JSTR
ASEAN Journal of Scientific and Technological Reports

Research article

Assessment of Background Radioactivity and Related Radioactive Hazard Indices in Glutinous Rice (*Oryza sativa* var. glutinosa)

Prasong Kessaratikoon[1*], Nathanicha Boonkong[2], Ruthairat Boonkrongcheep[3] and Noppharit Changkit[4]

[1] Nuclear and Material Physics Resrarch Unit (NuMPRU), Department of Basic Science and Mathematics, Faculty of Science, Thaksin University, Songkhla, 90000, Thailand; prasong_mi@hotmail.com
[2] Education Program in Science - Physics, Faculty of Education, Thaksin University, Songkhla, 90000, Thailand; noo_ni_zaza@hotmail.com
[3] Nuclear and Material Physics Resrarch Unit (NuMPRU), Department of Basic Science and Mathematics, Faculty of Science, Thaksin University, Songkhla, 90000, Thailand; ruthairat.b@hotmail.com
[4] Thailand Institute of Nuclear Technology (Public Organization), Nakhon Nayok, 26120, Thailand; careza777@hotmail.com
[*] Correspondence E-mail: prasong_ mi@hotmail.com

Citation:
Kessaratikoon, P.; Boonkong, N.; Boonkrongcheep, R.; Changkit, N.; Assessment of Background Radioactivity and Related Radioactive Hazard Indices in Glutinous Rice (*Oryza sativa* var. glutinosa)). *ASEAN J. Sci. Tech. Report.* **2021**, *24(3), 36-46*

Article history:
Received: March 12, 2021
Revised: August 5, 2021
Accepted: August 9, 2021
Available online: December 28, 2021

Abstract: Specific activites of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radionuclides in 30 glutinous rice samples bought from some local retailers and department stores in Songkhla Province have been measured and analyzed. Experiment results were carried out by using a high-purity germanium (HPGe) detector and gamma spectrometry analysis system at Radiation Laboratory in Thailand Institute of Nuclear Technology (Public Organization) (TINT). The results show that the specific activities of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in 30 glutinous rice samples ranged from < 592.21 – 896.36, < 3.73 – 11.92, < 2.49 – 7.84 and < 1.54 – < 2.35 Bq/kg respectively, with mean values of 683.13 ± 33.61, 6.09 ± 1.78, 4.20 ± 1.52 and < 1.92 ± 0.21 Bq/kg respectively. Furthermore, some related radioactive hazard indices and the excess lifetime cancer risk (ELCR) value were also evaluated and found in the safety values. Moreover, all the results were compared with Office of Atoms for Peace (OAP) data, research data in Thailand, international studies and some recommended values.

Keywords: Background Radioactivity, Glutinous Rice, Radioactive Hazard Index, Excess Lifetime Cancer Risk

1. Introduction

It is well known that natural (primordial) radionuclides (^{40}K, ^{226}Ra and ^{232}Th) that arise simultaneously with the Earth would be accumulated and mixed with the natural samples as rocks, soil, sand, water and air. Moreover, the anthropogenic radionuclides (^{137}Cs) arising from human activities such as nuclear bomb experiments, nuclear power plant accidents and causing leakage of radioactive material into nature, etc., would also be mixed and contaminated to all of those mentioned natural samples. At present, international researchers and relevant agencies are interested in the determination of concentrations or specific activities of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radioactive materials in soil, sediment, sand and water around the world [1-6]. To evaluate the specific activity values of radioactive substances of such interest, samples of food vegetables such as wheat, rice, local fresh vegetables and fruits etc., were also interested in by some national and international researchers [7-12]. Since these vegetables and fruits were grown in soil, and when fertilizers, watering and shedding the soil were operated during the agricultural process, those plants had to absorb nutrients and some amount of radioactive materials accumulated in the roots, leaves, flowers and seeds. The value is more or less dependent on each plant and vegetable's nature and biological structure. For considering and searching for information on the accumulation of specific activity of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radionuclides in some ordinary milled rice, it was found that studies and measurements were made in Japan, China, Iraq, India and Malaysia [13-17]. There is also some research and studies about measuring specific activities in rice samples cultivated in the south and northeastern parts of Thailand [10, 12, 18].

One major food crop and the principal staple food for Thai people is Glutinous or sticky rice (*Oryza sativa* var. glutinosa). Almost all Thai people usually stay in the northern and northeastern parts of Thailand like to eat glutinous rice in their basic daily diet. Hence, in dining, rice is treated as the most significant pathway for transferring radioactive materials into humans [17]. The glutinous rice is always consumed in white rice and is also classified as the main component of the famous dish of food named "Somtum or Papaya Salad". According to the Office of Agricultural Economics (OAE) of the Ministry of Agriculture and Cooperatives (MOAC, Thailand), the estimated area of paddy planting for glutinous rice in 2020/21 was about 16,253,000 rai (2,600,480 hectares) with a potential yield of 5,770,000 metric tons. The domestic consumption of glutinous rice per capita per year in Thailand is approximately 100 kg. For this reason, it is considered to find information of radioactivity baseline of all required radionuclides mentioned above, which were accumulated in the glutinous rice.

In this study, we have focused on the measurement and assessment of backgroud radioactivity in glutinous rice samples chosen and collected from some local retailers and department stores in Songkhla Province using a high-purity germanium detector and gamma spectrometry analysis system. Consequently, the results would be taken to evaluate some related radioactive hazard indices and compare with some studies and research data at both national and worldwide levels.

2. Materials and Methods

2.1 Sample collection and preparation

According to its largest size and most populated on the southern border of Thailand, Songkhla Province was organized to be the centre of this area. Hence, Songkhla Province should be chosen for the studied area. At least 8 kilograms of milled glutinous rice samples were randomly selected and collected from some local retailers and department stores in Songkhla Province in the lower southern part of Thailand. After collection, all glutinous rice was treated and prepared following the IAEA sampling and vegetable and fruit samples [19]. For example, the glutinous rice samples would be ground until fine using a commercial grinding machine. Then, all glutinous rice would be sieved through a 325 mm mesh-sized sieve to remove some coarse parts. A slow-airflow temperature (60 °C) for 12 hours in the drying closet will accelerate to remove the moisture without loss of radionuclides from the samples. Then, each sample (about 250 gms) 30 glutinous rice samples were placed and packed in a Polyvinylchloride (PVC) cylindrical container of diameter 7.0 cm and height 7.0 cm. The containers were wrapped tightly with a thick cellophane tape around their necks to avoid any gas escape from them and kept for a minimum of 4 weeks to ensure equilibrium between ^{222}Rn and its daughter products.

2.2. High-purity germanium (HPGe) detector with the gamma-ray spectrometry analysis system

In the present study, the specific activities of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radionuclides in 30 glutinous rice samples were determined by using a high-purity germanium detector (HPGe, EG&G ORTEC Model GEM 20 P4) and gamma spectrometry analysis system at the advanced laboratory, Thailand Institute of Nuclear Technology (Public Organization) (TINT). The detector was enclosed in a massive 10 cm thick lead shielding. The gamma-ray background spectra were measured frequently to examine the background's stability and improve the net count rate of the selected gamma-ray photopeaks of the samples. The measuring time was 10,800 s. The IAEA-473 (Milk Powder) reference materials (International Atomic Energy Agency (IAEA), Vienna, Austria) was used to determine the geometric efficiency for matrices in the container.

2.3. Measurement and analysis of the gamma-ray energy spectrum

The TINT laboratory's high-purity germanium (HPGe) detector with gamma-ray spectrometry analysis system will measure and record the gamma-ray energy spectrum from every glutinous rice sample. Then, the specific activities of all required radioactive materials could be analyzed using a special computer program associated with the measurement system. The results will be presented in subsection 3.1.

2.4. Study of the frequency distribution of specific activities

By using the SPSS computer program, the frequency distribution of specific activities of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in 30 glutinous rice samples were studied and analyzed. The result will be presented and shown in subsection 3.2.

2.5. Calculation of some related radioactive hazard indices and the excess lifetime cancer risk (ELCR) value

Some related radiological hazard indices are gamma absorbed dose rate (D) [20], radium equivalent activity (Ra_{eq}) [21], external hazard index (H_{ex}) [21], annual external effective dose rate (AED_{out}) [20] and the excess lifetime cancer risk (ELCR (outdoor)) [22] were evaluated and presented by using the suitable medium values of specific activities of ^{40}K, ^{226}Ra and ^{232}Th which were analyzed, determined and chosen from subsection 3.3. Set of equations which used to evaluate four related radiological hazard indices (D, Ra_{eq}, H_{ex}, AED_{out}) and ELCR (outdoor) were shown in the following equations (1) – (5):

$$D\ (nGy/h) = 0.0414C_K + 0.461C_{Ra} + 0.623C_{Th} \quad (1)$$

$$Ra_{eq}\ (Bq/kg) = 0.077C_K + C_{Ra} + 1.43C_{Th} \quad (2)$$

$$H_{ex} = C_K/4810 + C_{Ra}/370 + C_{Th}/259 \leq 1 \quad (3)$$

$$AED_{out}\ (mSv/y) = D\ (nGy/h) \times 8760\ h \times 0.2 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (4)$$

$$ELCR\ (outdoor) = AED_{out} \times LF \times RF \quad (5)$$

where C_K, C_{Ra}, and C_{Th} are the medium values of specific activity of ^{40}K, ^{226}Ra, and ^{232}Th in Bq/kg, respectively. In addition, the LF and RF are the life expectancy of Thai people (75 years) and risk factor (0.05 Sv^{-1}), respectively. Moreover, the results were also compared with some research data in Thailand and global recommended values as shown in subsection 3.4.

3. Results and Discussion

3.1 Example of gamma-ray energy spectrum

The example of gamma-ray energy spectrum measured and recorded using the special computer program is shown in Figure 1.

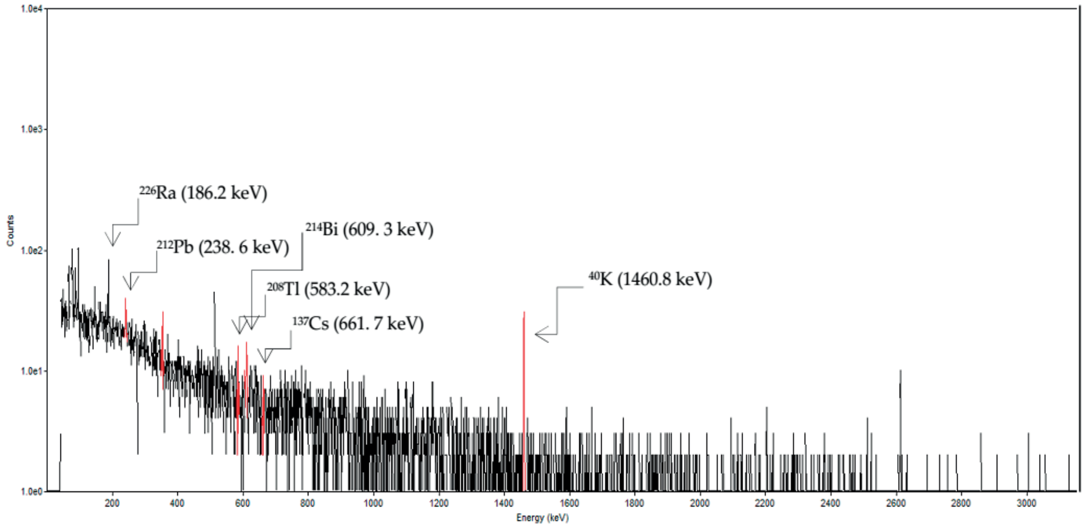

Figure 1. Gamma-ray energy spectrum measured from the glutinous rice sample collected in Songkhla Province.

3.2 Ranges and mean values of specific activity

The ranges and mean values of specific activities of the studied radionuclides measured and evaluated from all 30 glutinous rice samples collected from the studied area are presented in Table 1.

Table 1. Specific activity ranges and mean values of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in Bq/kg were analyzed in 30 glutinous rice samples collected from Songkhla Province.

Glutinous rice samples collected from Songkhla province (30 Samples)	Specific Activities (Bq/kg)			
	^{40}K	^{226}Ra	^{232}Th	^{137}Cs
Ranges	< 592.21 – 896.36	< 3.73 – 11.92	< 2.49 – 7.84	<1.54 – <2.35
Mean values	683.13 ± 33.61	6.09 ± 1.78	4.20 ± 1.52	< 1.92 ± 0.21

3.3 Frequency distribution of specific activities and some statistic values

The SPSS computer program was used to study and determine the frequency distribution of specific activities of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in 30 glutinous rice samples collected from Songkhla Province. These frequency distributions are shown in the following Figures 2 – 5. Furthermore, some related statistic values calculated from this study were also presented in Table 2.

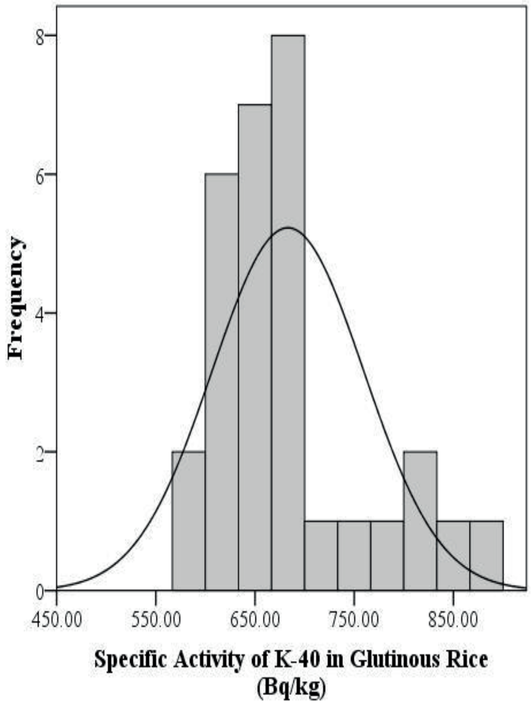

Figure 2. Frequency distribution of specific activities of ^{40}K in 30 glutinous rice samples of the studied area.

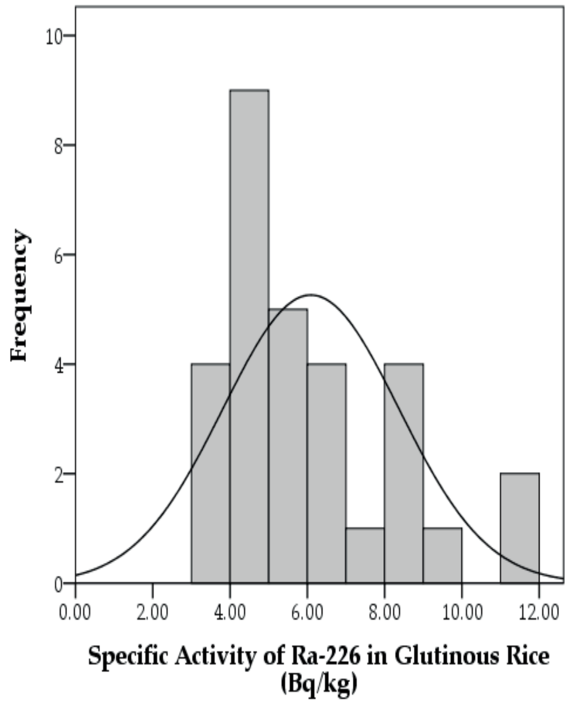

Figure 3. Frequency distribution of specific activities of ^{226}Ra in 30 glutinous rice samples of the studied area.

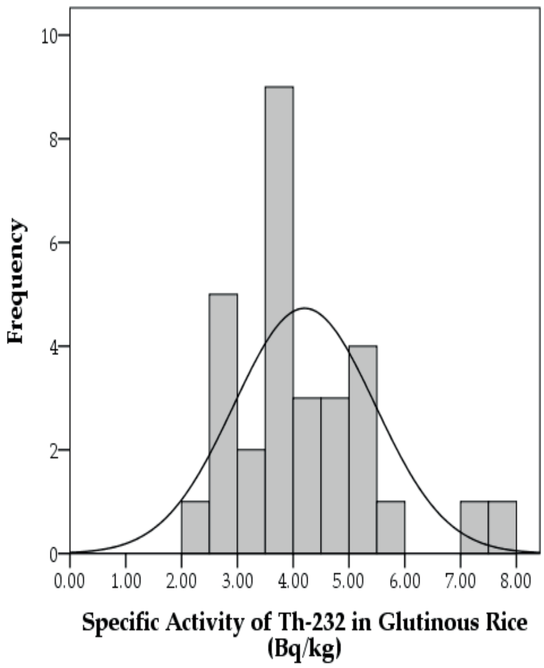

Figure 4. Frequency distribution of specific activities of ^{232}Th in 30 glutinous rice samples of the studied area.

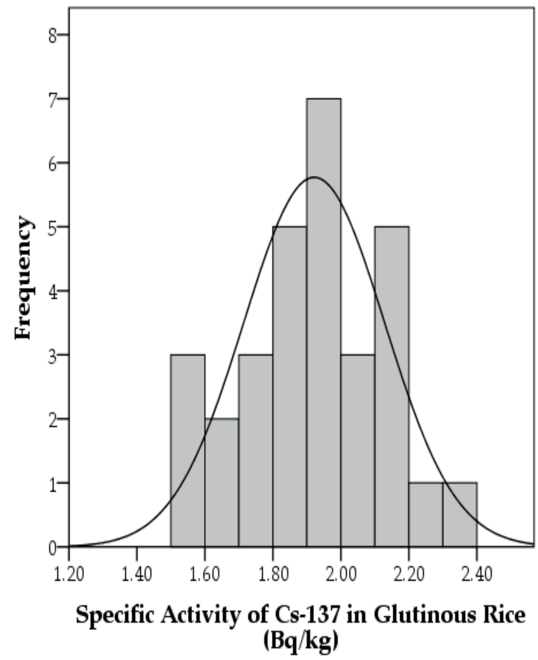

Figure 5. Frequency distribution of specific activities of ^{137}Cs in 30 glutinous rice samples of the studied area.

3.4. Some related radiological hazard indices values and comparison

Figure 2-5 in subsection 3.3 shows that the frequency distribution of specific activities of the studied radionuclides in 30 glutinous rice samples collected from Songkhla Province was asymmetrical distribution with the skewness of 1.40, 1.08, 1.17 and -0.19, respectively. This means that the frequency distribution is not normal. The normal distribution has a skewness of zero. Hence, the median values of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs, which were 667.41 ± 34.01 Bq/kg, 5.82 ± 1.79 Bq/kg, 3.94 ± 1.43 Bq/kg, and < 1.95 ± 0.21 Bq/kg for this investigated area, were the recommended medium value and should be chosen for calculation some related radiological hazard indices and the excess lifetime cancer risk (ELCR (outdoor)) for this study. Moreover, the present results and their average values were evaluated and compared with some researches data in Thailand, foreign countries, Office of Atoms for Peace (OAP) annual report data and the recommended values reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and International Atomic Energy Agency (IAEA) as shown in Table 3.

Table 2. Some related statistic values from the study of the frequency distribution of specific activities of ^{40}K, ^{226}Ra, ^{232}Th and ^{137}Cs in 30 glutinous rice samples collected from Songkhla Province, Thailand.

Statistic values	**Analyzed values**			
	^{40}K	**^{226}Ra**	**^{232}Th**	**^{137}Cs**
Mean (Bq/kg)	683.13	6.09	4.20	< 1.92
Median (Bq/kg)	**667.41**	**5.82**	**3.94**	**< 1.95**
Mode (Bq/kg)	592.21	4.50	3.60	< 1.54
Std deviation	76.30	2.27	1.26	0.21
Skewness	1.40	1.08	1.17	-0.19
Kurtosis	1.42	0.44	1.54	-0.43
Minimum value (Bq/kg)	< 592.21	< 3.73	< 2.49	< 1.54
Maximum value (Bq/kg)	896.36	11.92	7.84	< 2.35

Table 3. Comparison between four radiological hazard indices and ELCR(outdoor) for the present study with research data in Thailand, foreign counties, Office of Atoms for Peace (OAP) annual report data, UNSCEAR and IAEA.

Literatures	**D(nGy/h)**	**Ra_{eq}(Bq/kg)**	**H_{ex}**	**AED_{out}(mSv/y)**	**ELCR(outdoor) $\times 10^{-3}$**
Rice samples in Nakhon Nayok [23]	196.64 ± 1.72	373.87 ± 3.19	1.01 ± 0.01	0.24 ± 0.002	0.91 ± 0.01
Sungyod rice in Phatthalung [24]	54.69 ± 9.06	104.12 ± 17.64	0.28 ± 0.05	0.07 ± 0.01	0.25 ± 0.04
Jusmin rice in Songkhla [25]	52.61 ± 21.72	113.29 ± 47.42	0.31 ± 0.13	0.06 ± 0.03	0.24 ± 0.10
Pratum rice in Songkhla [25]	62.12 ± 30.41	138.93 ± 67.55	0.38 ± 0.18	0.08 ± 0.04	0.29 ± 0.14
Organic rice in Phatthalung [26]	30.03 ± 1.81	57.77 ± 3.54	0.16 ± 0.01	0.04 ± 0.002	0.14 ± 0.01
Rice in Penang Malasia [27]	4.28 ± 127	8.45 ± 2.53	0.02 ± 0.01	0.01 ± 0.002	0.02 ± 0.01
Canned rice in Iraq [28]	8.28 ± 2.15	17.44 ± 4.21	0.05 ± 0.01	0.01 ± 0.003	0.04 ± 0.01
Amber rice samples in Iraq [15]	5.09	11.03	0.03	0.01	0.02
Rice samples in Egypt [29]	2.22	4.40	0.01	0.00	0.01
Rice samples in Saudi Arabia [30]	6.02	11.31	0.03	0.01	0.03
Rice samples in Italy [31]	8.02	16.09	0.04	0.01	0.04
Rice samples in India [32]	27.79	61.42	0.17	0.03	0.13
Rice samples in Ghana [33]	9.19	18.95	0.05	0.01	0.04
Glutinous rice in Songkhla*	**32.77 ± 3.12**	**62.84 ± 6.45**	**0.17 ± 0.02**	**0.04 ± 0.004**	**0.15 ± 0.01**
OAP [34]	231.81± 2.97	512.90 ± 6.50	1.39 ± 0.02	0.28 ± 0.01	1.07 ± 0.01
UNSCEAR [35-37]	55	370	1	0.48	1.8
IAEA [38]	-	-	-	1.00	-

* Present study

From Table 3, the D values of the present study were 32.77 ± 3.12 nGy/h, which mainly was lower than all research and studies data in Thailand (except in organic rice in Phatthalung Province), OAP data, and the recommended value (55 nGy/h) as reported by UNSCEAR but higher than in all of the international research data. The Ra_{eq} value in this study was lower than 370 Bq/kg [37], which is acceptable for safe use, mostly all of the research data in Thailand (except in organic rice in Phatthalung Province) OAP data but higher than in all research data of foreign countries. The H_{ex} value evaluated in this study was equal to 0.17 ± 0.02, which was less than 1, lower than most research data in Thailand and OAP data but higher than in all research data of foreign countries (equal to data in rice samples in India). Furthermore, the AED_{out} value in this study was calculated and similar to 0.04 ± 0.004 mSy/y, which is lower than the worldwide average value of 0.48 mSv/y as presented by UNSCEAR and mostly also lower than all research data in Thailand (except in organic rice in Phatthalung Province), OAP data but again higher than in all research data of foreign countries (except in India). This value was also less than the maximum dose constraint value of 1.0 mSv/y as presented by the International Atomic Energy Agency (IAEA) [38]. In addition, the excess lifetime cancer risk (ELCR(outdoor)) was also calculated and equal to $(0.15 \pm 0.01)\times 10^{-3}$, which is lower than OAP data and all research data in Thailand (not included in Phatthalung Province) and UNSCEAR recommended values but higher than all of the research data of foreign countries. Hence, Thai people and everyone who usually likes to consume the glutinous rice for their favorite dishes should not get the radiological hazard impact on their health. However, the transfer factor (TF value) from paddy soil to rice and rice to humans should be studied and evaluated for normal and glutinous rice every year. Moreover, the results of this study could be considered and used to be the baseline reference for the glutinous rice and green and safe society in the future.

4. Conclusions

The evaluated median values of specific activity of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radionuclides in 30 glutinous rice samples collected from Songkhla Province were 667.41 ± 34.01, 5.82 ± 1.79, 3.94 ± 1.43 and <1.95 ± 0.21 Bq/kg, respectively. The median values of specific activity of ^{40}K, ^{226}Ra and ^{232}Th were chosen to evaluate four radiological hazard indexes (D, Ra_{eq}, H_{ex} and AED_{out}) and the excess lifetime cancer risk (ELCR(outdoor)) for the study area. The results obtained in this study fall within the range of values reported in similar studies conducted nationwide and worldwide. The D value was lower than the recommended value 55 nGy/h and the Ra_{eq} value was lower than the acceptable limits 370 Bq/kg. The H_{ex} and AED_{out} values were less than the acceptable limit of unity and 0.48 mSv/y, respectively. Moreover, this study's ELCR(outdoor) was also calculated and found lower than recommended value 1.8×10^{-3}. We can see that all four radiological indexes (Ra_{eq}, H_{ex} and AED_{out}) and the ELCR(outdoor) were below the values that can cause a significant radiation hazard to both the environment and human health. Hence, this study could be a preliminary study for scientists or researchers interested in assessing or measuring the concentration of natural and anthropogenic radionuclides in some foodstuffs and medicinal plants samples for human consumption without any radiological risk. Furthermore, this data may provide a general background for the glutinous rice being studied and serve as a guideline for future measurement and assessment of possible radiological risks to human health. Therefore, subsequent studies and evaluations need to study, measure and assess the transfer factor of natural and anthropogenic radionuclides from glutinous rice to people who enjoy having it for their favourite dishes.

5. Acknowledgements

This research project was partially supported by the Department of Basic Science and Mathematics, Faculty of Science, Thaksin University, Songkhla Campus, Thailand. The authors are grateful for the support and technical cooperation provided by the Thailand Institute of Nuclear Technology (Public Organization) (TINT) to access all the facilities and equipment needed to complete this study. The authors would also like to thank some undergraduate and graduate students for their works and patience in samples collection, preparation, measurement and calculation of some parts of these data.

Author Contributions: Conceptualization, P.K.; methodology, P.K., N.B.; validation, R.B., P.K.; formal analysis, N.C. and R.B.; investigation, N.C., N.B., and P.K.; resources, P.K.; data curation, N.C., N.B., and P.K.; writing—original draft preparation, N.C., N.B., and P.K.; writing—review and editing, P.K.; visualization, P.K.; supervision, P.K.; funding acquisition, P.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

References

1. Alshahri, F. Radioactivity of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in beach sand and sediment near to desalination plant in eastern Saudi Arabia: Assessment of radiological impacts. *Journal of King Saud University - Science.* 2017, *29*, 174–181. DOI: http://dx.doi.org/10.1016/j.jksus.2016.08.005.
2. Menshikova, E.; Perevoshchikov, R.; Belkin, P.; Blinov, S. Concentrations of natural radionuclides (^{40}K, ^{226}Ra, ^{232}Th) at the potash salts deposit. *Journal of Ecological Engineering*. 2021, *22*(3), 179–187. DOI: https://doi.org/10.12911/22998993/ 132544.
3. Ahmad, A.Y.; Al-Ghouti, M. A.; AlSadig, I.; Abu-Dieyeh, M. Vertical distribution and radiological risk assessment of ^{137}Cs and natural radionuclides in soil samples. *Scientific Reports.* 2019, 9:12196. DOI: https://doi.org/ 10.1038/s41598-019-48500-x.
4. Kodcharin, P.; Youngchuay, U.; Chinwetkitvanich, S.; Natural radioactivity in groundwater in Phra Nakhon Si Ayutthaya province. *Applied Environmental Research*. 2018, *40*(3), 11–18.
5. Altıkulaç, A.; Turhan, Ş.; Gümüş, H. Activity concentration of terrestrial and anthropogenic radionuclides (^{226}Ra, ^{222}Rn, ^{232}Th, ^{40}K and ^{137}Cs) in soil samples. *Environmental Earth Sciences*. 2016, *75*(1), 41. DOI: https://doi.org/ 10.1007/s12665-015-4841-5.
6. Chakraborty, S.R.; Azim, R.; Rahman, A. K. M. R.; Sarker, R. Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and plants in the Chittagong city of Bangladesh. *Journal of Physical Science*. 2013, *24*(1), 95–113.
7. Changizi, V.; Shafiei, E.; Zareh, M. R. Measurement of ^{226}Ra , ^{232}Th, ^{137}Cs and ^{40}K activities of wheat and corn products in Ilam province – Iran and resultant annual ingestion radiation dose. *Iranian Journal of Public Health*. 2013, *42*(8), 903–914.
8. Canbazoglu, C.; Dogru, M. A preliminary study on ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs activity concentrations in vegetables and fruits frequently consumed by inhabitants of Elazıg Region, Turkey. *Journal of Radioanalytical and Nuclear Chemistry*. 2013, 295, 1245–1249. DOI: 10.1007/s10967-012-1995-4.

9. Hosseini, T.; Fathivand, A. A.; Barati, H.; Karimi, M. Assessment of radionuclides in imported foodstuffs in Iran. *Iranian Journal of Radiation Reserach*. 2006, *4*(3), 149–153.
10. Raikham, C.; Jantawongrit, P. Using of organic or inorganic fertilizers to grow Thai Jasmine rice 105 in soil with natural radioactivity (^{226}Ra, ^{232}Th and ^{40}K); transfer of radioactivity to roots. *Science Technology and Engineering Journal* (STEJ). 2020, *6*(1), 57–66.
11. Al-Hassan, A. A.; Abdel-Salam, A.M.; El-Taher, A. Assessment of natural radioactivity levels and heavy metals in different types of rice consumed in Qassim, Saudi Arabia. *Life Sciences - Journal*. 2014, *11*(11), 829–836.
12. Quinram, P.; Jitpukdee, M.; Pornnumpa, C.; Kranrod, C. Risk assessment to natural radiation exposure from soil samples in the Jasmine rice cultivated area, Roi Et province, Thailand. *Journal of Physics: Conference Series.* 2019, 1285(2019), 012014. DOI :10.1088/1742-6596/1285/1/012014.
13. Uchida, S.; Tagami, K.; Hirai, I.; Soil-to-plant transfer factors of stable elements and naturally occurring radionuclides for rice collected in Japan. *Journal of Nuclear Science and Technology*. 2007, *44*(5), 779 – 790.
14. Wang, J.J.; Wang, C.J.; Huang, C.C.; Lin, Y.M.; Transfer factors of ^{90}Sr and ^{137}Cs from paddy soil to the rice plant in Taiwan. *Journal of Environmental Radioactivity.* 1998, *39*(1), 23–34.
15. Younis, A.S.; Tawfiq, N. F. Assessment of natural radioactivity level and annual effective dose of Amber rice samples cultivated in the south of Iraq. *E3S Web Conferences.* 2019, 122, 05004 (2019). DOI: https://doi.org/10.1051/ e3sconf/ 201912205004.
16. Karunakara, N.; Chetan, R.; Ujwal, P.; Yashodhara, I.; Sudeep, K.; Ravi, P.M. Soil to rice transfer factors for ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{40}K and ^{137}Cs: a study on rice grown in India. *Journal of Environmental Radioactivity*. 2013, *118*, 80–92.
17. Asaduzzaman, Kh.; Khandaker, M.U.; Amin, Y.M.; Mahat, R. Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular malaysia for the estimation of ingestion dose to man. *Annals of Nuclear Energy*. 2015, *76*(2015), 85–93.
18. Chaydana, H.; Intan, M.; Sukkaew, A.; Jaaoh, D.; Dorloh, S. Measurement of specific activities of radionuclide (^{40}K, ^{226}Ra and ^{232}Th) in native rice samples (*Oryza sativa*) from Pattani province by gamma spectrometry. *Academic Journal of Council of University Administrative Staff of Thailand*. 2017, *6*(2), 41–46.
19. International Atomic Energy Agency (IAEA), *Measurement of Radionuclides in Food and the Environment: A Guidebook (IAEA Technical Reports Series No. 295)*, IAEA, Vienna, Austria, 1989.
20. Singh, S.; Rani, A.; Mahajan, R. K. ^{226}Ra, ^{232}Th and ^{40}K analysis in soil samples from some areas of Punjab and Himachal Pradesh, India using gamma ray spectrometry, *Radiation Measurements.* 2005, *39*(4), 431–39.
21. Veiga, R. S. L.; Sanches, N.; Anjos, R. M. D.; Macario, K.; Bastos, J.; Iguatemy, M.; Aguiar, J. G.; Santos, A. M. A.; Mosquera, B.; Carvalho, C.; Filho, M. B.; Umisedo, N. K. Measurement natural radioactivity in Brazilian beach sands. *Radiation Measurements.* 2006, *41*(2), 189–196.
22. Qureshi, A. A.; Tariq, S.; Din, K. U.; Manzoor, S.; Calligaris, C.; Waheed, A. Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan. *Journal of Radiation Research and Applied Sciences.* 2014, *7*(2014), 438–447.
23. Office of Atoms for Peace (OAP). *OAP Annual Report from 1991-2003*. OAP, Ministry of Science and Technology, Bangkok, Thailand. 1991–2003.

24. Sungthong, U. Measurement of specific activities of Natural (^{40}K, ^{226}Ra and ^{232}Th) radionuclides in Sungyod rice samples collected from Phatthalung province, Thailand, *Undergraduate Science Project*, Thaksin University, Phatthalung Campus, Thailand, 30 March 2009.
25. Boonkrongcheep, R.; Maeha, A.; Kessaratikoon, P. Measurement and analysis of specific activities of Natural radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in Thai rice bag samples. *Thaksin University Journal.* 2015, *18*(3), 241–247.
26. Chauychoo, R. Measurement and analysis of specific activities of Natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic radionuclides in organic rice collected from Don Pradu sub-district in Pak Phrayun district in Phatthalung province, Thailand, *Undergraduate Science Project*, Thaksin University, Songkhla Campus, Thailand, 28 March 2018.
27. Alsaffar, M. S.; Jaafar, M. S.; Kabir, N. A.; Ahmad, N. Distribution of ^{226}Ra, ^{232}Th, and ^{40}K in rice plant components and physico-chemical effects of soil on their transportation to grains, *Journal of Radiation research and Applied Sciences*. 2015, *8*(3), 300–310.
28. Abass, A. H.; Muttaleb, M. K. Study of natural (^{238}U, ^{232}Th, ^{40}K) for canned rice samples in local markets in Hilla City. *Plant Archives.* 2018, *18*(2), 1847–1850.
29. Alrefae, T.; Nageswaran, T. N.; Radioactivity of long lived gamma emitters in rice consumed in Kuwait. *Journal of the Association of Arab Universities for Basic and Applied Sciences.* 2013, *13*, 24–27.
30. Al-Hassan A. A.; Abdel-Salam A.M.; El-Taher, A. Assessment of natural radioactivity levels and heavy metals in different types of rice consumed in Qassim, Saudi Arabia. *Life Sciences - Journal.* 2014, *11*(11), 829 – 836.
31. Desideri, D.; Meli, M. A.; Roselli, C.; Forini, N.; Rongoni, A.; Feduzi, L. Natural radionuclides in Italian diet and their annual intake. *Journal Radioanalytical and Nuclear Chemistry*. 2014, *299*(3), 1461–1467.
32. Al-Zahrani, J. H. Natural radioactivity and heavy metals measurement in rice and flour consumed by the inhabitants in K.S.A. *International Journal of Current Research.* 2016, *8*(06), 32892–32897.
33. Awudu, A.; Faanu, A.; Darko, E.; Emi-Reynolds, G.; Adukpo, O.; Kpeglo, D.; Otoo, F.; Lawluvi, H.; Kpodzro, R.; Ali, I. Preliminary studies on ^{226}Ra, ^{228}Ra, ^{228}Th and ^{40}K concentrations in foodstuffs consumed by inhabitants of Accra metropolitan area, Ghana. *Journal of Radioanalytical and Nuclear Chemistry*. 2012, *291*(3), 635–641.
34. Office of Atoms for Peace (OAP). *OAP 1994–2002 Annual Reports*, OAP, Ministry of Science and Technology Bangkok, Thailand, 1994–2002.
35. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Source, Effects and Risks of Ionizing Radiation (UNSCEAR 1988 Report to the General Assembly, with Scientific Annexes)* UNSCEAR, New York, U.S.A. 1988.
36. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Sources and Effects of Ionizing Radiation (UNSCEAR 1993 Report to the General Assembly, with Scientific Annexe*s), UNSCEAR, New York, U.S.A. 1993.
37. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Sources and Effects of Ionizing Radiation (UNSCEAR 2000 Report to the General Assembly, with Scientific Annexe*s), UNSCEAR, New York, U.S.A. 2000.
38. International Atomic Energy Agency (IAEA). *IAEA-TECDOC-1778: Criteria for Radionuclide Activity Concentrations for Food and Drinking Water*, IAEA, Vienna, Austria. 2016; 1–63.