johor state (Saleh et al., 2015). Most of the spring waters found in this study area are located in the region of intrusive rocks. Therefore, it is considered necessary to quantify ^{222}Rn in such waters to ensure the safety of its users. Additionally, assessment of the effective doses due to ^{222}Rn inhalation is considered utmost due to its significant contribution to the total lifetime radiological dose to humans (Bem et al., 2014). Therefore, this research was conducted to assess the annual effective doses due to ^{222}Rn in spring and some surface water of Johor state, Malaysia.

2. 0 Materials and methods

2.1 Study Area

Johor state has geological formations grouped according to their geological age broadly as Cretaceous-Jurassic, Devonian, Intrusive rocks, Permian, Quaternary, Tertiary, and Triassic geological formations. According to the geological map of peninsular Malaysia (Director-General of Geological Survey Malaysia, 1985). Table 1 below presents the geological formations of the water sampling locations.

Table 1: Geology of the water sampling locations

Geology	Composition
Intrusive rocks	Undifferentiated intrusive rocks, classified as granite biotite
Triassic	Combination of undifferentiated shale, siltstone, sandstone, mudstone, and minor limestone lenses

2.2 Sampling

A total of 11 water samples were collected, five samples from the spring water source and the rest from other surface water sources in the vicinity of residential areas, with the view that these water sources have potential exposure of ^{222}Rn to the environs. The water samples were collected directly from the source by immersing the 250 ml glass vials (of the RAD H_2O kit) into the water source, ensuring that no bubbles of air were getting into the sampling bottle. The 250 ml glass vials have a radon extraction efficiency of 94%. The sample collected was measured within less than 10 hours from the sampling time to avoid loss of radon from the water sample.

2.3 Measurement of ^{222}Rn in water

Measurement of ^{222}Rn activity concentration in water was conducted using the RAD7 alpha detector coupled with RAD H_2O. Prior to measurement, the equipment was thoroughly purged with outdoor air for several minutes to ensure that the equipment's humidity drops below 5% and it is free from old radon. After purging, the measurement was conducted with the equipment set at the Wat250 protocol. The time taken to aerate the sample, equilibrium rest, and counting of the sample was 30 minutes at the end of the last counting cycle, The printer attached to the detector printed out the average radon readings counted, a bar chart of the readings and a cumulative spectrum. The average ^{222}Rn activity concentration in the water was calculated and stored automatically by the system. The RAD7 was letter connected to the PC, and the measurement results were downloaded to the RAD-Capture, where necessary corrections are done (DURRIDGE Company Inc., 2011). The coordinates of the sampling locations were recorded using a global positioning system (GPS), which were later plotted on the map of the geological survey of the study area to identify the geological formation of the water sample.

2.4 Annual Effective dose due to ^{222}Rn water

The annual effective dose of inhalation due to ^{222}Rn in water was calculated using the parameters adopted from UNSCEAR (2000):

$$D_{inh}(\mu Sv\ y^{-1}) = AC_{RnW} \times R_{aw} \times E_f \times T_o \times DCF \quad (1)$$

where D_{inh} , is the effective dose for inhalation, AC_{Rnw} is the activity concentration of ^{222}Rn in water (Bq l^{-1}), R_{aW} is the ratio of ^{222}Rn in the air to ^{222}Rn in water (10^{-4}), $E_{f,}$ is the equilibrium factor between ^{222}Rn and its progenies (0.6), T_o is the average occupancy time per individual (1760 h y^{-1}), and DCF is the dose conversion factor for ^{222}Rn exposure (9 nSv (Bq h m^{-3})$^{-1}$) (UNSCEAR, 2000).

3. 0 Results and Discussion

3.1 ^{222}Rn activity concentration in water

The measured ^{222}Rn activity concentration in water samples was evaluated. Table 2, presents the variation of the data for ^{222}Rn activity concentration in spring and surface waters with the type of rock aquifer identified in the case of spring waters. The activity concentration of ^{222}Rn in water varies, from 80 ± 110 to 5400 ± 1100 mBq l^{-1} in surface and spring water, respectively. The highest ^{222}Rn activity concentration of 5400 ± 1100 mBq l^{-1} was obtained from the spring water sample of Sungai Batang waterfall of Segamat district, Johor state, Malaysia. While the lowest activity concentration of 80 mBql^{-1} was observed in the surface water sample from Sungai Tebarau in Johor Bahru district.

Table 2 Measured ^{222}Rn activity concentration in water and aquifer

Source of water	AC_{RnW} (mBq l^{-1})	Aquifer type
lake	690 ± 370	-
river	1480 ± 520	-
river	80 ± 110	-
river	230 ±190	-
river	270 ± 240	-
sea	200 ± 200	-
spring	2450 ± 640	Intrusive rock
spring	5400 ± 1100	Intrusive rock
spring	1050 ± 420	Intrusive rock
spring	1270 ± 510	Intrusive rock
spring	1200 ± 500	Triassic formation

The measured values of ^{222}Rn in water were all found to be below the maximum contaminant level (MCL) set by the United States Environmental Protection Agency of

11100 mBql^{-1}. This MCL is based on inhalation risk estimates of 10^{-4} as the ratio of radon in water to air, which is in agreement with the estimated lifetime cancer risk of 2×10^{-4} (Krishan et al., 2015). Table 3 presents the statistical summary of the activity concentration of ^{222}Rn in spring and surface waters. The values of ^{222}Rn in spring water varies from 1050 ± 420 to 5400 ± 1100 mBq l^{-1} with a mean value of 2264 mBq l^{-1}, while the values of ^{222}Rn measured in surface waters vary from 80 ± 110 to 1480 ± 520 mBq l^{-1} with a mean value of 492 mBq l^{-1}. The mean value of ^{222}Rn activity concentration measured in spring water by this study is about five times higher than the mean value obtained from the surface waters. The high value obtained from the spring waters can be associated to the reason that the spring waters are mostly discharging from an aquifer of intrusive granitic rocks. UNSCEAR (UNSCEAR, 2000), reported that granitic rocks contain a high concentration of natural radionuclides and this accounts for the reason why most of our spring water samples have higher ^{222}Rn activity concentration.

Table 3 Summary statistics of ^{222}Rn activity concentration in spring and surface waters

	N	Mean	Std. Error	Std. Dev.	Minimum	Maximum
^{222}Rn in Surface (mBq l^{-1})	6	493	214.2	526.9	80	1480
^{222}Rn in Spring (mBq l^{-1})	5	2264	820.4	1834.7	1050	5400

Table 4 presents the results of this study with those of other studies from different countries for ^{222}Rn activity concentration in spring and surface waters. The table shows that the data range for this study of ^{222}Rn activity concentration in spring water is comparable with that of Tabar and Yakut (Tabar and Yakut, 2014).

Table 4 Comparing the measured ^{222}Rn activity concentration in water with other studies

Location/ Country	**Method**	**^{222}Rn in water Range $*10^3$ (mBq l^{-1})**		**Reference**
		Spring waters	Surface waters	
Johor/Malaysia	RAD7	1.1 to 5.4	0.1 to 1.5	This study
Southwest coastal region of Peninsular Malaysia	RAD7			(Ismail et al., 2021)
Perak/ Malaysia	RAD7	0.04 to 0.62	0.33 to 3.98	(Nuhu et al., 2020)
Muzaffarabad/Pakistan	RAD7	0.3 to 34.4	NM	Khan et al. (Khan et al., 2019)
Istanbul/ Turkey	AlphaGUARD	1.6 to 14	NM	Doğan et al. (Doğan et al., 2018)
South of Catalonia/ Spain	LSC	1.4 to 104.9	NM	Fonollosa et al. (Fonollosa et al., 2016)

Shenzhen city/ South China	AlphaGUARD (PQ2000	3.1 to 82.0	0.15 to 0.51	Li et al. (Li et al., 2015)
Southern Kohat Plateau/ Pakistan	RAD7	1.1 to 25.1	NM	Khattak et al. (Khattak et al., 2014)
Yalova basin/ Turkey	RAD 7	0.21 to 5.82	NM	Tabar and Yakut (Tabar and Yakut, 2014)
Balakot and Mansehra/Pakistan	LUK-WG-1001	12.73 to 22.90	4.99 to 11.79	Khan et al. (Khan et al., 2009)
Transylvania /Romania	LUK-VR	2 to 129.3	0.5 to 10	Cosma et al. (Cosma et al., 2008)
Spain	HPGe	4 to 1868		Ródenas et al. (Ródenas et al., 2008)

****NM: Not measured**

3.*1 An annual effective dose of inhalation due to ^{222}Rn in water*

The annual effective dose of inhalation due to ^{222}Rn is defined by (UNSCEAR, 2018) as 1260 µSv y^{-1}. The summary statistics of the annual effective dose of inhalation due to ^{222}Rn in water are presented in Table 5. The estimated values range from 1.0 to 5.100 µSv y^{-1} with a mean value of 2.205 µSv y^{-1} for the measured spring waters, and 0.080 to 1.140 µSv y^{-1} with a mean value of 0.423 µSv y^{-1} for surface waters. The values of the annual effective dose of inhalation for all the water samples fall below the recommended level of 1260 µSv y^{-1} set by UNSCEAR. (UNSCEAR, 2008).

Table 5 Summary statistics of the calculated effective dose of inhalation

	N	Mean	Std. Error	Std. Dev.	Minimum	Maximum
D_{inh} for spring wasters (µSv y^{-1})	5	2.205	0.764	1.708	1.000	5.130
D_{inh} for surface wasters (µSv y^{-1})	6	0.423	0.165	0.403	0.080	1.140

4.0 Conclusion

The study was conducted to estimate the annual effective dose of inhalation due to ^{222}Rn in spring and surface waters of Johor state. The measured ^{222}Rn activity concentration has mean values of 2264 mBq l^{-1} and 492 mBq l^{-1} in spring and surface waters, respectively. The measured activity concentrations of ^{222}Rn were found to be below the maximum contaminant level set by the US Environmental Protection Agency and World Health Organisation. The calculated effective dose of inhalation has mean values of 2.205 µSv y^{-1} and 0.423 µSv y^{-1}for spring and surface waters respectively, the estimated values were found to be below the recommended limit of UNSCEAR (1260 µSv y^{-1}). Therefore, exposure to the measured water sources is considered to be within the safe limit from a radiological point of view.

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6.0 References

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Authors' Contribution

Rakiya Haruna handled conceptualization, methodology, analysis, drafting, and editing. Muneer Aziz Saleh contributed to conceptualization, supervision, and editing. Habila Nuhu assisted with field data collection.