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RESEARCH ARTICLE

Vertical distribution of the radon concentration at Batu Pahat district, Johor, Malaysia

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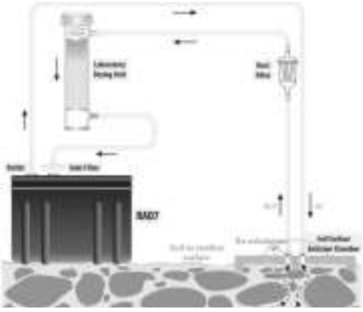
Graphical abstract



Abstract

This study investigated the vertical distribution of radon, ^{222}Rn concentrations in soil gas for different soil types and found the relation between the measured gamma dose rates and radon concentrations. The ^{222}Rn concentrations in soil gas were measured at depth of 20 cm, 60 cm, 80 cm and 100 cm using semiconductor detector (RAD7) coupled with soil gas probe. The overall activity concentrations of ^{222}Rn in soil were ranged from Minimum Detectable Activity (MDA) to 54000 ± 3000 Bq m^{-3} in Batu Pahat District. The results showed that the overall highest concentration of ^{222}Rn was recorded at 40 cm depth for most of the soil types, which could be the most reliable for taking the radon measurements than other depths. Soil type 32 (Dystric Nitosolse Orthic Ferrasols-Rengam Jerangau) has the highest radon concentration, which was 12,462 ± 5237 Bq m^{-3}. The gamma dose rates (GDR) above 1 m were measured using portable survey meters (Ludlum 19). A good relationship between radon concentrations in soil gas and the measured gamma dose rates was observed using Pearson Correlation. The results of ^{222}Rn concentration in soil gas obtained from this study were in agreement with results reported by other researchers.

***Keywords**: Radon, soil gas, RAD7, Gamma dose rate.*

INTRODUCTION

The main sources of ionizing radiation in the earth crust, to which humans are continuously exposed, are uranium, thorium and their progeny in the environment (Sharama *et al.*, 2011). Radon is a naturally occurring radioactive gas which can be found everywhere in our environment. It is chemically inert, cannot be seen nor its odour perceived in the environment. It has several isotopes, but the isotopes of interest for this study were ^{222}Rn (Radon) and ^{220}R (Thoron), due to their availability in the environment and negative health impacts on humans (Abumurad and Al-tamimi, 2005).

Radon is transferred from its origin by diffusion for longer distances and finally blown out into the atmosphere. The discharge of radon depends mainly on radium content and mineral grain size, as well as geophysical and geochemical parameters that rule its transport in the earth, in which its discharge is guided by hydro meteorological environments (Etiope and Martinelli, 2002).

Radon in the soil gas, which contributes the largest percentage of radon in indoor air, is considered to be a good predictor of radon potential in a given site (Nazaroff *et al.*, 1988). In addition, soil gas permeability, which is closely related to the migration of radon gas, has been revealed by previous studies for determining the room-entry rate of radon (Yasuoka *et al.*, 2010).

Soil is very essential to living things, especially humans. Therefore, soil type is important and must be controlled and protected. The largest natural source of radiation exposure to humans is radon gas that exists in air, water and soil. Since radon gas has always been in the environment, its contribution to human radiation exposure has increased in recent years (Audeem *et al*., 1993). Radon exposure can vary depending on the soil and rock structure beneath buildings. The radon concentration in soil gas was our main concern in the current study, thus the data obtained would be useful in understanding the behaviour of radon and its mobility in the environment and could be used for radiological protection purposes.

EXPERIMENTAL

The study area

The study area was Batu Pahat district and it lies southeast of Muar, southwest of Kluang, northwest of Pontian and south of Segamat and new Ledang district. Its population is approximately 417,458. These districts are increasing in line with current developments. However, it has 525 gazetted villages and village-clusters where smaller villages are annexed to their bigger immediate neighbors for the purpose of administration (Department of Statistics, Malaysia, 2015).

Type of soil in Batu Pahat district

The soil type in the study area could be classified into its soil code based on Table 1 (Department of Agriculture Peninsular Malaysia, 1973), which were Fluvisols, Gleysols, Dystric Gleysols, Nitosols, Ferrasols, Acrisols, Histosols and miscellaneous soils (Saleh *et al*., 2013; Department of Agriculture Peninsular Malaysia). Fluvisols includes two types of soil species, namely Thionic Fluvisols locally (known as Kranji) and Dystric Fluvisols that known as Telemong Akob. Ferrasols consists of Orthic Ferrasols, Rhodic Ferrasols, Plinthic Ferrasols and Xanthic Ferrasols. Acrisols group can be found in small areas across Batu Pahat District. The scientific names of this group are Ferric Acrisols and Orthic Acrisols. Histosols is a common soil type that covers the vast area in between Parit Raja and Ayer Hitam, Johor, which is in the middle part of Batu Pahat district. Locally known as peat soil, it is classified as Dystric Histosols. Miscellaneous soils such as steep land and urban land are also found in the area of Batu Pahat urban area (Saffuwan *et al*.,2012).

Table 1 Soil types within the study area.

	Soil type	
Label	**FAO UNIT**	**Local name**
1	Humic Podzols -Dytstric Fluvisols	Rudua- Rusila
2	Thionic Fluvisols	Keranji
3	Thionic Fluvisols	Linau- Sedu
5	Vertic Cambisols-Eutric Gleysols	Selangor-Kangkong
8	Dystric Gleysols- Humic Gleysols	Briah- Organic Clay and Muck
9	Humic Gleysols-Dystric Histosols	Organic Clay and Muck
10	Dystric Histosols	Peat
11	Dystric Fluvisols	Telemong Akob- local Alumina
18	Xanthic Ferrasols - Dystric Gleysols	Holyrood Lunas
21	Orthic Acrisols - Ferric Acrisols	Batu Anam -Durian
22	Orthic Acrisols - Plinthic Ferralsols	Batu Anam-Melaka - Tavy
25	Plinthic Ferralsols- Plinthic Ferralsols	Melaka- Tavy- Gajah Mati
31	Ferric Acrisols - Ferric Acrisols –Orthic Ferrasols	Serdang -Bungor - Munchong
32	Dystric Nitosols - Orthic	Rengam- Jerangau
36	Ferric Acrisols- Orthic Ferrasols	Prang
43	Rhodic Nitosols - Ferric Acrisols	Kulai-Yong Peng
49	Steep land	Tanah churam
50	Urban Land	Tanah bandar

Radon measurement for soil gas

The concentrations of radon in soil gas were measured at different depths profile for various soil types within the study area. The radon concentration was measured at each point at depth of 20 cm, 40 cm, 80 cm and 100 cm from the ground, using a semiconductor detector known as RAD7 (Durridge company Inc. 2015), RAD7 is an instrument that converts radiation from the decay to the electric signal.

During the measurement, the detector was first purged for at least 10 min, with relative humidity observed to be less than 6%. The detector was then connected with stainless steel probe (internal diameter of 0.25 inch) via a small desiccant tube containing $CaSO_4$ and inert filter that would suck soil gas from the depth. The soil gas samples were collected from the depth without exposing them to the outside air. The soil gas probe contained hollow tube with a hole near the tip that dipped inside the soil gently with stroke of hammer at ~~a~~ depth of 20 cm, 40 cm 60 cm, 80 cm and 100 cm from the ground. The surface soil around the probe was tamped to avoid leakage of fresh air into the soil gas at the depth. The soil was sucked through the tube pipe into the measuring instrument for 5 min pumping phase for 4 cycles to obtain accurate results, a process which took about 30 min. The detector is an instrument that converts alpha radiation from the decay of ^{222}Rn to electric signal. It is developed for measurements of radon in any kind of air; indoor air, outdoor air and soil. The detector amplifies, filters and sorts the signal according to its strength. It is insensitive to beta and gamma radiation, so there will be no interference from beta emitting gases or from gamma radiation fields. The location of each sampling point was recorded with a global positioning system (GPS). The instrument sensitivity for radon was 0.0130 cpm/(Bq m^{-3}) normal mode and 0.00624 cpm/(Bq m^{-3}) for sniff mode under the following conditions; mean temperature of 18.5 °C, flow rate of 0.853 L/min, equilibration period of 5 min and spill factor of 0.016). The overall calibration error was estimated to be within +/- 5%.

RESULTS AND DISCUSSION

The radon concentrations in different soil types at different depths

The mean activity concentrations of ^{222}Rn for each soil type at 20 cm depth were presented in Fig. 1. Soil type 32 (Dystric NitosolseOrthic Ferrasols -Rengam Jerangau), located at the area of Minyak Beku Mukim, has the highest mean activity concentrations of ^{222}Rn with a value of 1330 ± 219 Bq m^{-3}. The lowest mean activity concentrations of ^{222}Rn was found to be 6 ± 18 Bq m^{-3} at Kajang River Village, which covered by soil type 2 (Thionic Fluvisols -Kranji).

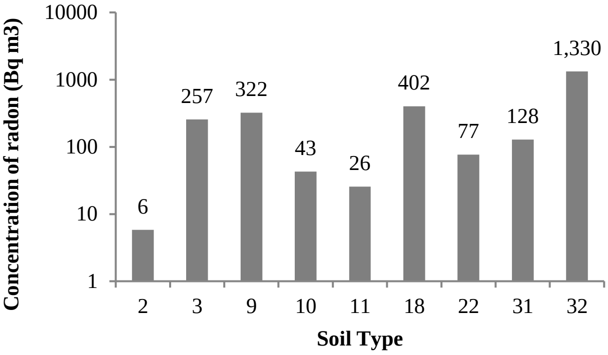


Fig 1. The mean activity concentrations of ^{222}Rn in different soil types at 20 cm depth.

Fig. 2 shows the results of the mean activity concentrations of ^{222}Rn at 40 cm depth for different soil types. Soil type 9 (Humic Gleysols-Dystric Histosols-Organic Clay and muck), which is dominant at Yong Peng Mukim, has the highest mean activity concentrations of ^{222}Rn, which was 54000 ± 3000 Bq m^{-3}. The lowest mean activity concentrations of ^{222}Rn was found at Kajang River Village, which has a soil type 2 (Thionic Fluvisols -Kranji).

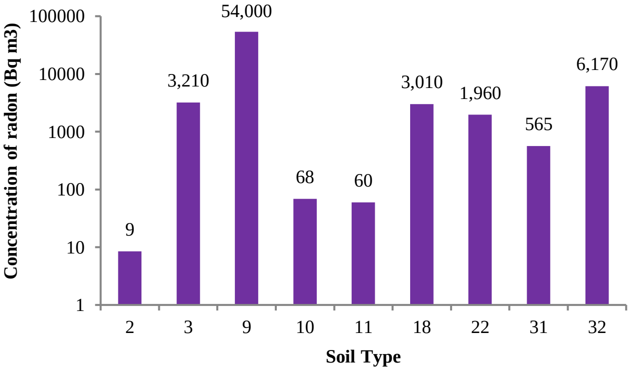


Fig 2. The mean activity concentrations of ^{222}Rn in different soil types at 40 cm depth.

The mean activity concentrations of ^{222}Rn for each soil type at 80 cm depth were presented in Fig. 3. Soil type 32 (Dystric NitosolseOrthic Ferrasols –Rengam Jerangau) has the highest mean activity concentrations of ^{222}Rn of 9610 ± 886 Bq m^{-3}, while soil type 11 (Dystric FluvisolseDystric Gleysol-Telemong Akobelocal alluvium) has the lowest mean activity concentrations of ^{222}Rn with a value of 9 ± 17 Bq m^{-3}, found at the area of Bagan Mukim.

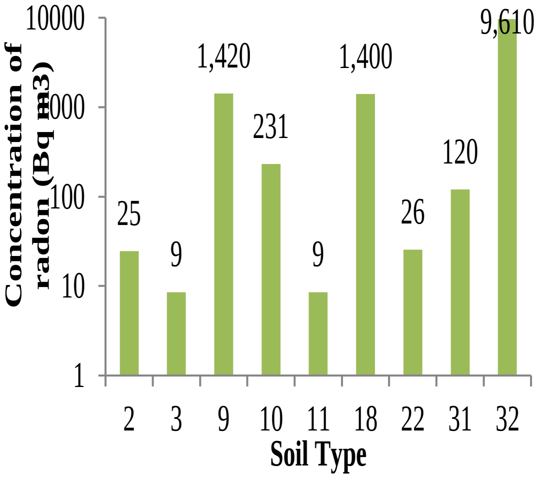


Fig 3. The mean activity concentrations of ^{222}Rn in different soil types at 80 cm depth.

Fig. 4 shows the results of the mean activity concentrations of ^{222}Rn for 100 cm depth at different soil types. Soil type 32 (Dystric NitosolseOrthic Ferrasols -Rengam Jerangau) has the highest mean activity concentrations of ^{222}Rn of 32400 ± 2060 Bq m^{-3}, while the lowest the mean activity concentrations of ^{222}Rn was found to be 9 ± 17 Bq m^{-3} at Hj Mohd Noor Trench and the area was covered by soil type 18 (Xanthic Ferrasolse Dystric Gleysols -Holyrood Lunas).

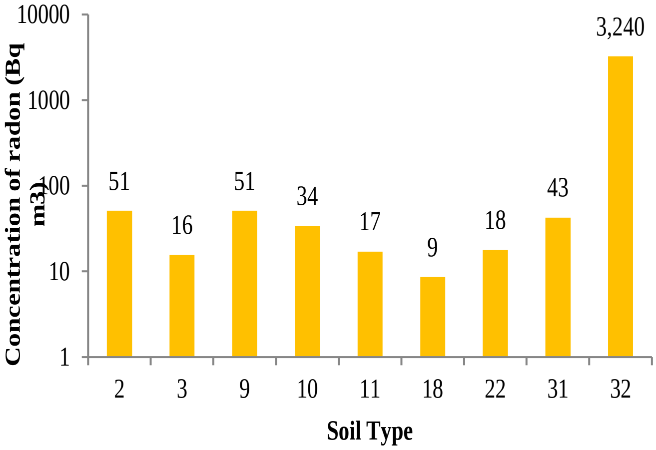


Fig 4. The mean activity concentrations of ^{222}Rn in different soil types at 100 cm depth.

Fig. 5 shows the vertical distribution of the mean activity concentrations of ^{222}Rn in different soil types. For Soil type 2 (Thionic Fluvisols) and Soil type 32 (Dystric NitosolseOrthic Ferrasols-Rengam Jerangau), the mean activity concentrations of ^{222}Rn were increased with depth, with the highest activity concentrations of ^{222}Rn was recorded at 100 cm depth while the lowest activity concentration of ^{222}Rn was recorded at 20 cm depth.

Soil type 2 (Thionic Fluvisols), soil type 9 (Humic Gleysols-Dystric Histosols), Soil type 11 (Dystric Fluvisolse Dystric Gleysol), Soil type 18 (Xanthic Ferrasolse Dystric Gleysols), Soil type 22 (Orthic Acrisolse- Plinthic Ferralsols) and soil type 31 (Ferric Acrisolse Ferric AcrisoIse Orthic Ferrasols) recorded the highest mean activity concentrations of ^{222}Rn at 40 cm depth.

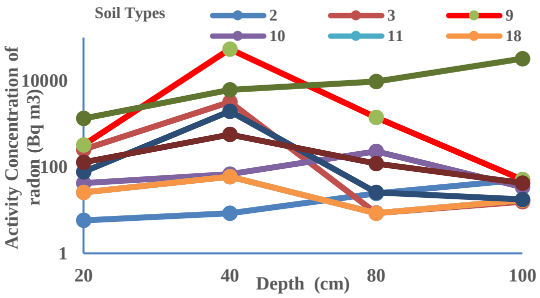


Fig 5. Overall vertical distribution of the mean activity concentrations of ^{222}Rn in different soil types

Table 2 shows the overall mean activity concentrations of ^{222}Rn at different depths. The overall highest mean activity concentrations of ^{222}Rn at 40 cm depth was 4291±464 Bq m^{3}. The overall lowest mean activity concentrations of ^{222}Rn was found at the depthof 20 cm with value of 180±77 Bq m^{3}.

Table 2. Overall mean activity concentrations of ^{222}Rn in different soil types.

Depth (cm)	Mean activity concentrations of ^{222}Rn for the soil types (Bq m^{3})				
	Thionic Fluvisols	Thionic Fluvisols	Humic Gleysols - Dystric Histosols	Dystric Histosols	Dystric Fluvisolse Dystric Gleysol
20	6±10	257±81	322±87	43±43	26±33
40	9±17	3210±134	54000±3000	68±74	60±43
80	25±48	9±17	1420±242	231±99	9±17
100	51±65	16±31	51±65	34±40	17±34
Depth (cm)	Mean activity concentrations of ^{222}Rn for the soil types (Bq m^{3})				
	Xanthic Ferrasolse Dystric Gleysols	Orthic Acrisolse - Plinthic Ferralsols	Ferric Acrisolse Ferric Acrisolse Orthic Ferrasols	Dystric Nitosolse Orthic Ferrasols	Overall Mean
20	402±129	77±17	128±71	1330±219	180±77
40	3010±277	1960±243	565±106	6170±286	4291±464
80	1400±212	26±51	120±59	9610±886	800±181
100	9±17	18±24	43±33	32400±2060	1938±263

In-situ gamma dose rate measurement

The mean gamma dose rate was plotted to study the variation for gamma dose rate based on soil type, as presented in Fig. 5. Soil type 32 (Dystric NitosolseOrthic Ferrasols -Rengam Jerangau) has the highest gamma dose rate, which was 190 nGy h^{-1}, while soil type 18 (Xanthic Ferrasolse Dystric Gleysols -Holyrood Lunas) has the lowest gamma dose rate with a value 60 nGy h^{-1}.

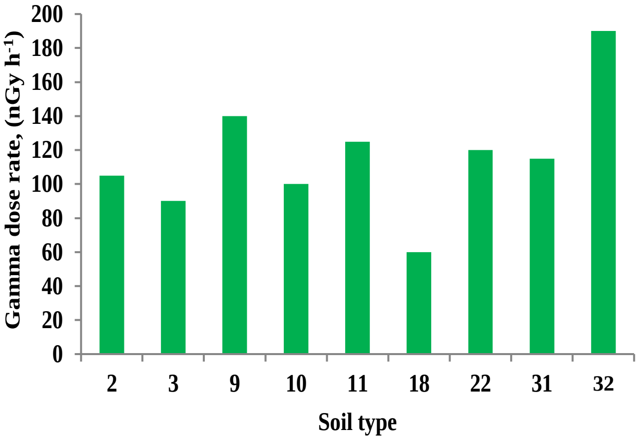


Fig 6. The mean gamma dose rate reading with different soil types.

The relationship between gamma dose rate and activity concentrations of ^{222}Rn

The gamma dose rate was related to the radon activity concentrations in different types of soil. Soil type 32 (Dystric Nitosols Orthic Ferrasols-Rengam Jerangau) has the highest gamma dose rate of 190 nGy h^{-1}. Soil type 18 (Xanthic Ferrasolse Dystric Gleysols-Holyrood Lunas) has the lowest gamma dose rate, with a value of 60 nGy h^{-1}. Figure 7 shows the relation between gamma dose rate and activity concentrations of radon. It showed a good relationship between radon concentrations and gamma dose rates with correlation coefficient of R = 0.75.

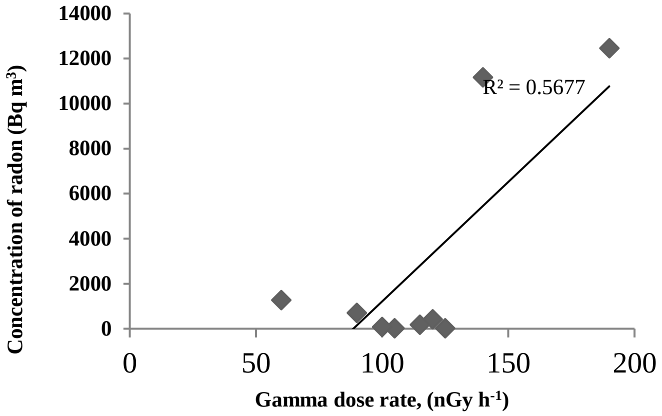


Fig 7. The relationship between the radon concentration and the gamma dose rate.

CONCLUSION

The vertical distribution of ^{222}Rn concentrations in soil gas was investigated for various soil types. The overall highest mean activity concentrations of ^{222}Rn was found at 40 cm depth with value of 4291±464 Bq m^3. The overall lowest mean activity concentrations of ^{222}Rn was found at depth of 20 cm with value of 180 ± 77 Bq m^3. Most of the soil types recorded the highest activity concentration of ^{222}Rn at vertical profile depth of 40 cm. The mean activity concentrations of ^{222}Rn in the study area was found to be 3166 ± 246 Bq m^{-3}, which was in good agreement with other researchers (Ali *et al.*, 2010; Ali *et al*., 2011; Singh *et al*., 2010; King and Minissale, 1994; Bajwa *et al*., 2010; Abumurad and Al-Tamimi, 2005; Yasuoka *et al*., 2010; Sharman, 1993; Duggal *et al*., 2014). The relationship between radon concentration in soil gas and the measured gamma dose rate was determined, which revealed that there was a relationship.

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