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ASSESSMENT OF NATURAL RADIATION LEVELS AND ASSOCIATED DOSE RATES FROM SURFACE SOILS IN PONTIAN DISTRICT, JOHOR, MALAYSIA

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The radiation survey of the ambient environment was conducted using two gamma detectors and the measurement results were used in the computation of the mean external radiation dose rate, mean weighted dose rate, annual effective dose and the collective effective dose, which are 69 nGy h^{-1}, 0.447 mSv y^{-1}, 237 μSv and 0.126×10^2 man Sv y^{-1}, respectively. A hyper purity germanium (HPGe) detector was used to determine the activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K in soil samples. The results of the gamma spectrometry of the soil samples show a range from 2 ± 1 to 113 ± 9 Bq kg^{-1} for ^{232}Th, 3 ± 1 to 68 ± 6 Bq kg^{-1} for ^{226}Ra, and 26 ± 3 to 683 ± 29 Bq kg^{-1} for ^{40}K. Radium equivalent activity (Ra_{eq}) and external hazard index (H_{ex}) were 136 Bq kg^{-1} and 0.366 respectively; which were with recommended level for the population. The Mean lifetime dose and life time cancer risk for each person living in the area are 5.91 mSv, 3.44×10^{-4} Sv year, respectively. The results was compared with values giving in UNSCEAR 2000.

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Keywords: Natural radiation; Annual effective dose equivalent; Health hazard; Cancer risk; Th-232; Ra-226; K-40

1. Introduction

Exposure to ionizing radiation from natural sources is a continuous and unavoidable feature of life. Human beings are exposed to natural background radiation every day from the ground, building materials, air, food, outer space, and even elements in their own bodies. Gamma radiation emitted from primordial radionuclide and their progeny is one of the main external sources of radiation exposure to the humans [1]. Terrestrial radioactivity, and the associated external exposure due to gamma radiation, depend primarily on the geological formation and soil type of the location; and these factors (geology and soil type) greatly influence the dose distribution from natural terrestrial radiation [2, 3].

Since natural radiation is the largest contributor of external dose to the world population, assessment of gamma radiation dose from natural sources is of particular importance. The concentrations of ^{232}Th, ^{226}Ra and ^{40}K vary widely depending on the location. Majority of the external gamma dose rate above typical soils (95%) arises from primordial radionuclides incorporated in the soil [4].

In addition, soil acts as a source of transfers of radionuclides through the food chain depending on their chemical properties and the uptake process by the roots to plants and animals [5]; hence, it is the basic indicator of the radiological status of the environment. These radionuclides take part in several biogeochemical p**roces**ses that determine their mobility and availability for biological update [6]. The major potential hazard from the natural radiation is from external exposure either by direct exposure to soil or as they enter in many building materials.

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The present study aims to assess the health risk due to exposure to naturally occurring terrestrial radionuclides in the Pontian District, Johor Malaysia.

2. Materials and Methods

2.1 The study area

Pontian district is located between latitudes of 1° 15′ and 1 ° 46′ N, and longitudes 103 °10′ and 103 °35′ E. It is located in the southwest of the Johore State in Peninsular Malaysia. It covers a total land area of 919.5 km^2, and has a population of about 149,938 as of Statistics 2010 [7]. The Pontian district is overlain by twelve soil types as classified by FAO/UNESCO [8] as shown in Figure 1 and Table 1.

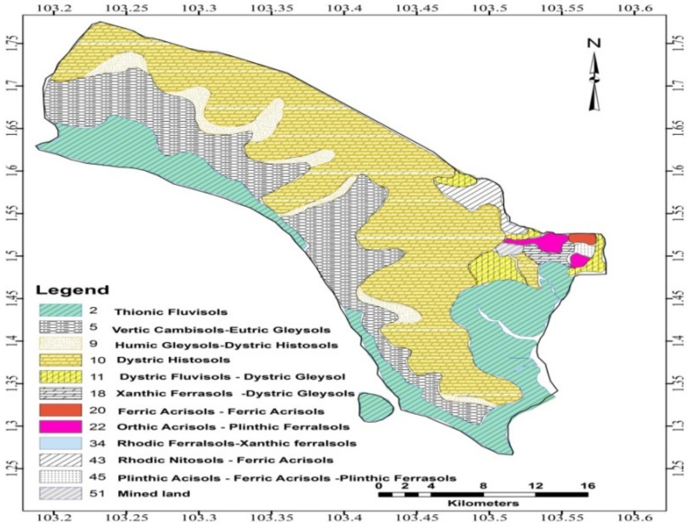

Fig. 1. Soil types in the Pontian district of Johor, Malaysia.

Table. 1. The soil types in the Pontian district of Johor, Malaysia.

Label	FAO UNIT	Local name
2	Thionic Fluvisols	Keranji
5	Vertic Cambisols-Eutric Gleysols	Selangor-Kangkong
9	Humic Gleysols-Dystric Histosols	Tanah Liat organan dan Tanah Kapor
10	Dystric Histosols	Gambut
11	Dystric Fluvisols - Dystric Gleysol	Telemong Akob- Tanah Lanar Tempatan
18	Xanthic Ferrasols -Dystric Gleysols	Holyrood Lunas
20	Ferric Acrisols - Ferric Acrisols	HarimauTampoi
22	Orthic Acrisols - Plinthic Ferralsols	Batu Anam-Melaka -Tavy
34	Rhodic Ferralsols-Xanthic ferralsols	Segamat - Katong
43	Rhodic Nitosols - Ferric Acrisols	Kulai Yong Peng
45	Plinthic Acisols - Ferric Acrisols -Plinthic Ferrasols	Pohoi - Durian - Tavy
51	Mined land	Tanah lombong

The Pontian district has mainly three geological formations underlying the soils [9] as follows: Quaternary, Triassic and Acid Intrusive. (38) as shown in table 2 and figure 2 [10].

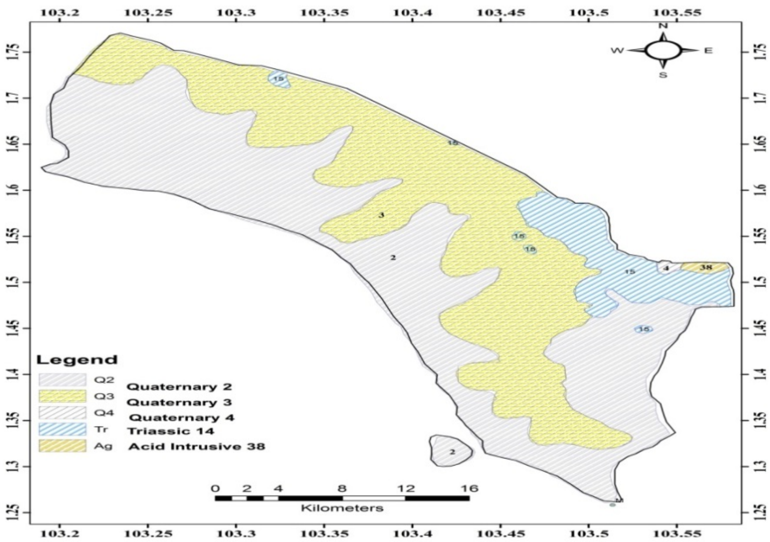

Fig. 2 Geological background in Pontian district of Johor, Malaysia.

Table 2. The geological background type of Pontian district

Label	Geological name	Composition	Lithology
G 2	Quaternary 2	Continental and marine deposits	Unconsolidated deposits with silt and clay (marine)
G 3	Quaternary 3	Continental and marine deposits	Unconsolidated deposits with humic clay, peat and silt.
G 4	Quaternary 4	Continental and marine deposits	Unconsolidated deposits with clay, sand, silt and gravel-undifferentiated.
G 14	Triassic 14	Interbedded sandstone, siltstone and shale; widespread volcanics , mainly tuffs of rhyolitic to dacitic composition in central peninsula	
G 38	Acid Intrusive 38	Intrusive rock	Undifferentiated with igneous rock

2.2. Measurements of Gamma Radiation Dose (GRD)

Gamma radiation dose measurements were made at the crossing points of the latitudinal and longitudinal lines as far as possible. Dose measurements were performed at point location using two survey meters manufactured by Ludlum Measurement, USA; Figure 2 shows the locations where measurements were conducted. Dose rate measurements were made until the readings were stable [11]; and at least two measurements were taken around the measuring point using each of the two detectors. The meter display was in microroentgen per hour (μR h^{-1}); and the instruments have relativity linear energy response to gamma radiation between 0.04 and 1.2 MeV

[12]. The instrument was calibrated at higher dose rates by the Malaysian Nuclear Agency, which is a recognized by the IAEA as a Secondary Standards Dosimetry Laboratory (SSDL).

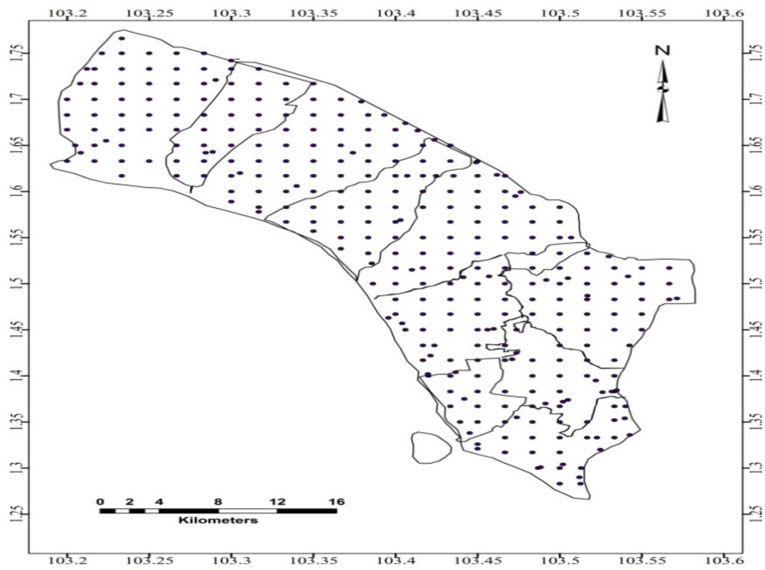

Fig. 3 External dose rate measurement locations.

2.3. Gamma spectrometry

Soil samples were collected from different mukims (parish) in the Pontian district. Thirty two samples were taken from the upper 10 cm layer of soil. Samples were collected away from buildings, roads and rivers. The samples were packed in labeled polythene bags. The locations of samples were recorded with a global positioning system. In the laboratory, the samples were first dried in air for 24 h, cleared of stones and pebbles, dried at 105 °C overnight, crushed and ground to a fine powder, homogenized, weighted and packed in standard 500 mL Marinelli beakers. About 5 g of each soil sample was used for the measurement of the gross alpha and gross beta. Samples were sealed and stored for four weeks to achieve secular equilibrium between radium and its progeny [13, 14].

Gamma activities were measured using spectroscopy with a coaxial high purity germanium detector (GC2018-7500 SL) with a relative efficiency of 20 %, and a resolution of 1.8 keV for the 1332 keV gamma ray emission of ^{60}Co. Genie 2000 (VI.3) software from Canberra was used to analyze the spectra. Energy was calibrated using a point source whereas efficiency was calibrated using a 500 mL multi-nuclide standard solution of: ^{210}Pb(46.54 keV), ^{241}Am (59.54 keV), ^{109}Cd (88.04 keV), ^{57}Co(122.07 keV), ^{123m}Te (159.00 keV), ^{51}Cr(320.07 keV), ^{113}Sn(391.71 keV), ^{85}Sr (513.99 keV), ^{137}Cs(661.62 keV), ^{88}Y(898 and1836 keV) and ^{60}Co(1173 and1332 keV). An empty Marinelli beaker was counted to strip the background from the samples. The value of Minimum Detectable Activity (MDA) was 13.23 Bq kg^{-1} for ^{40}K, 1.00 Bq kg^{-1} for ^{226}Ra and 1.69 Bq kg^{-1} for ^{232}Th for a counting time of 21600 s [15, 16].

The activity of ^{226}Ra was determined based on gamma ray emissions of ^{214}Pb (295.21 and 352 keV) and ^{214}Bi (609 and 1120.29 keV), ^{232}Th was determined based on the emissions of ^{212}Pb (238.6 keV), ^{208}Tl (583.1 keV) and ^{228}Ac (911.2 keV) and that of ^{40}K was determined from the emission at 1461.8 keV. The concentrations of ^{226}Ra and ^{232}Th were calculated from the weighted mean activity values determined for various emissions. IAEA S-14, IAEA S-16 and IAEA SL-2 were used for quality assurance.

2.5. Mapping isodose lines and production of an isodose map

Global Positioning System receiver Garmin (GPS 12 XL) was used to record the latitude and longitude of each location. Geological features, soil types and contour lines were mapped using ARCGIS software. The coordinates of each sample point were converted to the degree decimal unit. The World Geodetic System of 1984 was used for definition of the coordination system and it was used to generate the contour lines. Adjustments were made to take into account the boundaries of geological features and soil types [17].

3. Results and discussion

3.1. Measurement of external gamma radiation dose rate

The reading was taken at 330 locations in the Pontian district at 1 m above the ground using two NaI based gamma detectors. The mean values of external measured dose rate and the 95% confidence interval for each mukim are shown in Table 3. Table 3 shows the external gamma dose rates ranged from 9 to 261 nGy h^{-1}. The mean external measured gamma dose rate is 69 nGy h^{-1}. The lowest mean dose rate is found to be 33 nGy h^{-1} in Sungai Karang mukim. The highest mean gamma dose rate was 94 nGy h^{-1} in Jeram Batu, which is higher than of average dose rate worldwide (59 nGy h^{-1}).

Table 3. The mean external measured gamma dose rate for each Mukim

Mukim	N	Mean (nGy h^{-1})	Std. Deviation	Std. Error	Range (nGy h^{-1})
Benut	46	78	47	7	9-131
Sungei Pinggan	22	65	46	10	9-113
Ayer Baloi	50	65	51	7	9-157
Api-Api	28	64	50	10	9-131
Pontian	41	69	47	7	9-139
Rimba Terjun	31	73	44	8	9-131
Air Masin	13	55	44	12	9-131
Serkat	30	72	40	7	9-157
Sungai Karang	24	33	22	4	9-78
Jeram Batu	39	94	53	8	13-261
Pengkalan Raja	6	41	44	18	17-131
Pontian district	330	69	48	3	9-261

The mean weighted dose rate to the population from gamma radiation in the Pontian district is estimated to be 0.447 mSv y^{-1}. The annual effective dose to the population was calculated using the conversion coefficient from the absorbed dose in air to the effective dose (0.7 Sv Gy^{-1}) received by adults [4] See Equation 1.

$$AE = DR(nGyh^{-1}) \times 24 \times 365.25 \times 0.2 \times 0.7 \times 10^{-3} \quad (1)$$

Where; AE = the outdoor annual effective dose equivalent
DR = the measured dose rate
The collective effective dose (SC), was estimated using the Equation 2

$$SC = AE \times N(P) \quad (2)$$

Where N(P) is the population in the district. The collective effective dose rate was calculated to be 0.126×10^2 man Sv y^{-1}. The cancer risk (R) to an individual was estimated using equation (3).

$$R = AE \times AL_t \times RF \quad (3)$$

Where; AL_t is the average life expectancy (70 years), RF is the risk factor (5.82×10^{-2}) [18, 19]. The computed lifetime effective dose and the lifetime cancer risk for each person living in Pontian. Table 4 shows the annual effective dose, mean lifetime dose and lifetime cancer risks for each Mukim.

Table 4. The mean annual effective dose, mean lifetime dose and lifetime cancer risks for each Mukim

Mukim	Population	Mean annual effective dose equivalent (μSv)	Mean lifetime dose (mSv)	Life time cancer risk
Benut	14,598	267.12	6.66	3.88×10^{-4}
Sungei Pinggan	7,183	224.74	5.60	3.26×10^{-4}
Ayer Baloi	12,220	223.85	5.58	3.25×10^{-4}
Api-Api	12,446	219.92	5.48	3.19×10^{-4}
Pontian	35,408	236.97	5.91	3.44×10^{-4}
Rimba Terjun	27,235	251.34	6.27	3.65×10^{-4}
Air Masin	4,695	187.82	4.68	2.73×10^{-4}
Serkat	7,994	248.24	6.19	3.60×10^{-4}
Sungai Karang	1,787	112.92	2.82	1.64×10^{-4}
Jeram Batu	25,184	323.89	8.08	4.70×10^{-4}
Pengkalan Raja	1,188	139.69	3.48	2.03×10^{-4}
Pontian district	149,938	236.84	5.91	3.44×10^{-4}
		72	5.00	2.93×10^{-4}

3.2 Activities of ^{226}Ra, ^{232}Th and ^{40}K radionuclides

The activity concentrations were determined for 32 soil samples using (HPGe) detector. The measured activity concentration of ^{232}Th varied from 2 ± 1 to 113 ± 9 Bq kg^{-1} with a mean value of 53 ± 4 Bq kg^{-1} as shown in Table 5. ^{226}Ra activity concentrations ranged from 3 ± 1 to 68 ± 6 Bq kg^{-1} with a mean value of 37 ± 3 Bq kg^{-1}. The activity concentrations of ^{40}K ranged from 26 ± 3 to 683 ± 29 Bq kg^{-1} with a mean value of 293 ± 14 Bq kg^{-1}. The measured activity concentration of ^{226}Ra and ^{232}Th are higher than the world average, whereas the ^{40}K is lower than the world average.

Table 5. The activity concentrations of radionuclides, Ra_{eq} and H_{ex} in soil samples for each mukim in the Pontian District.

Mukim	^{226}Ra (Bq kg^{-1})		^{232}Th (Bq kg^{-1})		^{40}K (Bq kg^{-1})		Ra_{eq} (Bq kg^{-1})	H_{ex}
	Mean ± Std Error	Range	Mean ± Std E	Range	Mean ± Std E	range		
Benut	32±3	6-53	60±6	6-94	349±13	91-480	145	0.392
Sungei Pinggan	58±4	52-63	44±4	33-55	209±10	170-247	136	0.368
Ayer Baloi	28±2	3-64	49±5	4-113	313±14	127-616	122	0.329
Api-Api	44±3	12-64	53±2	2-93	286±13	72-430	142	0.382
Pontian	30±2	12-48	47±4	45-49	49±5	26-72	101	0.271
Rimba Terjun	42±3	12-67	73±6	9-113	354±17	67-628	173	0.468
Air Masin	28±3	12-44	53±5	9-97	440±21	196-683	138	0.373
Serkat	39±4	5-67	47±4	MDA-75	363±17	204-453	134	0.361
Sungai Karang	21±2	3-48	17±1	4-29	113±8	26-196	54	0.147
Jeram Batu	52±4	31-68	76±5	48-109	406±21	183-574	192	0.519
Pengkalan Raja	10±1	8-12	33±2	29-36	99±7	87-110	64	0.173
Pontian district	37±3	3-68	53±4	MDA-113	293±14	26-683	136	0.366

According to UNSCEAR 2000 the average concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Malaysia are 66 Bq kg^{-1}(range from 49 Bq kg^{-1} to 86 Bq kg^{-1}); 82 Bq kg^{-1} (ranged from 63 Bq kg^{-1} to 110 Bq kg^{-1}); and 310 Bq kg^{-1} (ranged from 170 Bq kg^{-1} to 430 Bq kg^{-1}), respectively (UNSCEAR, 2000). The Mean lifetime dose and life time cancer risk for each person were slightly higher world average of 5.91 mSv and 3.44×10^{-4}, respectively. Table 6 shows a summary of ^{226}Ra, ^{232}Th and ^{40}K concentrations, annual effective dose, mean lifetime dose and life time cancer risk in different areas in Malaysia.

Table 6 shows a summary of ^{226}Ra, ^{232}Th and ^{40}K concentrations, annual effective dose, mean lifetime dose and life time cancer risk in different areas in Malaysia.

Estate / District	Concentration in soil (Bq kg^{-1}) ^{226}Ra Mean	^{232}Th Mean	^{40}K Mean	Dose rates (nGy h^{-1}) Mean	Mean effective dose (µSv)	Mean lifetime dose (mSv)	Life time cancer risk	Reference
Pontian District	37	53	293	69	237	5.91	3.44×10^{-4}	This study
Kinta District, Perak	112	246	277	222	272	19	1.11×10^{-3}	Lee 2009 [20]
Kg Sungai, Perak	196	628	475	458	562	39	2.29×10^{-3}	Ramli 2009 a [21]
Selama District, Perak	178	353	296	273	335	23	1.36×10^{-3}	Ramli 2009 b [22]
Ulu Tiram, Johor	44			200	245	17	1.00×10^{-3}	Abdul Rahman 2007 [23]
Palong, Johor				500	614	43	2.50×10^{-3}	Ramli 2004 [24]
Melaka State				183	225	16	9.15×10^{-4}	Ramli 2005
Johor State				163	200	14	8.15×10^{-4}	Ramli 2001 [25]
World	33	45	420	59	72	5	2.9×10^{-4}	UNSCEAR, 2000

3.3 Radium equivalent activity (Ra_{eq})

Ra_{eq} is used to assess the gamma radiation hazards associated with materials that contain ^{226}Ra, ^{232}Th and ^{40}K. It is assumed that 370 Bq kg^{-1}of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce similar γ-ray dose rates**.** Ra_{eq} (Bq kg^{-1}) is given by Equation 3 [26]:

$$Ra_{eq} = {}^{226}Ra + 1.43\ {}^{232}Th + 0.077\ {}^{40}K \quad (4)$$

The maximum value must be less than 370 Bq kg^{-1} so as to keep the annual radiation dose below 1.5 mGy y^{-1} [27]. As shown in Table 5, Ra_{eq} was ranged from 21 Bq kg^{-1} to 273 Bq kg^{-1} with a mean value of 136 Bq kg^{-1} .

The external H_{ex} is an assessment of the hazard of the natural gamma radiation. The main objective of hazard index to keep the value less than unity. In addition, H_{ex} is an assessment of the hazard of the natural gamma radiation. H_{ex} is defined in the following equation [28]:

$$H_{ex} = \frac{^{226}Ra}{370} + \frac{^{232}Th}{259} + \frac{^{40}K}{4810} \le 1 \quad (5)$$

H_{ex} was shown in Table 5, ranged from 0.056 to 0.737 with a mean value of 0.366.

3.4. Contour plots

Figures 4 shows the computer generated contour maps of gamma dose rate for the Pontian District.

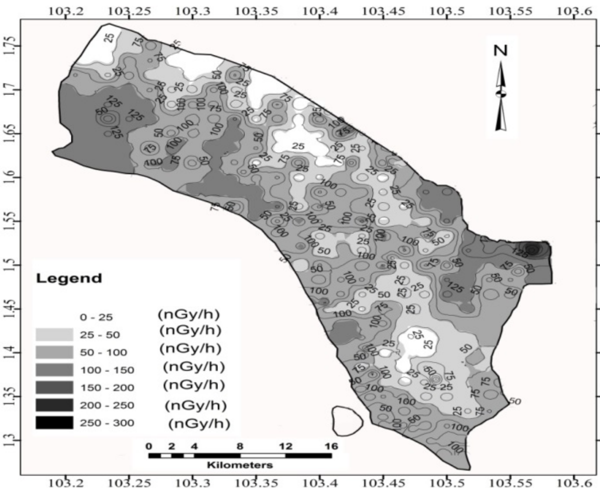

Fig. 4. Contour map of gamma dose rate (nGy/h).

4. Conclusion

This study assessed the natural radioactivity and the associated health risk in the Pontian District, Johor Malaysia. The average measured external dose rate is 69 nGy h^{-1}. The obtained value is lower than the Malaysian average (92 nGy h^{-1}). The mean population weighted dose rates and the annual effective dose from gamma radiation are 0.891 mSv y^{-1} and 178 µSv, respectively.

The mean activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K are 53 ± 4 Bq kg^{-1}, 37 ± 3 Bq kg^{-1} and 293 ± 14 Bq kg^{-1}, respectively. The measured activity concentration of ^{226}Ra and ^{232}Th are higher than the world average, whereas is less than of Malaysia. The Lifetime outdoor annual equivalent and relative excess lifetime cancer risks for each person living in Pontian District were 5.91 mSv, 3.44×10^{-4} Sv year, respectively.

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