Journal of Physics: Theories and Applications E-ISSN: 2549-7324 / P-ISSN: 2549-7316
J. Phys.: Theor. Appl. Vol. 5 No. 2 (2021) 81-91 doi: 10.20961/jphystheor-appl.v5i2.59099

Determination of Natural Radioactivity Level on Soil and Radiological Hazards in The Geotermal Area of Solok South, West Sumatera

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Received 10 July 2021, Revised 19 August 2021, Published 30 September 2021

Abstract: Solok Selatan is one of the areas in West Sumatra that has geothermal potential, contains much higher levels of radioactive substances in the soil in the form of Radium ($^{226}_{88}$Ra), Thorium ($^{232}_{90}$Th), and Potassium ($^{40}_{19}$K). This study aimed to measure the concentration of $^{226}_{88}$Ra, $^{232}_{90}$Th and $^{40}_{19}$K contained in the soil in the Solok Selatan which was then reviewed based on PERKA BAPETEN No. 9 of 2009 and UNSCEAR 2000, also evaluates the average radium equivalent activity (Ra_{eq}), representative level index ($I_{\gamma r}$), external hazard index (H_{ex}). Soil samples were collected from seven different locations. The radionuclide activity concentration was measured by using a gamma spectrometer in the PTKMR BATAN laboratory, with the results of the average radionuclide measurement $^{226}_{88}$Ra being 28.58 Bq/kg, $^{232}_{90}$Th was 44.74 Bq/kg and $^{40}_{19}$K at 323.29 Bq/kg. For the average value of Ra_{eq} is 118,051 Bq/kg, $I_{\gamma r}$ is 0.853 and H_{ex} is 0.335. Based on BAPETEN PERKA No. 9 of 2009 and UNSCEAR 2000, the radionuclide activity concentration was found still within safe limits. It does not pose a health hazard to the people living in the area.

Keywords: External hazard index, gamma spectrometer, geothermal, radioactivity, soil.

1. Introduction

Geothermal energy (or geothermal energy) is a relatively environmentally friendly energy source because it comes from the heat within the earth. This geothermal potential is used as a generator of electricity, heating pumps, toiletries and so on. Solok Selatan is one of the areas in West Sumatra that has geothermal potential which has been used as a geothermal power plant.

Geothermal potential contains natural radionuclides derived from soil, rock and water below the earth's surface. Natural radioactive substances in the soil in the soil come from Radium ($^{226}_{88}Ra$) with a half-life ($T_{1/2}$) of 1602 years, Thorium ($^{232}_{90}Th$) with $T_{1/2}$ of 14.05 million years and Potassium ($^{40}_{19}K$) with a $T_{1/2}$ of 1.28 Billion years (Seyis et al., 2010). This allows nearby humans to be exposed to background radiation coming from natural

sources. Natural radionuclides in soil can enter the human body through the process of digestion or inhalation which can cause damage and cell death due to free radicals from ionizing radiation.

The existence of this threat is important to identify the place of residence of the dangers of natural radioactive substances by measuring the level of radionuclide concentration to ensure the activity of radioactive substances is still below the threshold. The maximum nuclide radiation threshold allowed by BAPETEN based on BAPETEN PERKA No. 9 of 2009 which is 1000 Bq/kg for $^{226}_{88}Ra$, $^{232}_{90}Th$ and 10000 Bq/kg for $^{40}_{19}K$ and according to UNSCEAR 2000 it is 35 Bq/kg for $^{226}_{88}Ra$, 30 Bq/kg for $^{232}_{90}Th$, 400 Bq/kg for $^{40}_{19}K$ (BAPETEN, 2009;UNSCEAR, 2000).

Regional radiation monitoring is carried out in the work area and the environment. Monitoring is carried out with the aim of ensuring that the workplace conditions are guaranteed safe from radiation. This monitoring is also useful as a warning alarm in case of deviations from normal operating conditions so as to ensure that there is no release of radioactive substances into the environment. Monitoring can be done by taking environmental samples such as soil, grass, crops, water, air and so on, which are then processed and processed in the laboratory to obtain the level of radioactive content. Measurement of the concentration of natural radionuclide activity was carried out using a gamma spectrometer.

Research on the radioactivity level of the soil in the Dikili geothermal area, Turkey has been measured using a NaI(Tl) gamma spectrometer. Measurement of the level of radioactivity in the soil showed $^{238}_{92}U$ values of 28.7 Bq/Kg, $^{232}_{90}Th$ of 17.6 Bq/Kg and $^{40}_{19}K$ of 579.2 Bq/Kg. This study also evaluates health hazards associated with natural activities where the calculated radioactivity value is not too high and does not exceed a predetermined threshold value (Tabar et al., 2013).

In the area of Karimun Island, Riau Archipelago Province which has a lot of processing activities, the radioactivity level is obtained from $^{226}_{88}Ra$ of (23.63 – 139.45) Bq/Kg, $^{232}_{90}Th$ of (24.31 – 401.80) Bq/Kg, ($^{228}_{90}Th$ of (24.88 – 404.01) Bq/kg and $^{40}_{19}K$ of (19.46 – 871.00) Bq/Kg. Concentrations of $^{226}_{88}Ra$ and $^{232}_{90}Th$ in some locations are relatively higher than in other areas such as Bali and East Java, so it is necessary to conduct further studies on community and environmental safety (Wahyudi et al., 2012).

Another study regarding the concentration of natural radionuclide activity in Padang, West Sumatra, was measured using the gamma spectrometer method at a soil sample depth of 0-5 cm. The measurement results showed that the activity of radionuclide $^{226}_{88}Ra$ was (4.05 ± 0.29) to (53.44 ± 2.91) Bq/kg, activity $^{232}_{90}Th$ was (6.33 ± 0 .45) to (109.39 ± 5.75) Bq/kg and $^{40}_{19}K$ activity of (38.04 ± 22.86) to (1042.08 ± 76) Bq/kg. Radionuclide activity in soil samples in Padang City is still below the safe threshold and has not caused a health hazard to the people living in the area (Despriani et al., 2020).

Research on soil samples was also carried out in the Kirkuk area, Iraq by collecting 10 soil samples. The results showed that the concentration of radionuclide activity at $^{226}_{88}Ra$ was (27.4 – 57.0) Bq/Kg, $^{232}_{90}Th$ was (11.0 – 25.4) Bq/Kg and $^{40}_{19}K$ of (207.4 – 516.0) Bq/Kg. The results of this measurement have been compared with the UNSCEAR 1993

threshold value that was set and the value is lower than the safe threshold value. In general, there is no harmful radiation effect on the population living in this area, but there are some places that have values higher than the permissible values (Taqi et al., 2018).

Measurement of radiological hazards from natural radioactivity in soil samples has been carried out in several areas in Rize Province, Turkey with the average radioactivity level obtained for $^{226}_{88}Ra$ of (85.75 ± 11.77) Bq/Kg, $^{232}_{90}Th$ is (51.08 ± 9.42) Bq/Kg and $^{40}_{19}K$ is (771.57 ± 37.65) Bq/Kg. The quantities to assess radiological hazards from natural activities include the average value of radium equivalent activity (Ra_{eq}) is 218.20 Bq/kg, representative level index (Iyr) is 1.60, external hazard index (H_{ex}) is 0.59 where the obtained is higher than the safe limit that has been set (Dizman et al., 2016).

From several studies that have been carried out, it is known that soil samples from geothermal areas have natural radionuclide activity. Therefore, this study conducted a study on "Determining the level of natural radioactivity in soil and radiological hazards in the South Solok Geothermal Area, West Sumatra". The purpose of this study was to determine the level of natural radioactivity ($^{226}_{88}Ra$, $^{232}_{90}Th$, $^{40}_{19}K$) in soil collected from various points in South Solok Regency, West Sumatra and compared with the results. in the literature of BAPETEN No. 9 of 2009 and UNSCEAR 2000. Then, evaluating the average radium equivalent activity (Ra_{eq}) with the maximum value recommended by OECD (1975) which is 370 Bq/kg, the representative level index ($I_{\gamma r}$) and external hazard index (H_{ex})) with a maximum value of one (UNSCEAR 1988).

2. Experimental

2.1. Geology of Research Area

Solok Selatan is a district located in the eastern part of West Sumatra with a population of around 182,027 people. South Solok Geothermal is located in Muara Labuh. Soil sampling in the South Solok area was carried out in 7 study areas (Figure 1).

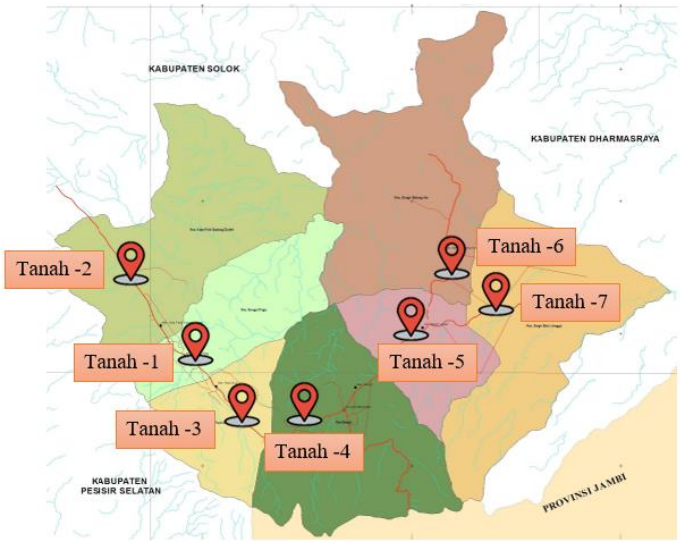

Figure 1. Map of soil sampling locations in South Solok

2.2. Sampling and Sample Preparation

Sampling is in the form of soil at seven points of collection location, where the seven points are land taken in one area randomly in each sub-district in South Solok district, the soil taken is at a depth of 0-5 cm. Then, the sample is dried in the sun so that the water contained in the sample can evaporate. Conditioning the sample to be more homogeneous and smaller grain size was sieved using a 100 mesh sieve on a dry sample. The soil sample was sent to the Environmental Safety Laboratory at PTKMR BATAN for radionuclide measurements on the sample using a gamma spectrometer.

2.3. Calculation of radiological effects

The concentration of activity ${}^{226}_{88}Ra$, ${}^{232}_{90}Th$, ${}^{40}_{19}K$ was measured in each soil sample. The radium equivalent activity is a hazard index used to compare the concentration of radionuclide activity in samples containing the radionuclides (${}^{226}_{88}Ra$, ${}^{232}_{90}Th$, and ${}^{40}_{19}K$, calculated using the relationships established by UNSCEAR, 1982 The maximum recommended value for radium equivalent activity (Ra_{eq}) is 370 Bq/kg (OECD, 1975).

$$Ra_{eq} = A_{Ra} + 1{,}43A_{Th} + 0{,}077A_k \quad (1)$$

Where A_{Ra}, A_{Th} and A_k are the activity concentration of ${}^{226}_{88}Ra$, ${}^{232}_{90}Th$, ${}^{40}_{19}K$ with units of Bq/kg.

Representative level index or known as radiation hazard index (I_{yr}) is to monitor radiation in the human body and to calculate the level of radionuclide risk in the human body when exposed to radiation from the soil, the value obtained must be less than one or equal to one to ensure the soil is hazard free. The representative level index can be formulated as follows (UNSCEAR, 1988):

$$I_{yr} = \frac{1}{150\ Bq/kg} A_{Ra} + \frac{1}{100\ Bq/kg} A_{Th} + \frac{1}{1500\ Bq/kg} A_k \quad \leq 1 \quad (2)$$

Where A_{Ra}, A_{Th} and A_k have the same meaning as equation 1.

The external hazard index (H_{ex}) is the external exposure hazard index of the gamma rays emitted by the sample, assuming that 370 Bq/kg from ${}^{226}_{88}Ra$, 259 Bq/kg from${}^{232}_{90}Th$ and 4810 from ${}^{40}_{19}K$, which gives the same gamma-ray dose rate (Beretka & Mathew, 1985). The calculated external hazard index must be less than or equal to one, it can be calculated through the following relationship (UNSCEAR, 1988):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \leq 1 \quad (3)$$

3. Results and Discussion

The study was conducted in seven areas of South Solok district around geothermal, namely in the Koto Baru area in Sungai Pagu District, North Pakan Rabaa in Koto Parik Gadang Diateh District, Alam Pauh Duo in Pauh Duo District, South Lubuk Gadang in

Sangir District, Lubuk Malako in the District Sangir Jujuan, Mirror Beach Realm in Sangir Batang Hari District and Sungai Kunyit Barat in Sangir Balai Janggo District. For radionuclide data collection $^{226}_{88}Ra$, $^{232}_{90}Th$, $^{40}_{19}K$ conducted in June 2021.

3.1. Concentration Measurement $^{226}_{88}Ra$, $^{232}_{90}Th$, $^{40}_{19}K$

The concentration of radionuclide activity was measured using a gamma spectrometer based on SOP 005.003/KN 05/KMR 2.1 referring to the IAEA Technical Report Series No. method. 295 and SNI ISO 10703.2009. The results of the measurement of the concentration of natural radionuclide activity $^{226}_{88}Ra$, $^{232}_{90}Th$, and $^{40}_{19}K$ are shown in Table 1.

Table 1. Concentration of Radioactivity in Soil Samples

Code	Coordinate	Location	Radioactivity Concentration (Bq/kg)		
			$^{226}_{88}Ra$	$^{232}_{90}Th$	$^{40}_{19}K$
Tanah-1	1.48360786S 101.06096782E	Koto Baru, Kec. Sungai Pagu	42.62 ± 4.32	87.20 ± 8.54	696.35 ± 66.08
Tanah-2	1.31352452S 100.94365343E	Pakan Rabaa Utara, Kec. Koto Parik Gadang Diateh	29.39 ± 3.06	25.20 ± 2.65	100.90 ± 10.17
Tanah-3	1.51489857S 101.08539331E	Alam Pauh Duo, Kec. Pauh Duo	29.76 ± 3.07	36.73 ± 3.72	403.50 ± 38.67
Tanah-4	1.59024767S 101.18023034E	Lubuk Gadang Selatan, Kec. Sangir	29.11 ± 3.05	44.90 ± 4.55	428.08 ± 40.98
Tanah-5	1.43298984S 101.3579404E	Lubuk Malako, Kec. Sangir Jujuan	20.41 ± 2.17	29.71 ± 3.05	315.86 ± 30.40
Tanah-6	1.37555669S 101.36515519E	Ranah Pantai Cermin, Kec. Sangir Batang Hari	16.74 ± 1.80	26.13 ± 2.69	271.60 ± 26.16
Tanah-7	1.42760308S 101.40739233E	Sungai Kunyit Barat, Kec. Sangir Balai Janggo	32.07 ± 3.32	63.31 ± 6.26	46.76 ± 5.19
Average			28.58	44.74	323.29
Bapeten No 9 Tahun 2009			1000	1000	10000
UNSCEAR 2000			35	30	400

From Table 1, the concentration of radionuclide activity obtained varied in each soil sample, with the activity concentration of $^{226}_{88}Ra$ ranging from 16.74 ± 1.80 Bq/kg to 42.62 ± 4.32 Bq/kg with an average average 28.58 Bq/kg. The highest concentration of $^{226}_{88}Ra$ was found in the Tanah-1 sample located in the Koto Baru area, Sungai Pagu sub-district and the lowest concentration was in the Tanah-6 sample located in the Ranah Pantai Cermin area, Sangir Batang Hari sub-district.

The activity concentration of $^{232}_{90}Th$ ranged from 25.20 ± 2.65 Bq/kg to 87.20 ± 8.54 Bq/kg with an average of 44.74 Bq/kg. The highest concentration $^{232}_{90}Th$ was found in the Tanah-1 sample located in the Koto Baru area, Sungai Pagu sub-district and the lowest concentration was in the Tanah-2 sample located in the North Pakan Rabaa area, Kec. Koto Parik Gadang Diateh.

The highest radionuclide concentration was found at $^{40}_{19}K$ which ranged from 46.76 ± 5.19 Bq/kg to 696.35 ± 66.08 Bq/kg with an average of 323.29 Bq/kg. The highest concentration of $^{40}_{19}K$ was found in the Tanah-1 sample located in the Koto Baru area, Sungai Pagu sub-district and the lowest concentration was in the Tanah-7 sample located in the Sungai Kunyit Barat area, Kec. Sangir Hall Janggo.

Tanah-1 sample has the highest radionuclide activity concentration values $^{226}_{88}Ra$, $^{232}_{90}Th$ and $^{40}_{19}K$ than the other soil samples, because Tanah-1 was taken in the Koto Baru area adjacent to Muara Labuh area. Based on the explanation of Wisnandary & Alamsyah (2012) regarding Muara Labuh, this area is a high permeability zone for the geothermal system (Geothermal), besides that the Muara Labuh area also has many magma channels as a geothermal source. Wisnandary and Alamsyah also explained that the results of a pre-feasibility study by Supreme Energy in 2008 showed the existence of high temperature geothermal in the Muara Labuh area with a liquid-dominated reservoir system with a temperature range of 210 -320 ^{o}C.

Based on BAPETEN PERKA No. 9 of 2009, the concentration of radionuclide activity in soil samples taken in the South Solok area, is currently still within the permissible limits, namely the maximum concentration for $^{226}_{88}Ra$, $^{232}_{90}Th$ is 1000 Bq/kg for $^{40}_{19}K$ is 10,000 Bq/kg. Where based on the BAPETEN PERKA, it can be concluded that this area is still safe and has not caused a health hazard to the people in the area.

Based on UNSCEAR 2000, the concentration of radionuclide activity $^{232}_{90}Th$ exceeds the specified threshold value of 30 Bq/kg with an average value $^{232}_{90}Th$ 44.74 Bq/kg while for $^{226}_{88}Ra$ and $^{40}_{19}K$ does not exceed the threshold of 35 Bq/kg for $^{226}_{88}Ra$ and 400 Bq/kg for $^{40}_{19}K$ with an average value of $^{226}_{88}Ra$ of 28.58 and $^{40}_{19}K$ of 323.29 Bq/kg. So it is necessary to carry out a further review of the measurement of the activity concentration of $^{232}_{90}Th$ in the South Solok area to ensure that the area is still safe and does not pose a health hazard to the community.

Table 2. Concentration of radionuclide activity from several studies

No.	Researcher	Region	Radioactivity Concentration (Bq/kg)		
			$^{226}_{88}Ra$	$^{232}_{90}Th$	$^{40}_{19}K$
1	Despriani et al, 2020	Kota Padang	22.96 ± 1.33	34.68 ± 1.98	290.66 ± 22.40
2	Taqi et al, 2018	Kirkuk, Iraq	40.11	15.87	302.82
3	Tabar et al, 2013	Dikili, Turki	-	17.6	579.2
4	Wahyudi et al, 2012	Pulau Karimun, Kepri	71.07 ± 6.19	195.48 ± 15.61	180.81 ± 17.63
5	Dizman et al, 2016	Rize, Turki	85.75 ± 11.77	51.08 ± 9.42	771.57 ± 37.65
6	Current research		28.58	44.74	323.29

Based on Table 2, the concentration of radionuclide activity $^{226}_{88}Ra$ Ra in the soil sample in South Solok is the second lowest of several studies that have been carried out previously in several areas, with the lowest concentration for$^{226}_{88}Ra$ found in the Padang City area with a value of The highest concentration is found in the Rize area of Turkey, which although it has a high value the area still has a radionuclide concentration value below the safe threshold allowed by BAPETEN.

For the concentration value $^{232}_{90}Th$ in the soil sample in South Solok, it is the third highest serial number under Karimun Island, Riau Archipelago and Rize, Turkey. However, the value of the radionulide concentration $^{232}_{90}Th$ for samples in the South Solok area is still below the safe threshold set by BAPETEN, but from several studies conducted in several areas the concentration of $^{232}_{90}Th$ is relatively high when compared to UNSCEAR 2000 value, where for the area of South Solok, Padang City, Karimun Island, and Rize-Turkey exceeds the threshold value of 30 Bq/kg.

The concentration of radionuclide $^{40}_{19}K$ in the South Solok area ranks third highest below the Rize-Turkey and Dikili-Turkey areas, although the values obtained are still below the safe threshold allowed by BAPETEN and UNSCEAR 2000.

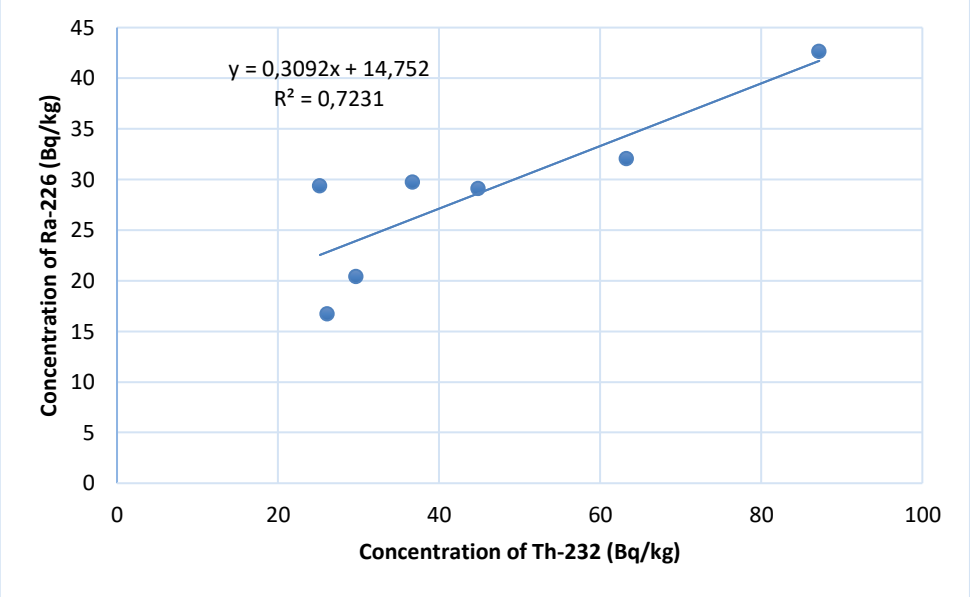

Figure 2. Correlation of the concentration of radionuclide activity between $^{226}_{88}Ra$ and $^{232}_{90}Th$

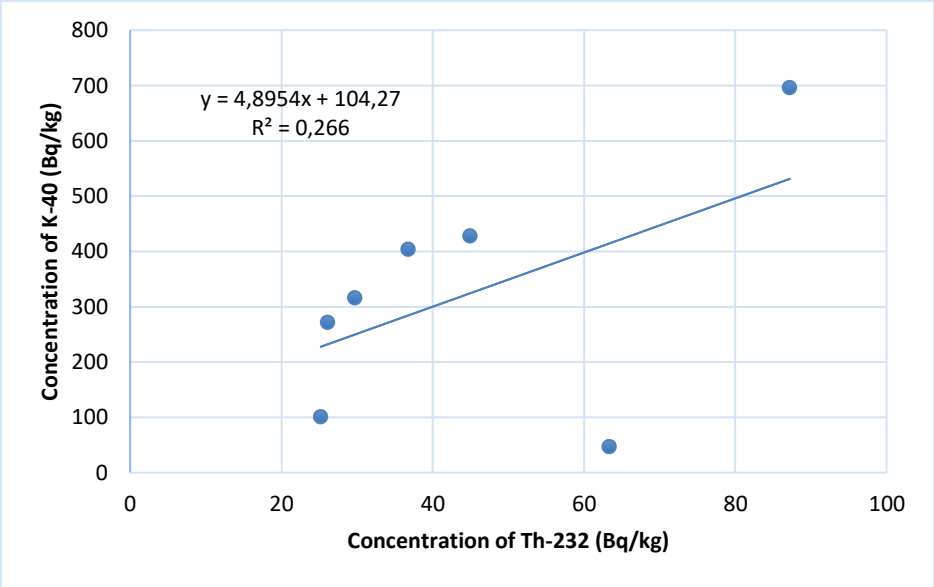

Figure 3. Correlation of radionuclide activity concentration between $^{40}_{19}K$ and $^{232}_{90}Th$

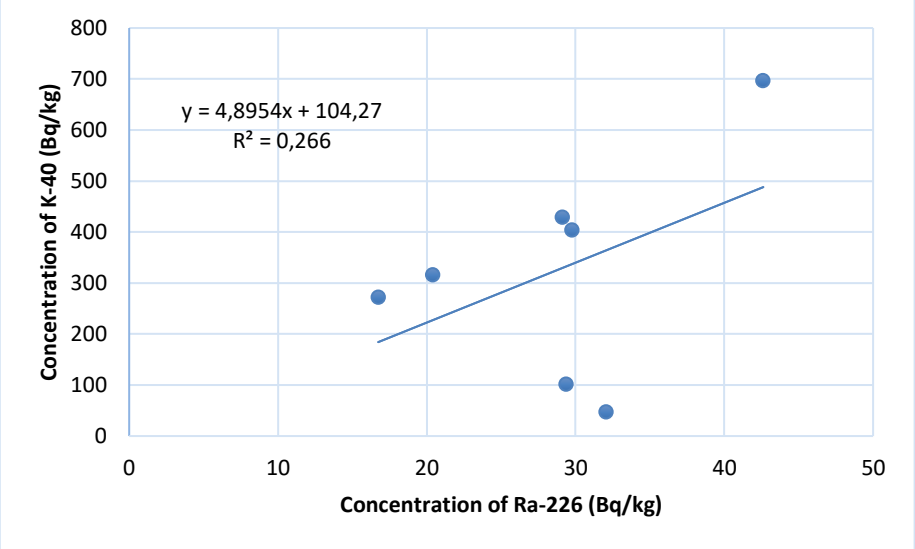

Figure 4. Correlation of radionuclide activity concentration between $^{40}_{19}K$ and $^{226}_{88}Ra$

3.2. Evaluation of Radiological Effects

Table 3. Result of calculation of radiological effect

Code	Ra_{eq} (Bq/kg)	I_{yr}	H_{ex}
Tanah-1	220,934	1,620	0,596
Tanah-2	73,195	0,515	0,197
Tanah-3	113,353	0,834	0,306
Tanah-4	130,437	0.928	0,341
Tanah-5	87,216	0,643	0,235
Tanah-6	75,019	0,553	0,202
Tanah-7	126,203	0,878	0,468
Rata-rata	118,051	0,853	0,335
OECD (1975)	370 Bq/kg		
UNSCEAR (1988)		≤1	≤1

Table 3 shows that the value of radium equivalent activity (Raeq) varies from 73.195 Bq/kg to 220.934 Bq/kg with an average of 118.051 Bq/kg. Where the average value in this study is lower than the maximum value recommended by OECD (1975) which is 370 Bq/kg. The representative level index value (I_{yr}) ranges from 0.515 to 1.620, with an average value of 0.853 which has a value lower than one. However, in Tanah-1, the representative level index value has a value of 1,620 which is more than one based on the UNSCEAR (1988) determination, this indicates a high risk of radionuclides entering the human body in the Koto Baru area. While the value of the external hazard index (H_{ex}) ranged from 0.197 to 0.596 with an average value of 0.335 for the soil sample in South Solok. The maximum value for H_{ex} is one based on the provisions of UNSCEAR (1988), in this study the value obtained is lower than one, this indicates that the level of radiation in the human body is low.

Table 4. Comparison of the calculation results of radiological health risk values with other researchers

Researcher / Region	Ra_{eq} (Bq/kg)	I_{yr}	H_{ex}
Dizman dkk, 2016 / Rize, Turki	218,20	1,60	0,59
Penelitian saat ini	118,051	0,853	0,335

In Table 4, the value of radium equivalent activity (Raeq) when compared with the research of Dizman, et al (2016) shows that the measured value is lower than the measured value in the Rize Province, Turkey by 218.20 Bq/kg. The value of the representative level index (Iyr) in this study is lower than the results of research from Dizman, et al (2016) with an Iyr value of 1.60, which is two times higher than the current research results. While the external hazard index (Hex) value obtained is lower than the measurements made by Dizman, et al (2016) of 0.59. This means that the South Solok area is still relatively safe from external radiation hazards.

4. Conclusion

Based on the research that has been done, it can be concluded that natural radionuclides $^{226}_{88}Ra$, $^{232}_{90}Th$ and $^{40}_{19}K$ were detected in all soil samples and obtained varying values in each sample. The concentration of radionuclide activity in soil samples was still below the threshold allowed by BAPETEN, with an average concentration of radionuclide $^{226}_{88}Ra$ obtained at 42.62 Bq/kg, $^{232}_{90}Th$ at 87, 20 Bq/kg and $^{40}_{19}K$ are 696.35 Bq/kg, while the allowable threshold for $^{226}_{88}Ra$, $^{232}_{90}Th$ is 1000 Bq /kg and for $^{40}_{19}K$ is 10,000 Bq/kg. However, for the value $^{232}_{90}Th$ in the measurement, it exceeds the threshold value set by UNSCEAR 2000 of 30 Bq/kg so that it is necessary to do a further review for radionuclide $^{232}_{90}Th$ in the South Solok area, for the value $^{226}_{88}Ra$ and $^{40}_{19}K$ is still below the threshold value set by UNSCEAR 2000. The average value of radium equivalent activity (Ra_{eq}) obtained in the sample is 118,051 Bq/kg where the average value in this study is lower than the maximum value. recommended by OECD (1975) is 370 Bq/kg, representative level index ($I_{\gamma r}$) is 0.853 and external hazard index (H_{ex}) is 0.335 which in this study the value obtained is lower than one based on UNSCEAR (1988) so that South Solok area is still relatively safe from external radiation hazards.

5. Suggestion

Based on the research that has been done, further research is recommended to conduct more specific research by measuring the concentration of radionuclide activity $^{226}_{88}Ra$, $^{232}_{90}Th$ and $^{40}_{19}K$in several areas in Sungai Pagu sub-district, because the area Koto Baru is one of the areas in the sub-district that has a higher concentration value than other sub-districts, to ensure that the radionulide concentration in the sub-district is still below the threshold set by BAPETEN and UNSCEAR 2000. Furthermore, it is recommended to measure the activity of radium equivalent ($\mathrm{Ra_{eq}}$) which is then compared with the maximum value recommended by OECD (1975), the measurement of the representative level index ($\mathrm{I_{\gamma r}}$)and external hazard index ($\mathrm{H_{ex}}$) in several Sungai Pagu sub-districts to ensure that the values obtained for the external hazard index are less from one.

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