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ASSESSMENT OF GROUNDWATER RADON CONCENTRATIONS IN KELANTAN, MALAYSIA

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ABSTRACT

This study aimed to assess radon concentration in groundwater and the associated dose receives by people in Kelantan, Malaysia. The measurements were carried out by means of continuous radon/thoron monitor model RTM1688-2 involving 8 dug wells and 21 boreholes in 6 districts. Generally, groundwater samples contained low radon concentrations. The range of measured radon concentrations was 0.05 – 22.63 Bq/L with the mean value of 5.1 Bq/L. This mean value was 50% lower than UNSCEAR (2000) average of 10 Bq/L and far less than WHO (2011) reference level of 100 Bq/L. Radon concentrations vary with location, well depth and season. The calculated annual effective dose was 9 µSv. Radon in groundwater poses no significant radiological hazard to the people in the state.

Keywords: Borehole, dug well, groundwater, health hazard, radon

INTRODUCTION

Radon originates in the ground, underlying rocks and groundwater, where its radioactive parents are found. Certain type of rock such as granite contains elevated radium. As ^{226}Ra decays, its gaseous daughter product ^{222}Rn is emanated and diffused into pore volume between soil and/or rock grains. Radon may remain in the material or find its way and be released to ambient air or migrated into groundwater. Groundwater that is in contact with radium-containing rock and soil will be a receptor of radon emanating from the surroundings. Radon may also be taken up by water as it passes over rocks and through the soil. The amount of radon dissolved in groundwater depends on a few factors such as aquifer characteristics, the water residence time in the aquifer, radium content in rock, etc. In groundwater, radon may be transported over some distances by diffusion and also by the mechanical flow of the water. Due to its relatively low solubility in water, radon is prone to degassing from water in contact with air. But due to its short half-life (3.8 days), much of radon will decay before reaching the water surface.

Radon and its short-lived decay products have been known as a potential health hazard as they can cause a significant radiation dose to human. They contribute about 50% of the total natural radiation dose to human (UNSCEAR, 2000). The accumulation of ^{222}Rn indoors and its associated potential health hazard has been given much attention by researchers around the world (Gosink et al., 1990). Besides the main contribution from the soil/ground, significant contribution to the radon concentrations in houses can come from groundwater sources. Dissolved radon may be released from the water and contributes to the radon indoors during household activities such as cleaning, cooking, showering, washing and flushing toilets. Thus, radon from water also contributes to the total inhalation risk associated with radon in indoor air. About 1-7% of lung cancer deaths in the United States were due to indoor radon derived from groundwater (Bajwa et al., 2005).

In addition to the exposure through inhalation, the contribution of radiation dose through ingestion of radon in drinking water has also been assessed by some researchers. The associated health risk due to ingestion of dissolved radon in water is stomach cancer. In consideration of potential hazards attributed to long-term consumption of water rich in radon, the interest in the study of radon in water has increased worldwide such as in Brazil (Bonotto, 2014), Cyprus (Sarrou and Pashalidis, 2003), India (Bajwa et al., 2005; Choubey et al., 2000, Choubey et al., 2010; Prasad et al., 2008). Iran (Pourhabib et al., 2011), Iraq (Al-Hamadwi et al., 2012; Al-Mashhadany et al., 2013), Italy (Kozlowska et al., 2009), Malaysia (Ahmad et al., 2015; Saat et al., 2012), Pakistan (Khan et al., 2010; Nasir and Shah, 2012), Saudi Arabia (Alabdula'aly, 1999), Spain (Moreno et al., 2014), Sweden (Erlandsson et al., 2001), Taiwan (Han et al., 2006) and USA (Gosink, et al., 1990; Sloto and Senior, 1998).

In some countries the rate of groundwater usage is quite high e.g., in the US, more than 50% of the population obtains their water from groundwater (Gosink, 1990). In certain areas, groundwater contains significantly high radon concentration and its usage as drinking water may increase the ingestion dose. WHO (2011) recommends to measure radon levels of domestic drinking water supplies originating from groundwater sources. If the reference levels are exceeded, remediation should be considered. In Malaysia, the usage of groundwater as a source of water is still very low. The main reason for the lack of groundwater use in the country is the easy availability of surface water resources. Groundwater contributes only about 3% of total water used (Fahnline, 2013; Huang et al., 2015) and the remainder is contributed by streams and rivers. However, one of the states in Malaysia i.e., Kelantan uses more than 50% of groundwater for its public water supplies. The groundwater was the main choice due to its abundance, easily accessible, more convenient and cheaper treatment required compared to surface water resources. A study has been carried out to assess radon concentration in groundwater and the expected associated dose received by the people in the state. This paper reports the results of the assessment.

MATERIALS AND METHODS

Study Area

The study has been conducted in the north of Kelantan state. Figure 1 shows the location of the study area. There were two types of wells available i.e., dug well and drilled well. Dug wells are wells that have been dug by hand or with a big machine like an excavator or backhoe. The wells are dug until it reaches level lower than the water table and when the incoming water surpasses the bailing rate of the digger. Dug wells are shallow because they only obtain water from shallow aquifers. This type of wells is normally found and used in villages and rural areas. Drilled wells or boreholes are built with machines for rotary or percussion drilling. There are drilled wells that can go far deeper (few hundred meters) penetrating unconsolidated materials.

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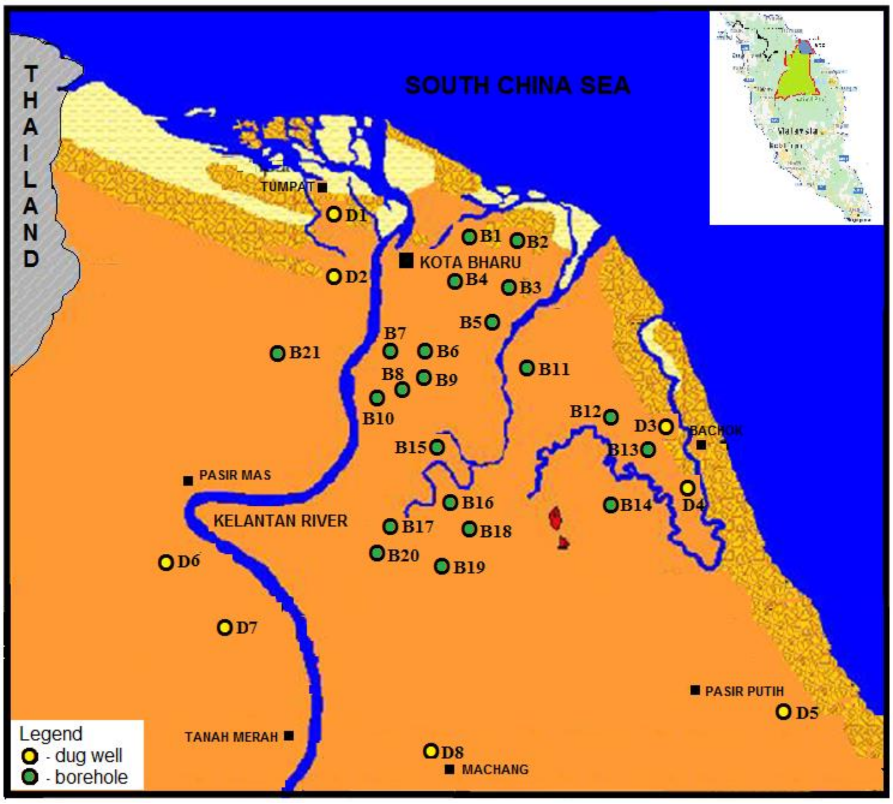

Figure 1: Location of the study area in Kelantan

There were 8 dug wells and 21 boreholes involved in the study. The dug wells (private owner) were located in the districts of Kota Bharu, Pasir Mas, Pasir Putih, Tumpat, Tanah Merah and Machang. The depths of dug wells were not available but they were assumed to be in the range of 5 – 10 m. The boreholes were located in the districts of Kota Bharu, Bachok, Tumpat, and Pasir Mas. The wells were owned by the State Waterworks' Department and used for water quality monitoring and resources management. The depths of boreholes were between 10 – 150 m.

Sampling and Measurements

All boreholes water samples were taken with a submersible pump while dug wells water samples were taken using a pail or a hand pump. Measurement of radon in water was made using continuous radon/thoron monitor model RTM1688-2 (Sarad, Germany). The monitor was equipped with alpha spectroscopy system which can discriminate alpha energy peaks emitted by radon progenies. The measurements were performed onsite for both dry and wet/rainy seasons.

Water samples were collected and put in 1 L plastic bottle. About 400 ml water sample was then transferred into a bubbling flask. Care was taken to prevent aeration of the samples during the process in order to avoid loss of radon. The bubbling flask then connected to the radon monitor to create a closed air loop. The air volume of the system circulates through the loop drawn by the internal pump of the monitor. The dissolved radon gas in a water sample will be de-gassed and the small bubbles created by the pump will transfer radon gas into the detector chamber. Radon gas decayed to progenies by emitting alpha particles which will subsequently be counted by the semiconductor detector. After at least 30 min pumping the equilibrium state between radon in air and water is achieved. Radon gas concentration (in Bq/m^3) in the air loop was then analyzed using

Radon Vision 4.0 software. Radon in water concentration (in Bq/L) was calculated using Radon in Water Calculator software.

RESULTS AND DISCUSSION

Radon in Groundwater Concentration

Radon concentrations in groundwater showed a slight variation depending on its source, location and season. Its distribution patterns are shown in Figure 2. Generally, all dug wells and boreholes contained low radon concentrations. About 50% of the measured groundwater samples contained radon concentration of less than 5 Bq/L. Radon concentrations in groundwater roughly followed a log-normal distribution similar to what was observed for radon in indoor air in Malaysia (Sulaiman, 2017). No anomaly of radon concentrations in groundwater was observed during the study.

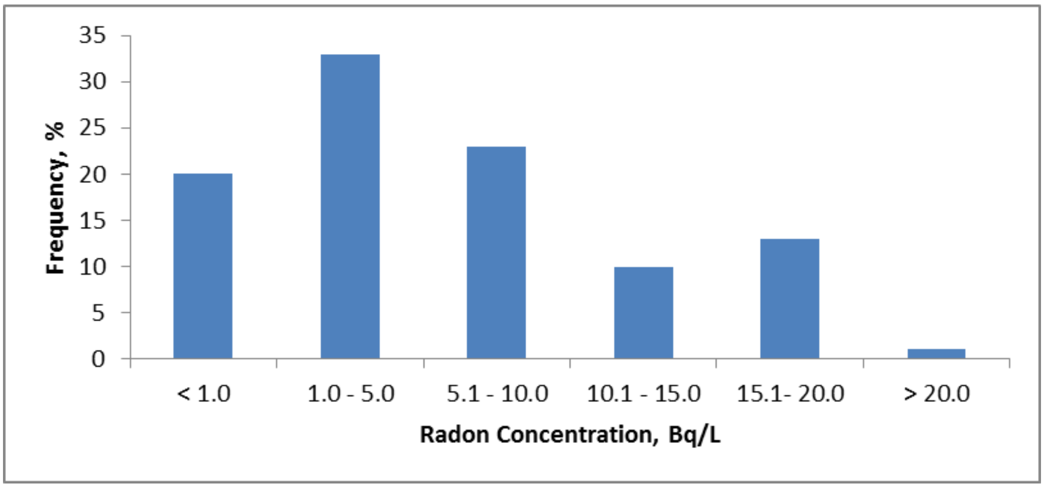

Figure 2: Distribution of radon concentrations in groundwater in Kelantan

The range of measured radon concentrations in groundwater samples was 0.05 – 22.63 Bq/L with both maximum and minimum values were found in Kota Bharu district. The mean radon concentrations were 5.1 Bq/L which is 50% lower than the average UNSCEAR (2000) reported value of 10 Bq/L and far less than WHO (2011) reference level of 100 Bq/L. The results were also compared with other studies (Table 1). Radon concentrations in groundwater found in this study were comparable with values reported in Malaysia by Ahmad et al. (2015) but higher than reported by Saat et al. (2012). The results were comparable with values reported in Iran, Iraq, Cyprus and Egypt but lower than Spain, USA, Italy, Brazil, China and Pakistan.

Table 1: Radon concentration in groundwater in various countries

Country (Region)	Radon Concentration (Bq/L)	References
Iran	5.32	Pourhabib et al. (2011)
Spain	11.4	Moreno et al. (2014)
USA	40	Gosink et al. (1990)
Iraq (Kufa)	0.27- 5.66	Al-Hamadwi et al. (2012)
Italy	12.7	Kozłowska et al. (2009)
Brazil	15.4 (0.02-112.5)	Bonotto (2014)
China	229.4 (0.71-3735)	Zhuo et al. (2001)
Cyprus	1.4 (0.1- 5.0)	Sarrou and Pashalidis (2003)
Pakistan (Balakot)	20.43 (17.31-24.52)	Khan et al. (2010)
Egypt (Western desert)	0.49 (0.22 - 2.36)	Hussein (2014)
Malaysia (Pahang)	0.09 – 0.48	Saat et al. (2012)
Malaysia (Kedah)	14.7 (12.4 - 17.0)	Ahmad et al. (2015)
Malaysia (Kelantan)	5.1 (0.05 – 22.63)	This study

Variation of Radon Concentrations with Location

Radon concentrations in groundwater generally vary between areas with the geological formation of an aquifer (e.g. rock types) plays an important role. Rocks bearing ^{226}Ra within an aquifer will directly inject or release radon into groundwater; therefore, high radon concentrations were found in granitic rocks aquifers (Asikainen and Kahlos, 1980; Brutsaert et al., 1981). As the study areas in Kelantan are mostly composed of sedimentary rock aquifers (UM, 2018), low groundwater radon concentrations were expected.

Radon concentration in groundwater was also found to vary between wells (located in the same area) which were separated by a distance of a few meters away. This situation was observed between wells B1 and B2 and also between wells B6 and B7 (Figure 3). The variations were due to differences in released and flowed of radon emanated from soil/rock which in contact with water. Sloto (2000) noted that radon concentrations in groundwater can also vary within the same geologic formation due to differences in radium content and rock fractures.

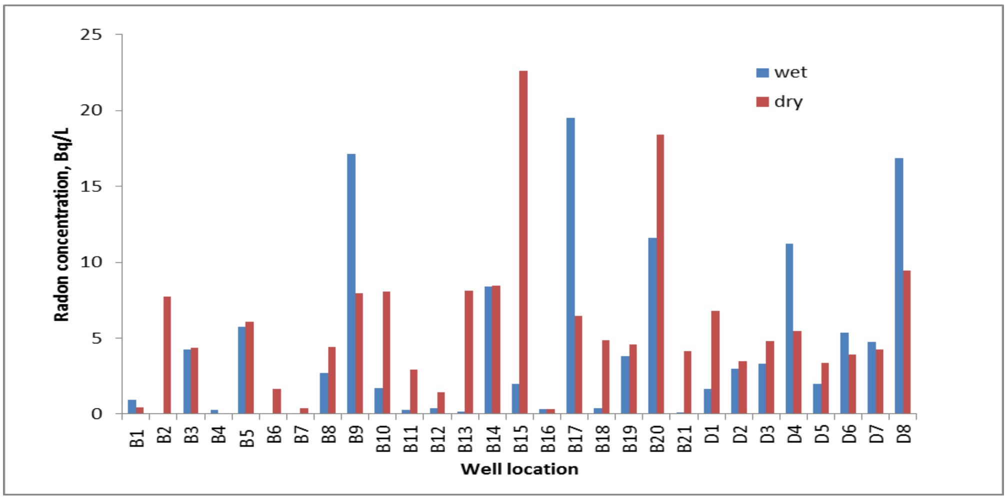

Figure 3: Variation of radon concentrations in groundwater with location and season

Variation of Radon Concentrations with Well Depth

Radon concentrations in groundwater also vary with well depth (Figure 4) but there was no clear correlation observed. A few wells with the same depth contained different radon concentrations. These were observed on wells B8, B11 and B21 (same depth of 12m) and B5, B9 and B10 (same depth of 15m). The slightly higher concentrations (> 10 Bq/L) were measured at depths of 15 m, 18 m, 45 m, and 59 m. Guiseppe (2006) showed that variations of radon concentrations exist throughout the depth of a well but it's not constant and depends on the fracture site/location. Moreno et al. (2014) found that higher radon concentrations were obtained in wells located in the volcanic zone close to important faults of the fractured rock.

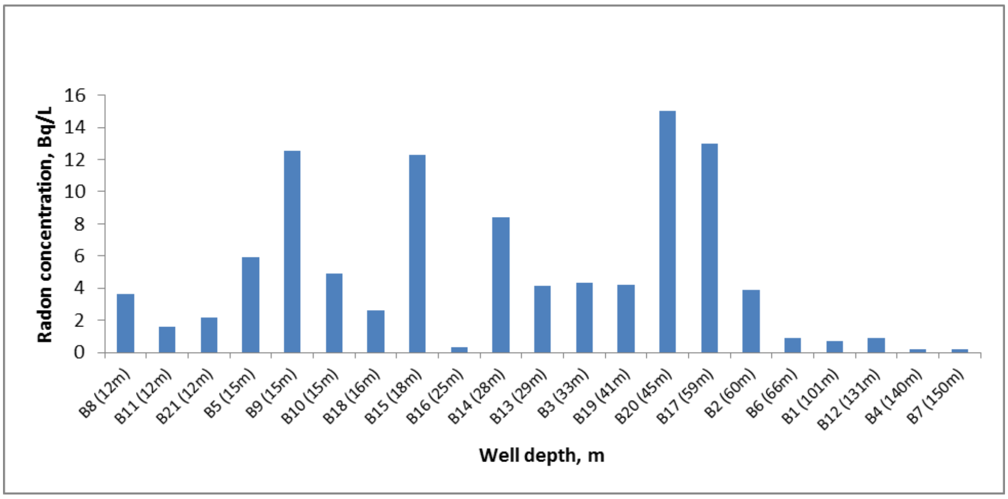

Figure 4: Variation of radon concentrations with well depth

Variation of Radon Concentrations with Seasons

Variations in radon concentration have generally been observed in connection with seasons. Radon concentrations in groundwater of the same well vary between wet and dry seasons (Figure 3). Generally, radon concentrations were slightly high in the dry season and low in the wet season. The low radon concentrations would be expected in the wet season due to the effects of dilution in a large volume of water as a result of recharge from nearby river or infiltration from rain water. However, wells B9, B17, D4, and D8 showed the opposite results (i.e. high radon concentrations in the wet season and low in the dry season). This was probably due to infiltration of rain water containing high dissolved radon as a result of the dissolution of soil gas during movement through the unsaturated zone.

Sloto and Senior (1998) noted that radon concentration in groundwater can change with time due to recharge and discharge. The variations of radon concentrations can also due to water table fluctuations and flow patterns. A higher radon concentration was found when the water table is closest to the ground surface (De Francesco et al., 2010). This was due to more interaction of water with the near-surface zone (where radon emanation was higher), leading to a higher groundwater radon concentration. Gonzalez-Diez et al., (2009) have also observed the variations in radon concentration in connection with water table elevations. Radon concentrations are lower in boreholes close to the rivers (i.e., B7, B10, and B12) in both wet and dry seasons probably due to river water infiltration into nearby aquifers and affect the radon concentrations in groundwater as surface water normally contain low radon concentrations.

Effective Dose

The annual effective dose for ingestion of radon in drinking water was calculated using equation (1)

$$E_d = R_c \times W_i \times D_f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

Where, E_d represents annual effective dose for ingestion, R_c is radon concentration in water, W_i is the intake of water, and D_f represents dose conversion factor for radon.

By using the mean radon in water concentration at source of 5.1 Bq/L, the average water consumption of 500 L/y and the dose conversion factor of 3.5 x 10^{-9} Sv/Bq (for adult) (UNSCEAR 2000), the calculated effective dose from drinking water containing radon was 9 µSv/y. The dose from radon in groundwater was very low and will not have a harmful effect on the human.

CONCLUSION

The radon concentration in groundwater in Kelantan showed slight variation attributable to differences in the geological formation of the area, depth of the water source and also climate/seasons. The mean radon concentration in groundwater was 5.1 Bq/L which is 50% lower than the average value reported by UNSCEAR and far less than WHO reference level. People in the area were expected to receive an effective dose of 9 µSv/y from radon in the drinking groundwater. This dose level was very low, thus, radon in groundwater poses no significant radiological hazard.

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REFERENCES

Ahmad, N., Jaafar, M.S. and Alsaffar, M.S. (2015). Study of radon concentration and toxic elements in drinking and irrigated water and its implications in Sungai Petani, Kedah, Malaysia, *J. Radiat. Res. Appl. Sci*. 8: 294-299.

Alabdula'aly, A. (1999). Occurrence of radon in the central region groundwater of Saudi Arabia, *J. Environ. Radioact.* 44(1): 85-95.

Al-Hamadwi, A.A., Al-Bayati, A.A. and Al-Mashhadani, A.H. (2012). Radon and thoron concentration measurement of groundwater in Kufa city by using RAD7 detector, *J. Kufa – Physics* 4(2): 44-49.

Al-Mashhadany, A.H., Kadhem, A.A. and Lefta, S.H. (2013). Radon and thoron concentration of shut al- Hella's water in Babylon Governorate, *Internat. J. Current Engin. Tech.* 3(3): 872-876.

Asikainen, M. and Kahlos, H. (1980). Natural radioactivity of drinking water in Finland, *Health Physics* 39(1): 77-38.

Bajwa, B.S., Mahajan, S., Singh, H., Singh, J., Singh S. and Walia, V. (2005). A study of groundwater radon concentrations in Punjab and Himachal Pradesh States, India, *Indoor Built Environ.* 14(6): 481-486.

Bonotto, D.M. (2014). ^{222}Rn, ^{220}Rn and other dissolved gases in mineral waters of southeast Brazil, *J. Environ. Radioact.* 132: 21-30.

Brutsaert, W.F., Norton S.A., Hess C.T. and Williams J.S. (1981). Geologic and hydrologic factors controlling radon-222 in ground water in Maine, *Ground Water* 19(4): 407-417.

Choubey, V.M., Bartarya, S.K. and Ramola, R.C. (2000). Radon in Himalayan springs: a geohydrological control, *Environ. Geol*. 39: 523-530.

Choubey, V.M., Ahmad, I., Kamra, l. and Ramola, R.C. (2010). Radon variations in soil and groundwater of Bhilagana Valley, Garwhal Himalaya, India. *Jpn. J. Health Phys*. 45 (3): 278- 283.
De Francesco, S., Pascale Tommasone, F., Cuoco, E., Verrengia, G. and Tedesco, D. (2010). Radon hazard in shallow groundwaters: amplification and long term variability induced by rainfall, *Sci. Total Environ.* 408: 779-789.

Erlandsson, B., Jakobsson, B. and Jönsson, G. (2001). Studies of the radon concentration in drinking water from the horst Söderåsen in southern Sweden, *J. Environ. Radioact*. 53: 145-154.

Fahnline, E. (2013). The protection and remediation of Malaysia's Groundwater Resources. http://ensearch.org/wp-content/uploads/2013/10/paper-14-the-protection-and-remediation-of-malaysias-groundwater-resources.pdf (Accessed on 1 December 2018).

González-Díez, A., Soto, J., Gómez-Arozamena, J., Bonachea, J., Martínez-Díaz, J.J., Cuesta, J.A., Olague, I., Remondo, J., Fernández Maroto, G. and Díaz de Terán, J.R. (2009). Identification of latent faults using a radon test, *Geomorphology* 110: 11-19.

Gosink, T.A., Baskaran, M and Holleman, D.F. (1990). Radon in the human body from drinking water, *Health Physics* 59(6): 9l9-924.

Guiseppe, V.E. (2006). Radon in groundwater: A study of the measurement and release of waterborne radon and modeling of radon variation in bedrock wells. *Electronic Theses and Dissertations*. http://digitalcommons.library.umaine.edu/etd/315 (Accessed on 1 September 2018)

Han, Y.L., Tom Kuo, M.C., Fan, K.C., Chiang, C.J. and Lee, Y.P. (2006). Radon distribution in groundwater of Taiwan, *Hydrogeol. J.* 14:173-179.

Huang, Y.F., Ang, S.Y., Lee, K.M., and Lee, T.S. (2015). Quality of water resources in Malaysia. http://dx.doi.org/10.5772/5896. (Accessed on 15 December 2018).

Hussein, A.S. (2014). Radon measurements in water samples from western desert of Egypt using nuclear track detectors and estimation of corresponding doses, *Radiat. Prot. Environ*. 37: 165-168.

Khan, F., Ali, N., Khan, E., Khattak, N. and Khan, K. (2010). Radon monitoring in water sources of Balakot and Mansehra cities lying on a geological fault line, *Radiat. Prot. Dos.* 138(2): 174-179.

Kozłowska, B., Morelli, D., Walencik, A., Dorda, J., Altamore, I., Chieffalo, V. and Zipper, W. (2009). Radioactivity in waters of Mt. Etna (Italy), *Radiat. Meas.* 44(4): 384-389.

Moreno, V., Bach, J., Baixeras, C. and Font, L. (2014). Radon levels in groundwater and natural radioactivity in soils of the volcanic region of La Garrotxa, Spain, *J. Environ. Radioact.* 128: 1-8.

Nasir, T. and Shah, M. (2012). Measurement of annual effective doses of radon from drinking water and dwellings by CR-39 Track Detectors in Kulachi City of Pakistan, *J. Basic & Appl. Sci.* 8: 528-536.

Pourhabib, Z., Binesh, A. and Mohammadi, S. (2011). Determination of radon and radium in springs, wells, rivers and drinking water samples of Ramsar in Iran, *Intern. Archive Appl. Sci. Tech.* 2(1): 32-36.

Prasad, G., Prasad, Y., Gusain, G.S. and Ramola, R.C. (2008). Measurement of radon and thoron levels in soil, water and indoor atmosphere of Budhakedar in Garhwal Himalaya, India. *Radiat. Meas.* 43: 375-379.

Saat, A., Zainal, N.S., and Hamzah, Z. (2012). Assessment of supported radon in ground water from highland area using portable continuous radon monitor, *J. Nucl. Relat. Tech*. 9(2): 22-33.

Sarrou, I., and Pashalidis, I. (2003). Radon levels in Cyprus, *J. Environ. Radioact.* 68(3): 269-277.

Sloto, R.A. (2000). Naturally occurring radionuclides in the ground water of southeastern Pennsylvania :USGS Fact Sheet 012-00. https://doi.org/10.3133/fs01200 (Accessed on 1 September 2018).

Sloto, R.A. and Senior, L.A. (1998). Radon in the ground water of Chester County, Pennsylvania: USGS Fact Sheet 120-98., https://doi.org/10.3133/fs12098. (Accessed on 1 September 2018).

Sulaiman, I., Kontol, M.K., Razalim, F.A.A. and Jaafar, A. (2017). Indoor radon concentration in Kinta Valley, *Jurnal Sains Nuclear Malaysia* 29(1): 37-44.

UM (2018). University of Malaya. http://studentsrepo.um.edu.my/3865/3/Chapter_2_Geology_And_Hydrology.pdf. (Accessed on 15 October 2018).

UNSCEAR (2000). Sources, effects and risks of ionizing radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, United Nation, New York.

WHO (2011). Guidelines for drinking-water quality, fourth edition. World Health Organization, Geneva

Zhuo, W., Iida, T. and Yang, X. (2001). Occurrence of ^{222}Rn, ^{226}Ra, ^{228}Ra and ^{238}U in groundwater in Fujian Province, China, *J. Environ. Radioact.* 53(1): 111-120.