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Radon in soil gas of Johor, Malaysia

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Abstract: *This study was conducted to establish baseline data for radon (^{222}Rn) activity concentration in soil gas of Johor, Malaysia. RAD7 alpha detector was used to measure the activity concentration of ^{222}Rn in soil gas. The descriptive statistic and hypothesis tests were done using SPSS software. An inverse distance weighting interpolation (IDW) technique was used to obtain the spatial distribution of the measured ^{222}Rn in soil gas in the ArcGIS software. The measured activity concentration of ^{222}Rn in soil gas varies from MDA to 127250 Bq m^{-3}. Higher values of ^{222}Rn in soil gas were found in the soil developed from granitic rocks. A statistically significant difference in the median values of ^{222}Rn activity concentration among the soil types and geological formations of Johor state (P=0.008 and P=0.028, respectively) was observed. A map of the spatial distribution of the measured ^{222}Rn activity concentration in soil gas was created.*

Keywords: *^{222}Rn in sol gas; geological formations; soil types; spatial distribution.*

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1.0 Introduction

Radon (^{222}Rn) is a naturally occurring colorless, odorless, and inert radioactive gas that originates from the ^{238}U decay series found in the rock, soil and earth crust (Liu *et al*., 2016). ^{222}Rn and its progenies are the primary sources of natural background radiation, accounting for more than 50 % of the total radiation dose to humans (UNSCEAR, 2008). The World Health Organisation (WHO) categorised radon as a class-one carcinogen, and it is estimated as the second cause of lung cancer after smoking (Field 2015; WHO 2009).

The activity concentration of indoor-air ^{222}Rn is characterized by complex features, for instance, type of building material, presence of a basement, lifestyle of the inhabitant as well as the geological nature of the area (Alonso *et al*., 2019). Among these features, the concentration of ^{222}Rn in the subsurface of a building, which depends on the soils and rocks composition, is recognized as the primary source of indoor radon which acts as a good predictor of radon potential of a given location (Alonso *et al*., 2019; Kardos et al., 2015; Liu *et al.*, 2016; Mose *et al.*, 1992; Nazaroff *et al*., 1988).

Studies conducted at various locations of Johor state to assess the natural radionuclide in the surface soil indicate elevated levels in amounts greater than the estimated world mean value. For example, Ramli *et al.* (2005), measure the activity concentration of natural radionuclides in the surface soil in Palong, Johor, and reported a mean value of 242.05 Bq kg^{-1} for ^{238}U. Saleh et al. (2013a), reported an average value of an activity concentration of ^{226}R in the surface soil of Segamat District, Johor of 162 ± 6 Bq kg^{-1}. Saleh et al. (2013b), measured the activity concentration of natural radionuclides in Pontian, Johor, and reported average values of 37 ± 3 Bq kg^{-1} for ^{226}Ra. Saleh et al. (2013), conducted a study in Mersing, Johor, Malaysia and reported mean values of ^{226}Rn of 77 ± 4 Bq kg^{-1} and 140 nGy h^{-1}. A study was conducted in Muar, Johor, by Saleh *et al*. (2014), and an average value of 78 ± 4 Bq kg^{-1} for ^{226}Ra was reported.

Studies on natural radionuclide in Johor, Malaysia have been found, however, a knowledge of natural radionuclide levels in the surface soil is not sufficient to describe the radon risk of a given area. Therefore there is a need to establish baseline data of ^{222}Rn in soil gas to identify regions at risk of radon exposure. Therefore, this research was conducted to determine the original data for estimation of the radon potential of the study area and characterized the measured soil gas ^{222}Rn based on the geological formations and soil types of the study area. Also, the study shall develop a map for the spatial distribution of ^{222}Rn in soil gas of Johor state, Malaysia.

2.0 Materials and Method

2.1 The study area

The state of Johor is located in the southern part of Peninsular Malaysia. It is located in between latitudes 1° 16′ to 2° 50′ North, and longitude 102° 28.5′ to 104° 18′ East, in the southern part of Peninsular Malaysia (Haruna *et al*., 2020; Saleh *et al*., 2015). Johor State Forestry Department. (2006) states that 20.6 % of the entire land area in Johor, is covered in the forest. It is the fifth-largest state in Malaysia, with a population of about 3,350,000 (Department of Statistics Malaysia, 2015).

The main geological formations that underlay Johor's soil, classified based on their geological ages are Quaternary, Tertiary, Cretaceous-Jurassic, Triassic, Permian, Intrusive rocks. (Ramli *et al*., 2001; Saleh *et al*., 2015) as shown in Table 1 (Director-General of Geological Survey Malaysia, 1985). The soils of Johor state, are classified, based on their parent materials into three broad groups: Alluvial, Miscellaneous, and Sedentary soils (Saleh et al., 2015; Ministry of Agriculture peninsular Malaysia, 1973). The distribution format of the soil series and associations demonstrates a close link with those of different geological lithology within the state (Saleh *et al*., 2015). Table. 2 displays the main soil groups and their subdivision together with the composition of each soil type.

2.2 *In situ measurement of ^{222}Rn in soil gas*

RAD7 monitor was used for the measurement of ^{222}Rn activity concentration in soil gas. The equipment encloses a solid-state ion-implanted planar silicon detector with a built-in pump of 1 L/min flow rate. It has an internal sample cell of 0.7 L conducting hemisphere with 2000 - 2500 V potential relative to the detector at the centre of the hemisphere. A soil probe hammered to the depth of 0.8 m from the soil surface was coupled to the RAD7 alpha detector. The detector has a built-in pump that collects ^{222}Rn samples through the Probe linked with a laboratory drying unit (desiccant of $CaSO_4$) via an inlet filter to the detector sample volume. The measurement was conducted, in 5-minutes cycles for six recycle periods. The average of the last four cycles of ^{222}Rn activity concentration was considered (DURRIDGE Company Inc., 2015). The data obtained for the measurement of ^{222}Rn in the soil gas were later analysed in the CAPTURE software. In all the sampling points, geographical coordinates were recorded using a global positioning system (GPS).

2.3 *Statistical analysis*

Descriptive statistic was applied to obtain measures of central tendency and variability, for the measured data of ^{222}Rn activity concentration in soil gas. To confirm the variation in ^{222}Rn activity concentration among the soil types and geological formations within the study area, the Kruskal-Wallis test was conducted under the null hypothesis that the median values of ^{222}Rn activity concentration in soil gas across the geological formations and soil types are the same.

2.3 Spatial interpolation of the measured soil gas ^{222}Rn

The software ArcGIS was used to create the shapefile for the study area boundary, selecting the sampling points, from the soil and geological maps, and spatial interpolation of the measured parameter. According to Demšar and Skeppström. (2005); Salih et al. (2002); Skeppström & Olofsson. (2006), the inverse distance weighted (IDW) interpolation technique gives more accurate interpolated images than the Kriging method. Therefore in this work, the IDW interpolation technique was used to create a spatially interpolated surface for the measured ^{222}Rn activity concentration in soil gas.

3.0 Results and Discussion

A total of 111 sampling points were measured, which belong to the six main geological formations and seven soil types in Johor state. The measured data were categorised and evaluated based on the soil types and geological formations of the study.

3.1 Radon activity concentration in soil gas

The measured activity concentration of ^{222}Rn in soil gas varies from MDA to 127250 Bq m^{-3} with mean and median values of 7900 ± 400 and 740 Bq m^{-3}, respectively. The average value obtained in this study is found to be within the range obtained in northern Peninsular Malaysia by Almayahi *et al.* (2013), of 130 to 143060 Bq m^{-3}. The low median value of ^{222}Rn activity concentration in soil gas signifies that 50 % of the data obtained belongs to low activity concentration. The highest ^{222}Rn activity concentration was obtained from measurement in the soil derived from granitic igneous rock underlain by Triassic geological formation that composes shale, mudstone, siltstone, sandstone, and minor limestone lenses. Whereas Quaternary geological formation, which is mostly marine and continental deposits; such as clay, silt, sand, peat with minor gravel, and basalt of the early Pleistocene overlain by soil developed from peat records the lowest ^{222}Rn activity concentration in soil gas.

The recommended limit for ^{222}Rn in soil-gas is not found in the literature. However, some recent assessments of risks from radon have been suggested. For example, according to the Sweden criteria, soils presenting ^{222}Rn concentrations in soil gas between 10000 and 50000 Bq m^{-3} are classified as “normal risk” while, a ^{222}Rn concentration in soil gas above 50000 Bq m^{-3} is classified as “high risk” and requires buildings with safety criteria against radon. Also, soils with ^{222}Rn activity concentration below 10000 Bq m^{-3} are considered “low risk”, (Cinelli *et al.*, 2015; García-Talavera *et al.*, 2013; Lara *et al.*, 2015). Approximately 21% of the data obtained in this work indicated ^{222}Rn activity concentration that ranges from 10000 to 50000 Bq m^{-3} and is therefore considered as a normal risk. 2.7% of the data presented concentrations greater than 50000 Bq m^{-3}, which is an indication for the high risk” class.

3.1.1 Variation of ^{222}Rn activity concentration in soil gas with geological formations

Table 3 presents the statistical summary of ^{222}Rn activity concentration in soil gas for each geological formation with the overall mean and median values for this study. It can be deduced from the result presented in the table that all the geological formations have median values of ^{222}Rn activity concentration in soil gas higher than the overall median value except, the Quaternary geological formation, which has a median value of 110 Bq m^{-3}, which is a geological formation that developed from marine and continental deposits that contain clay, silt, sand, peat, with minor gravels (Director-General of Geological Survey Malaysia, 1985). It is also illustrated in the table that the geological formations of Intrusive rocks composed of undifferentiated igneous rocks of granitic origin record the highest median value of 3400 Bq m^{-3}. The higher ^{222}Rn activity concentration obtained from measurement in regions underlain with Intrusive rocks is in agreement with UNSCEAR (2000).

Table 1 Summary statistics for ^{222}Rn activity concentration in soil gas for each geological formation

Geology Formations	**Activity concentration of ^{222}Rn in soil gas (Bq m^{-3})**						
	Mean	**Std. Dev**	**Min**	**Max**	**Q_1**	**Median**	**Q_3**
Intrusive Rocks	7200 ± 400	9200	MDA	33520	70	3400	12380
Permian	8000 ± 400	16200	MDA	57080	40	1020	8780
Quaternary	2000 ± 200	4300	MDA	17760	10	110	910
Triassic	11700 ± 500	22000	MDA	127250	70	1050	21390
Johor State	7900 ± 400	16400	MDA	127250	40	740	8420

The data set for ^{222}Rn activity concentration in soil gas was also analysed using a non-parametric Kruskal-Wallis test among the geological formations, and the result shows a p-value of .028; therefore, the null hypothesis is rejected. Table 4 presents the result of the pairwise comparison test, The Table shows, the median value of ^{222}Rn activity concentration in soil gas, for Quaternary geological formation significantly different from that of Triassic and Intrusive rock formations with p=.01 and p=.02 respectively. However, it is not different from the median value of the activity concentration of ^{222}Rn in soil gas for Permian geological formation. Therefore, the Intrusive rocks, Triassic, and Quaternary geological formations can be used to describe the ^{222}Rn activity concentration in soil gas of Johor.

Table 2 Comparison of ^{222}Rn activity concentration in soil gas across the geological formations

Geological formations		**Test statistic**	**Std. Error**	**Sig**
Quaternary	Triassic	-21.045	7.446	.01
Quaternary	Intrusive rock	21.903	9.307	.02
Quaternary	Permian	14.751	10.509	.16
Permian	Triassic	-6.293	9.790	.52
Permian	Intrusive rock	7.152	11.271	.53
Triassic	Intrusive rock	.859	8.487	.92

3.1.2 Variation of ^{222}Rn activity concentration in soil gas with soil type

Table 5 presents the statistical summary of ^{222}Rn activity concentration in soil gas for each soil type, with the overall mean and median values. It can be observed from Table 5 that the soil of marine alluvium and soil from peat have median values of ^{222}Rn activity concentration of 110 and 100 Bq m^{-3}, respectively, less than the overall median value. In contrast, the soil of riverine alluvium, soils from metamorphic and sedimentary rocks, soils from granitic rock, and soils of steep lands have their median values of ^{222}Rn activity concentration as 770, 3540, 5670, and 12330 Bq m^{-3} respectively, above the overall median value. Among all the soil types studied, soils from the steep lands had the highest median value of ^{222}Rn activity concentration in soil gas. This soil developed from granitic igneous rocks is recognized with a high level of radon precursors (UNSCEAR, 2000). The result obtained also reveals that, the soil of urban and mined land has the lowest median value of ^{222}Rn activity concentration in soil gas. However, soil from peat had the lowest mean value of ^{222}Rn activity concentration, which was lower than the mean value from soils in the urban and mined land. This class of soils developed from the product of partially decomposed vegetation, and are associated with a low concentration of natural radionuclides (Malanca et al., 1996; Ramli et al., 2003; Saleh et al., 2013a).

Table 3 Summary statistics for ^{222}Rn activity concentration in soil gas for each soil type

Soil Types	**Activity concentration of ^{222}Rn in soil gas (Bq m^{-3})**						
	Mean	**Std. Dev.**	**Min**	**Max**	**Q_1**	**Median**	**Q_3**
Soils from granitic rocks	14800 ± 570	28760	MDA	127250	50	4440	17220
Soils from marine alluvium	3330 ± 220	6670	MDA	21900	20	110	1240
Soils from metamorphic & sedimentary rocks	13210 ± 560	18100	MDA	59630	140	3530	21850
Soils from Peat	590 ± 100	1060	MDA	3110	20	100	500
Riverine alluvium	4270 ± 290	6060	MDA	22900	80	810	6390
Soils of steep lands	13500 ± 750	5740	8410	19730	10390	12380	16050
Soils of urban and mined lands	4470 ± 290	10300	MDA	32980	20	70	1090
Johor State	7890 ± 380	16440	MDA	127250	50	740	8410

Kruskal-Wallis test on the data set of ^{222}Rn activity concentration in soil gas among the soil types shows a statistically significant result with p=.008. Therefore, the null hypothesis is rejected, and a pairwise comparison test, presented in Table 6, shows that soils from peats are significantly different from soils developed from sedimentary & metamorphic rocks, soils from granitic rocks, and soils of steep lands. However, it is not significantly different from the alluvial soils and soils of urban and mined lands.

3.2 Spatial interpolation of the measured parameter

Fig. 1 displays the spatial distribution of the measured activity concentration of ^{222}Rn in soil gas. The map illustrates a spatial distribution pattern of ^{222}Rn activity level in soil gas, of our study area with the highest concentration in the north-western part. The northernmost zone is generally, characterised with a higher ^{222}Rn activity concentration in soil gas, as illustrated by the Figure. This area is mostly underlain with geological formations of Triassic age that compose shale, mudstone, siltstone, sandstone, and minor limestone lenses. The Figure also demonstrates that the areas from the centre to the eastern part of our study boundary are generally characterized with low ^{222}Rn activity concentration with the lowest value of 4 Bq m^{-3} found in Mersing district of the north-eastern part of this study area. Activity concentrations of ^{222}Rn in soil gas, greater than 40000 Bq m^{-3} are also spotted at the south-western part of our study area, as illustrated in Fig.1.

Table 4 Comparison of median values of ^{222}Rn in soil gas across the soil types

Soil Types		Test Statistic	Std. error	Sig
Soil from peat	Soils of urban and mined lands	-4.179	12.770	0.743
	Marine alluvium	8.104	11.396	0.477
	Riverine alluvium	-20.923	11.111	0.060
	Soil from granitic rocks	25.958	10.980	0.018
	Soil from metamorphic and sedimentary rocks	31.229	10.430	0.003
	Soils of steep lands (granites)	-51.967	20.345	0.011
Soils of urban and mined lands	Marine alluvium	3.925	12.448	0.753
	Riverine alluvium	16.744	12.188	0.169
	Soil from granitic rocks	21.780	12.075	0.710
	Soil from metamorphic and sedimentary rocks	27.051	11.570	0.190
	Soils of steep lands (granites))	47.788	20.953	0.023
Marine alluvium	Riverine alluvium	-12.819	10.739	0.233
	Soil from granitic rocks	17.854	10.612	0.092
	Soil from metamorphic and sedimentary rocks	-23.126	10.034	0.021
	Soils of steep lands (granites)	-43.126	20.145	0.029
Riverine alluvium	Soil from granitic rocks	5.036	10.036	0.625
	Soil from metamorphic and sedimentary rocks	10.307	9.709	0.288
	Soils of steep lands (granites)	-31.044	19.985	0.120
Soil from granitic rocks	Soil from metamorphic and sedimentary rocks	-5.271	-9.568	0.582
	Soils of steep lands (granites)	-26.008	19.917	0.192
Soil from metamorphic and sedimentary rocks	Soils of steep lands (granites)	-20.737	19.615	0.290

4.0 Conclusion

This research was conducted to establish a baseline data of ^{222}Rn activity concentration in soil gas and categorize the measured data based on the soil type and geological formations of Johor, Malaysia. Therefore, the ^{222}Rn activity concentration in soil gas was measured, and a mean value of 7890 ± 380 Bq m^{-3} was obtained. The finding of this work shows that the soil type of Johor state has a better influence on the soil gas ^{222}Rn activity concentration than the underlying geology. The highest median value of ^{222}R in soil gas is found in the soil developed from undifferentiated granitic rocks, while the lowest median value of ^{222}Rn in soil gas is found in the soil developed from decayed organic matter. This study finds that the central region of Johor state is generally characterised with low soil gas ^{222}Rn activity concentration.

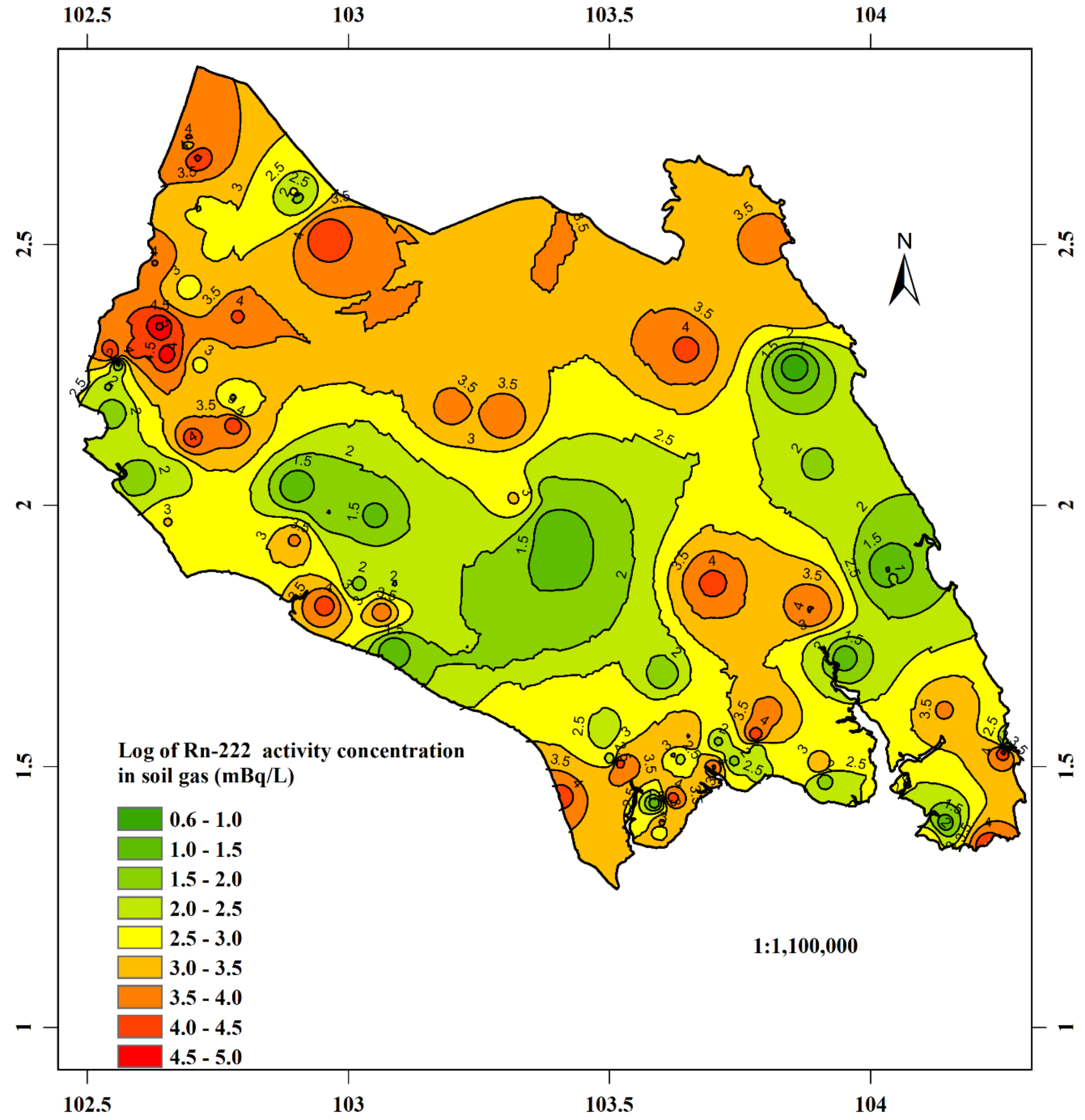

Fig. 1 Spatial distribution of ^{222}Rn activity concentration in soil gas of Johor state, Malaysia

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Conflict of Interest

Thr suthors declared no conflict of interest

Apendix 1: The geological formations of Johor, Malaysia (Director-General of Geological Survey Malaysia, 1985)

Geological formations	Age (10×10^6 yr)	Descri
Quaternary	2-3	Compo peat wi in the w while s
Tertiary	7-70	Compo in: lime and thi
Cretaceous-Jurassic	138-180	Found They c bands a
Triassic	199-251	These a wide b minor areas e northwe Bahru
Permian	280	The Pe shale, s an almo the east
Intrusive rocks	>500	Undiffe

Appendix 5: Soil types of Johor, Malaysia

Soil units	Soil groups	USDA soil classification	Characteristics
Alluvium soil	Riverine alluvium	Entisols/Histosols/Inceptisols	These soils developed over the riverbanks of the riverine alluvial plain. They consist of recent, older formations and developed over mixed riverine soils. They are characterized by poor water retention capacity due to their high content of sand and gravel. Occurs mostly in the interior parts of this study location
	Marine alluvium	Entisols	These soils developed over flat marine alluvial plains and more than 50% clay composition. A weak drainage capacity characterizes them; they are typically found along the west coast and in smaller amounts in the east coastal region.
Sedentary soil	Soil from granitic igneous rocks	Paleudult - Kandiudulta Paleudult - Hapludulta	These soils are located on undulating, rolling, and hilly terrain. They are brownish-yellow soil, which developed from granitic rocks. It is characterized by coarse angular quartz grits and sand all over the soil profile
	Soils from sedimentary and metamorphic rocks	Ultisols/Oxisols	These are soils developed from interbedded sandstones, siltstones, quartzite, iron-rich sandy shales, and conglomerate parent material· They occur on undulating and gently hilly terrain.
Miscellaneous soils	Peat	Histosols	It is sectioned into deep and shallow organic soil types that mostly developed from decayed vegetation materials. They typically occur in either swampy

			land or coastline and inland flood plains.
	Steep land	-	Undifferentiated soil types, commonly developed on granitic plutons, highlands and deep tropical forests
	Disturbed soils	Mining and urban land	-

Adopted from Sanusi *et al*. (Sanusi *et al*., 2017)