The influence of geology on terrestrial gamma radiation dose rate in Pahang state, Malaysia

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Terrestrial gamma radiation dose (TGRD) rate measurements have been made in Pahang state, Malaysia. Significant variations were found between TGRD measurements and the underlying geological formations. In some cases revealing significant elevations of TGRD. The acid-intrusive geological formation has the highest mean TGRD measurement of 367 nGy h^{-1}. This is more than six times the world average value of 59 nGy/h^{-1}, while the quaternary geological formation has the lowest mean gamma radiation dose rate of 99 nGy h^{-1}. The annual effective dose equivalent outdoor to the population was 0.216 mSv. The lifetime equivalent dose and relative lifetime cancer risks for an individual living in Pahang state were 81 mSv and 4.7 × 10^{-3} respectively. These values are more than two times the world average of 34 mSv and 1.95 × 10^{-3} respectively.

Keywords: Annual effective dose, cancer risk, geological formations, terrestrial gamma radiation dose.

NATURAL environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions of the area[1]. The presence of naturally occurring radionuclides in the environment may result in an external and internal dose received by a population exposed to them directly and via ingestion or inhalation pathways.

The assessment of radiological impact on a population as a result of radiation emitted by natural radionuclides is important, since it contributes to the collective dose on the population[2]. Exposure to ionizing radiation from natural sources is a continuous and unavoidable feature of life on earth[1]. An assessment of the gamma radiation dose rate from natural source is of particular importance because natural radiation is the largest contributor of the external dose to the world population. The worldwide average annual effective dose equivalent due to terrestrial gamma radiation is 0.48 mSv (ref. 1). This study therefore aimed at determining the influence of geology on terrestrial gamma radiation dose (TGRD) rate in Pahang state, Malaysia. It also aimed at extending and combining with a data from previous study to explore the distribution of TGRD over all the geological formations in the region. The lifetime effective dose rate and lifetime cancer risk for persons living in the state were also estimated.

Pahang is the largest state in the Malaysian peninsula. It covers an area of 36,137 sq. km with a population of 1,500,817 (ref. 3) and is located between lat. 2°29′ and 4°46′N and long. 101°20′ and 103°37′E. The state has the long Pahang River. The bordering states include Kelantan to the north, Perak, Selangor, Negeri Sembilan, to the west, Terengganu state to the east and Johor to the south. Kuantan is the capital and the royal house is at Pekan. Jerantut, Kuala Lipis and Raub are the other major towns in the state. Pahang state has 11 districts with 15 underlying geological formations (Figure 1)[4]. These formations are described in Table 1.

The data collection method was based on the geological formations in the area of survey. A geological map of the area (Figure 1) was used to mark the points of measurements for TGRD; coordinates of the points located were recorded and traced in the field using a GPS. Where the location was found to be inaccessible, a nearby accessible location on the same geological formation was used for measurements. TGRD was measured by holding the survey meter 1 m above level ground at the location. Measurements were made at 640 locations (Figure 2) in the area using Survey Meter model 19, micro R Meter (Ludlum Measurement, USA)[5]. It has linear energy response to gamma radiation between 0.08 and 1.2 MeV (ref. 6), which is considered to be acceptable for covering the majority of gamma ray emissions from major sources of natural gamma radiation. The instrument uses a 2.54 cm × 2.54 cm sodium iodide (NaI) crystal doped with thallium (Tl). The survey meter was calibrated at the Malaysian Nuclear Agency, which is recognized by the IAEA as a Secondary Standards Dosimetry Laboratory. The meter display was in micro roentgen per hour (μR h^{-1}). Global positioning system receiver Garmin (GPSmap 76CSx) with an accuracy of ±10 m recorded the latitude and longitude of each measurement location.

The terrestrial gamma dose rates ranged from 26 to 750 nGy h^{-1}, with a mean value of 176 ± 5 nGy/h (ref. 7). Also, 68% of dose rates values ranged between 50 and 200 nGy h^{-1}, which indicated that the mean value in the study area should be within this range. This value is three times the world and two times the Malaysian average of 59 and 92 nGy h^{-1} respectively[1]. The readings were then transformed using natural logarithm to fit a normal distribution. The skewness (symmetry) and kurtosis (pointiness) in natural logarithm had a good fit to normal distribution (bell shape), as shown in Figure 3. This shows that the measured gamma dose rate data are normally distributed and can be used to draw reliable conclusions. It also indicates that the distribution of gamma dose rates measurements satisfied the null hypothesis of

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Table 1. Geological formations of Pahang state

Geological formations	Description
Quaternary 1	Continental and marine deposits with unconsolidated sand
Quaternary 2	Continental and marine deposits with unconsolidated silt and clay
Quaternary 3	Continental and marine deposits with unconsolidated humic clay, peat and silt
Quaternary 4	Continental and marine deposits with unconsolidated clay, sand, silt and gravel – undifferentiated
Cretaceous–Jurassic 9	Continental deposits of thick, cross-bedded shale/mudstone. Volcanic products are present
Cretaceous–Jurassic 10	Cretaceous–Jurassic 9 with metamorphic and sedimentary rocks of sandstone/metastone
Triassic 14	Interblended sandstone, siltstone and shale; widespread volcanic products, mainly tuff of rhyolite dacitic composition in the central Peninsular
Triassic 15	Triassic 14 with acid to intermediate volcanic extrusive rocks
Permian 20	Shale, slate and phyllite with subordinate schist and sandstone. Prominent development of limestone through the succession. Volcanic media, rhyolitic to andersitic in composition, widespread
Permian 21	Permian 20 with extrusive rocks deposits of intermediate to basic volcanic rocks
Carboniferous 25	Phyllite, slate and sandstone; argillaceous rock are commonly carbonaceous
Devonian 30	Phyllite, schist and slate; limestone and sandstone locally prominent
Silurian–Ordovician 35	Schist, phyllite, slate and limestone. Minor intercalations of sandstone and volcanic rocks
Acid intrusive 38	Basalt and rhyolite undifferentiated
Acid intrusive 39	Igneous rocks with intermediate intrusives, undifferentiated

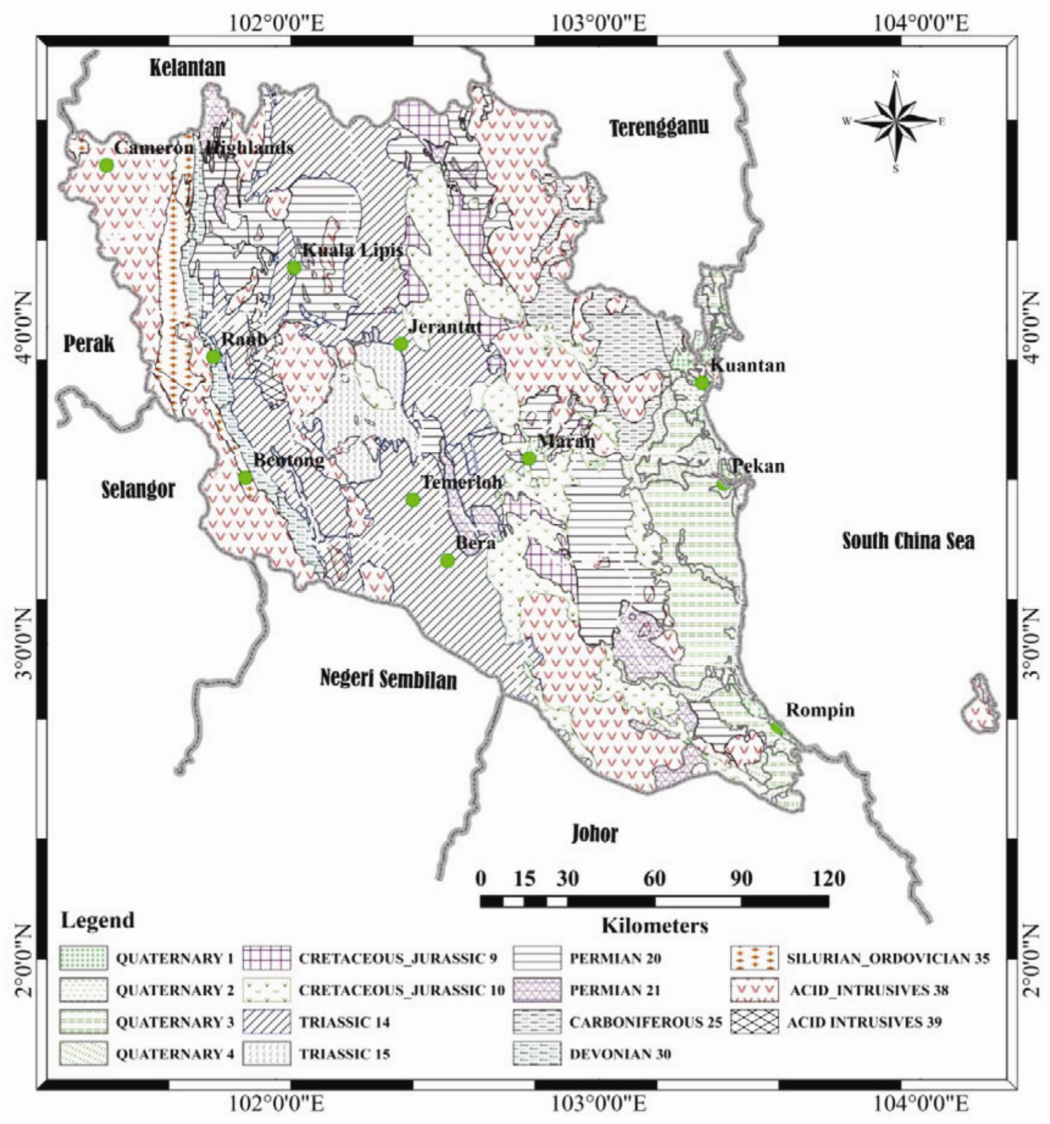

Figure 1. Geological formations of Pahang state, Malaysia[4].

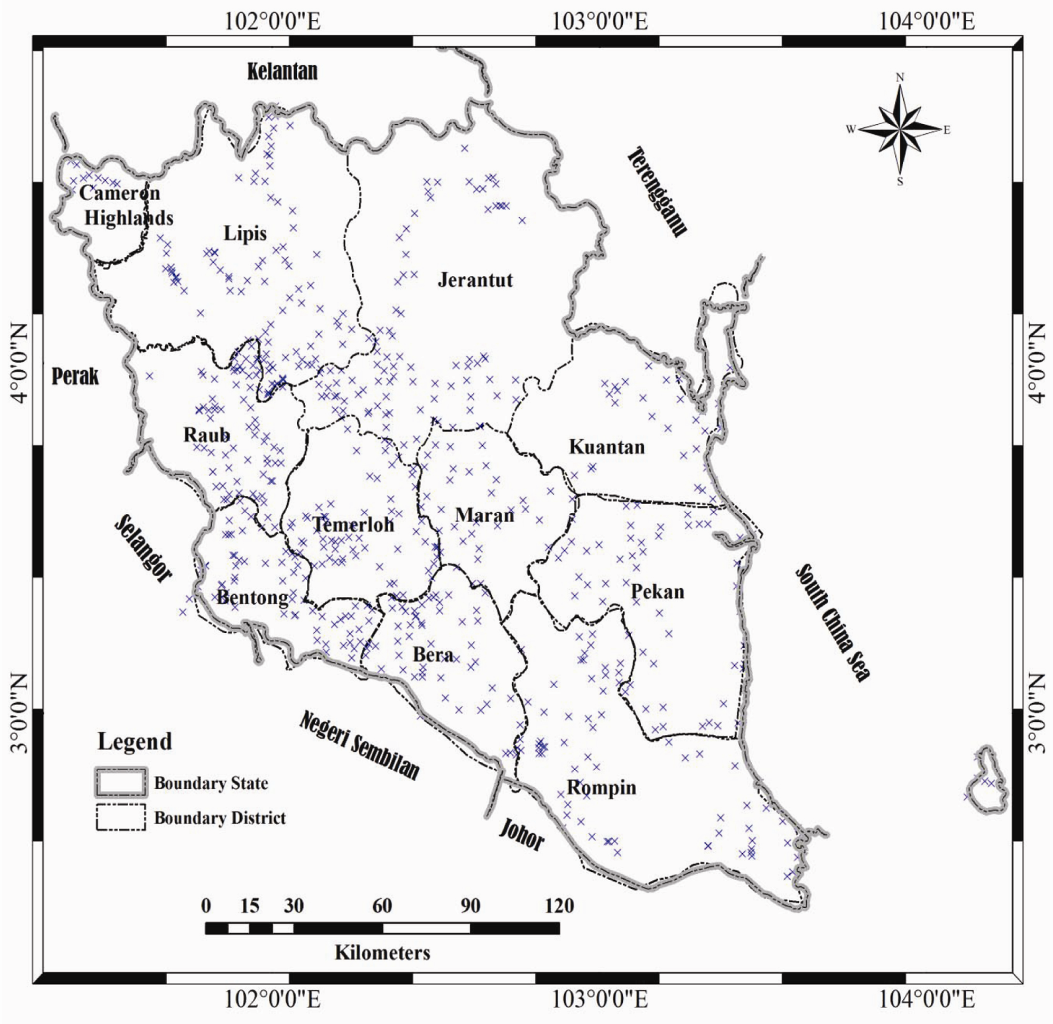

Figure 2. Location of measurements.

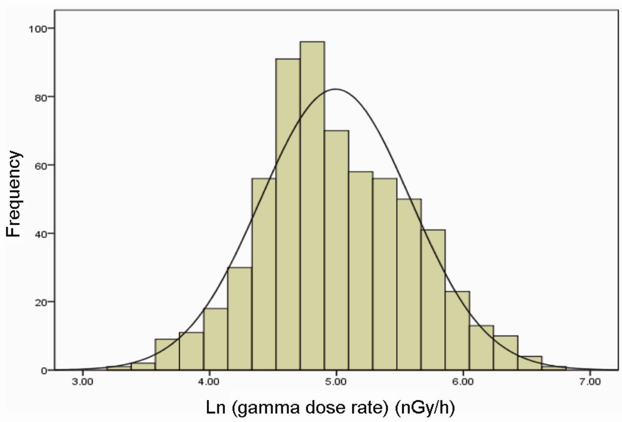

Figure 3. Frequency distribution of logarithm terrestrial gamma dose rates in Pahang state.

normality and therefore, the measured data are reliable to a great extent.

The mean values of dose rate at 95% confidence interval for each district in Pahang state are shown in Table 2. The distribution of gamma radiation dose rate through various districts has been reported[7]. The district of Cameron Highlands appears to have the highest mean gamma radiation dose rates values of 285 ± 13 nGy h^{-1}, which is approximately five times the world average. The district of Maran has the lowest gamma dose rate of 102 ± 9 nGy h^{-1}, which is approximately two times the world average. Jerantut district, which covers total land area of 21% of the state, has a mean gamma radiation dose rates of 158 ± 9 nGy h^{-1}.

The standard deviation is used to estimate the variability of gamma radiation dose rates for each group of geological formations, whereas standard error is used to estimate the uncertainty of dose rates since the population size of each group of geological formation was not the same. The 95% confidence interval was used to test the significant difference between the gamma radiation dose rates for each group of the geological formation.

Table 3 shows the mean values of TGRD and 95% confidence interval for each geological formation. Triassic 14, which is the most abundant geological formation in

Table 2. Statistical distribution of gamma radiation dose rates in Pahang state, Malaysia

District	N	Dose rate ($nGy\ h^{-1}$) Mean	Standard error	Standard deviation	Minimum	Maximum	95% confidence interval for mean Lower bound	Upper bound
Cameron Highlands	11	285	13	42	222	350	257	313
Raub	85	235	17	158	26	750	201	269
Lipis	65	135	8	68	46	302	118	152
Temerloh	62	192	14	111	44	511	164	220
Jerantut	90	158	9	81	35	435	141	175
Bentong	62	248	19	146	78	631	211	286
Bera	84	139	10	89	39	522	119	158
Rompin	93	169	11	110	35	620	146	192
Pekan	32	154	14	78	39	348	126	182
Maran	29	102	9	51	39	216	82	121
Kuantan	27	149	13	68	59	349	122	176
Mean	640	176	5	115	26	750	167	185

Table 3. Mean of gamma radiation dose rate for each geological formation of Pahang state

Geological formation	Dose rate ($nGy\ h^{-1}$) Mean	Standard error	Standard deviation	Minimum	Maximum	95% confidence interval for mean Lower bound	Upper bound
Quaternary 1	103	16	33	59	134	51	155
Quaternary 2	121	10	45	39	216	101	141
Quaternary 3	99	8	32	54	160	82	116
Quaternary 4	133	17	57	45	209	94	171
Cretaceous–Jurassic 9	126	17	56	48	216	89	164
Cretaceous–Jurassic 10	148	16	89	57	435	116	180
Triassic 14	158	7	107	35	620	144	172
Triassic 15	180	13	75	59	339	153	207
Permian 20	132	7	61	35	315	118	146
Permian 21	153	19	80	39	348	114	193
Carboniferous 25	143	12	49	72	228	117	169
Devonian 30	180	21	116	44	587	137	224
Siurian–Ordovician 35	165	18	81	26	302	129	202
Acid intrusive 38	258	12	125	36	631	234	281
Acid intrusive 39	367	43	194	99	750	276	457
Mean	176	5	115	26	750	167	185

the state, has a mean gamma radiation dose rate of $158 \pm 7\ nGy\ h^{-1}$. Geological formations 38 and 39, which consists of acid and intermediate intrusive, have the highest mean gamma radiation dose rate of $367 \pm 43\ nGy\ h^{-1}$ and $258 \pm 12\ nGy\ h^{-1}$ respectively. These areas are acidic and extensively intruded by granitic rocks. The granite is relatively rich in radioactive minerals[1]. The lowest mean gamma radiation dose rate of $99 \pm 8\ nGy\ h^{-1}$ was recorded in the Quaternary 3 geological formation, which comprises of continental and marine deposits with unconsolidated humic clay, peat and silt.

The annual effective dose (AED) outdoors and indoors was obtained using the conversion coefficient ($0.7\ Sv\ Gy^{-1}$) from the absorbed dose in air. The outdoor and indoor occupancy factor was 0.2 and 0.8 respectively[1]. AED was calculated using eqs (1) and (2) as follows

$$AED_{out}\ (mSv) = D\ (nGy\ h^{-1}) \times 8760\ h \times 0.2 \times 0.7\ (Sv\ Gy^{-1}),$$

$$AED_{out}\ (mSv) = 176 \times 8760 \times 0.2 \times 0.7,$$

$$AED_{out} = 0.216\ mSv. \tag{1}$$

The mean outdoor and indoor gamma radiation dose rate in Malaysia are approximately the same, 92 and $94\ nGy\ h^{-1}$ respectively[1]. Therefore, the indoor gamma radiation dose rate in Pahang state should also be approximately $176\ nGy\ h^{-1}$

$$AED_{in}\ (mSv) = D\ (nGy\ h^{-1}) \times 8760\ h \times 0.8 \times 0.7\ (Sv\ Gy^{-1}),$$

$$AED_{in}\ (mSv) = 176 \times 8760 \times 0.8 \times 0.7,$$

$$AED_{in} = 0.863\ mSv. \tag{2}$$

The value of annual effective dose rate outdoors and indoors in the study area was found to be 0.216 and

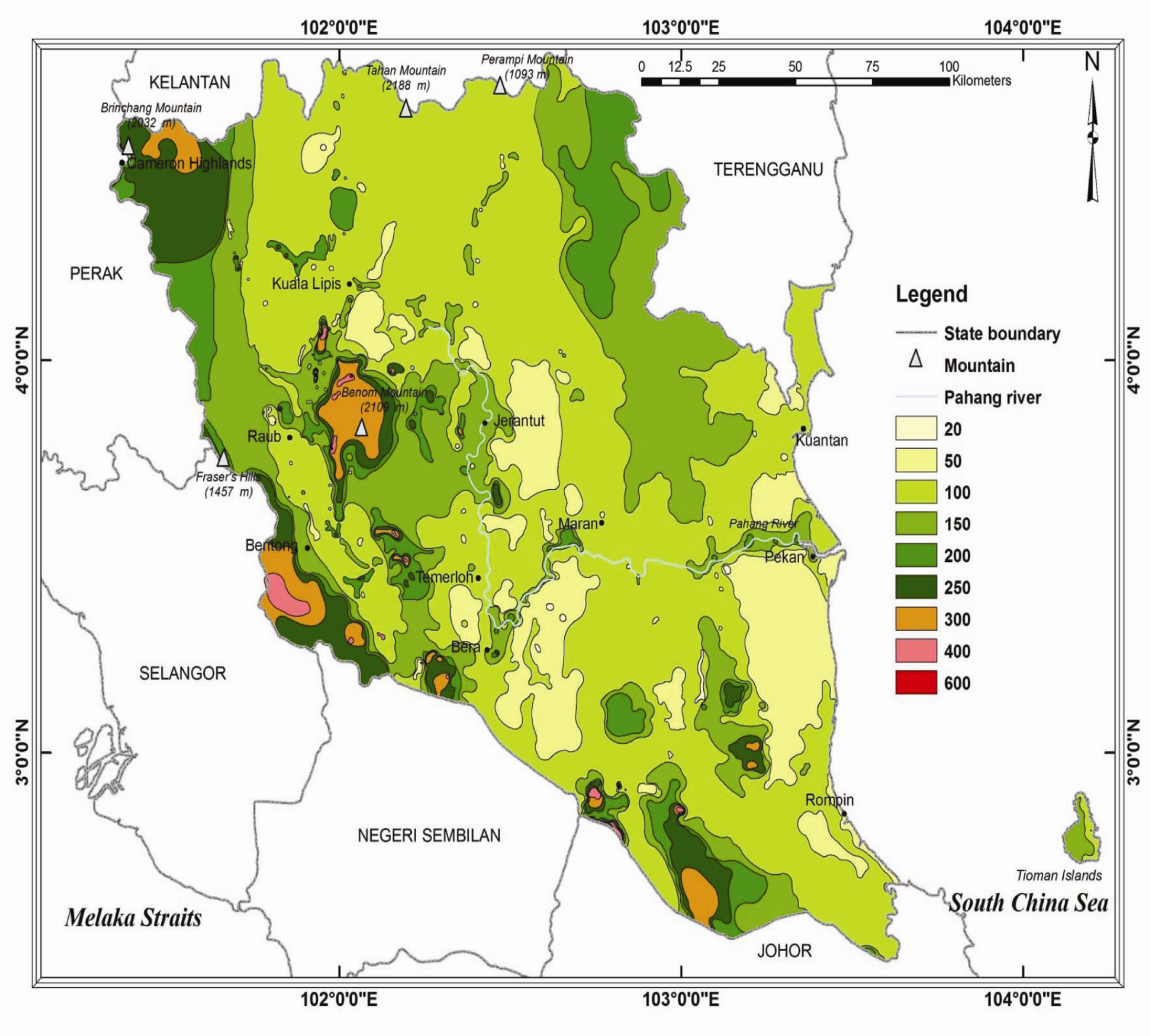

Figure 4. Isodose map of gamma dose rates in Pahang state.

0.863 mSv respectively. These values are three and two times the world average value of 0.07 and 0.41 mSv respectively[1]. The total annual effective dose rate is therefore given by

$$\mathrm{AED_{tot}} = \mathrm{AED_{out}} + \mathrm{AED_{in}},$$

$$\mathrm{AED_{out}} = 0.216 + 0.863 = 1.079 \text{ mSv}. \quad (3)$$

This is more than two times the world average value of 0.48 mSv. The collective effective dose (SC) was estimated using eq. (4)

$$\mathrm{SC} = \mathrm{AED_{tot}} \times N(P), \quad (4)$$

where $N(P)$ is the inhabitant population in the state, which is 1,500,817 (ref. 3)

$$\mathrm{SC} = 1.079 \times 1500817 = 1.62 \times 10^{6} \text{ mSv}.$$

The average lifetime dose rate (ALED) and cancer risk (R) for an individual living in Pahang state were estimated using eqs (5) and (6) (ref. 8)

$$\mathrm{ALED\ (mSv)} = \mathrm{AED_{tot}\ (mSv)} \times \mathrm{AL}_i(y), \quad (5)$$

where AL_i is the average life expectancy of 75 years in Pahang state (ref. 9)

$$\mathrm{ALED\ (mSv)} = 1.079 \times 75 = 80.93 \text{ mSv}.$$

The cancer risk

$$R = \mathrm{AED_{tot}} \times \mathrm{RF}, \quad (6)$$

where RF is the risk factor which is 5.82×10^{-2} $\mathrm{Sv^{-1}}$ (ref. 10). Therefore

$$R = 1.079 \times 10^{-3} \times 5.82 \times 10^{-2} = 6.28 \times 10^{-5}.$$

Table 4. Summary of radiological indices in different areas of Malaysia and the world

State/district	Mean dose rates (outdoor) (nGy h^{-1})	AED_{out} (µSv)	Mean lifetime dose (mSv)	Cancer risk	Lifetime cancer risk	Reference
Pahang state	176	216	81	6.28×10^{-5}	4.7×10^{-3}	Present study
Negeri Sembilan	330	405	30	2.36×10^{-5}	1.8×10^{-3}	11
Jhelum valley, Pakistan	116	654	43	3.29×10^{-5}	2.17×10^{-3}	12
Terengganu state	150	184	69	5.35×10^{-5}	4.0×10^{-3}	13
Mersing district, Johor	140	172	13	1.00×10^{-5}	0.8×10^{-3}	14
Kerala, India	414	508	36	2.43×10^{-5}	1.7×10^{-3}	15
W. Mazandaran, Iran	612	750	53	3.71×10^{-5}	2.6×10^{-3}	16
Kg. Sg. Durian, Perak	458	562	42	3.27×10^{-5}	2.5×10^{-3}	17
Kirklareli, Turkey	118	144	10	0.71×10^{-5}	0.51×10^{-3}	18
Palong, Johor	500	613	46	3.56×10^{-5}	2.7×10^{-3}	19
Malaysia	92	113	43	3.34×10^{-5}	2.5×10^{-3}	1
World	59	72	34	2.79×10^{-5}	1.95×10^{-3}	1

The lifetime cancer risk R_L is given by

$$R_L = AL_i \times R, \quad = 75 \times 6.28 \times 10^{-5} = 4.7 \times 10^{-3}. \tag{7}$$

The computed lifetime effective dose, cancer risk and lifetime cancer risk for an individual living in Pahang state were 81 mSv, 6.28×10^{-5} and 4.7×10^{-3} respectively.

The results for gamma radiation dose rates at each measurement point were plotted using the ArcGIS software. Figure 4 shows a plot of the computer-generated Isodose map of gamma radiation dose rates in Pahang state.

A few areas of enhanced activity ranging between 500 and 750 nGy h^{-1} were noted. These areas are predominantly underlaid by acidic granitic intrusive rock formations. Lowest gamma radiation dose rate between 20 and 50 nGy h^{-1} was found mostly in the southeastern coast in Pekan district, which is underlaid by Quaternary geological formation covered by peat soil. Table 4 provides a summary of annual effective gamma radiation dose rate, mean lifetime dose rate and cancer risk in different areas in Malaysia. The United Nations Scientific Committee on the Effect of Atomic Radiation reported that the natural radiation dose rate outdoors in Malaysia is 92 nGy h^{-1}. Pahang state has recorded approximately twice the average value of Malaysia[10].

Thus, this study presents the distribution of gamma radiation dose rates over different underlying geological formations for Pahang state. The data supports a strong link between gamma radiation dose rates and underlying geological formations. Acid and intermediate intrusive igneous rock terrain (undifferentiated) in Pehang state gave the highest mean TGRD of 367 nGy h^{-1}, whereas Quaternary geological formations formed from continental and marine deposits with unconsolidated humic clay, peat and silt yielded the lowest mean TGRD of 99 nGy h^{-1}. From the distribution of gamma radiation dose rate in Pahang state, the mean gamma radiation dose rate was found to be 176 nGy h^{-1}. This gives the annual outdoor effective dose equivalent to the population of 0.216 mSv. The lifetime equivalent dose and relative life time cancer risk for an individual living in Pahang state are 81 mSv and 4.7×10^{-3} respectively. These values are more than two times the world average of 34 mSv and 1.95×10^{-3} respectively. However, this does not translate into significant cancer risk in the area. The data could be used as a baseline for future radiological studies in the area as well as other areas with similar geological formations.

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Invasion of the Himalayan hotspot by *Acacia farnesiana*: how the human footprint influences the potential distribution of alien species

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The invasion of alien species in their non-native range has resulted in inevitable consequences. Thus, the potential distribution of alien species must be delineated to anticipate and reduce their negative effect on native ecosystems. The potential distribution can be predicted using invasive species distribution models (iSDMs). Thus far, few studies have investigated the human influence on the distribution of alien species when modelling their potential distribution. In the present study, we predict the potential distribution of *Acacia farnesiana* in the Himalayan hotspot using a popular iSDM. The effect of human influence was studied by comparing the potential distribution predicted using only bioclimatic variables and that using both bioclimatic and human footprint variables. We found that using both bioclimatic and human footprint variables, the potential distribution of target species could be 55.38% larger than that of using only bioclimatic variables. This proves the positive effect of human activities on distribution of invasive species. Among the six considered bioclimatic variables, the mean temperature of the coldest quarter, the precipitation of the coldest quarter, and temperature seasonality are the most influential factors in determining the potential distribution of *A. farnesiana*.

Keywords: *Acacia farnesiana*, alien species, human footprint, potential distribution.

THE spread of alien species that have been deliberately or unwittingly introduced into new habitats has resulted in inevitable consequences to various native ecosystems[1,2]. The ecological consequence of alien species is a major one. For example, in South Africa, cattle grazing over the past six centuries has enabled invasive scrub and small trees to displace much of the original grassland, resulting in a massive reduction in forage for native bovid and other grazers[3]. Since the introduction of rabbits to Australia from Europe, these animals have become the most significant factors contributing to native species loss and have been identified to be responsible for serious erosion problems because they consume surface plants and leave the topsoil exposed and vulnerable to sheet, gully and wind erosion[4]. The invasion of alien species can also adversely affect the following: natural ecosystems[5,6], agriculture and forestry production[7], recreation activities such as fishing, hiking and hunting[8], human health[9,10] and genetic pollution[11].

The negative effects of invasive species on various ecosystems can be reduced if detailed information related to the actual distribution of these species is obtained. These negative effects can also be anticipated if the potential distribution of the species is delineated. Although the actual distribution of invasive species cannot be reliably obtained because of the expensive investigation cost, the potential distribution can be modelled using invasive species distribution models (iSDMs). The iSDMs have been used to project the potential distribution of invasive species, investigate the relationship between invasive species and environmental conditions, and provide useful information for conservation planning

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