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Prediction of terrestrial gamma dose rate based on geological formations and soil types in the Johor State, Malaysia

Muneer Aziz Saleh [a, c, *], Ahmad Termizi Ramli [b], Khaidzir bin Hamzah [a], Yasser Alajerami [d], Mohammed Moharib [b], Ismael Saeed [b]

[a] Nuclear Engineering Programme, Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johore Bahru, Johore, Malaysia
[b] Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johore Bahru, Johore, Malaysia
[c] National Atomic Energy Commission (NATEC), Sana'a, Yemen
[d] Department of Medical Radiography, Al-Azhar University, Gaza Strip, Palestine

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A B S T R A C T

This study aims to predict and estimate unmeasured terrestrial gamma dose rate (TGDR) using statistical analysis methods to derive a model from the actual measurement based on geological formation and soil type. The measurements of TGDR were conducted in the state of Johor with a total of 3873 measured points which covered all geological formations, soil types and districts. The measurements were taken 1 m above the soil surface using NaI [Ti] detector. The measured gamma dose rates ranged from 9 nGy h^{-1} to 1237 nGy h^{-1} with a mean value of 151 nGy h^{-1}. The data have been normalized to fit a normal distribution. Tests of significance were conducted among all geological formations and soil types, using the unbalanced one way ANOVA. The results indicated strong significant differences due to the different geological formations and soil types present in Johor State. Pearson Correlation was used to measure the relations between gamma dose rate based on geological formation and soil type ($D_{G,S}$) with the gamma dose rate based on geological formation (D_G) or soil type (D_S). A very good correlation was found between $D_{G,S}$ and D_G or $D_{G,S}$ and D_S. A total of 118 pairs of geological formations and soil types were used to derive the statistical contribution of geological formations and soil types to gamma dose rates. The contribution of the gamma dose rate from geological formation and soil type were found to be 0.594 and 0.399, respectively. The null hypotheses were accepted for 83% of examined data, therefore, the model could be used to predict gamma dose rates based on geological formation and soil type information.

1. Introduction

The natural radiation sources can be classified into terrestrial radiation and cosmic radiation. Exposure to ionizing radiation from natural sources is a continuous and unavoidable feature of life. Gamma radiation emitted from primordial radionuclides and their progenies is one of the main external sources of radiation exposure to humans (UNSCEAR, 2000). The terrestrial gamma dose rates (TGDRs) depend primarily on the geological formation and soil type of the location (Malanca et al. (1993), Ramli (1997), UNSCEAR (2000) and Quindós et al (1994)). Variation in TGDR due to the geological formations and soil type could be classified and is useful in the prediction of TGDR based on geological formations or soil type. Since it is expensive, and time consuming to measure TGDR, such a form can be used to predict terrestrial gamma dose for any gamma using soil type and geological data, in particular for larger or poorly accessible areas.

Ramli et al. (2001, 2003) and Saleh et al. (2013b) have identified the relationship of soils and geology with TGDR using one way analysis of variance (ANOVA). Strong correlations were found between the gamma dose rates and geological formations or soil types. Statistical methods were used to compare the differences between

* Corresponding author. Nuclear Engineering Programme, Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johore Bahru, Johore, Malaysia.
E-mail addresses: mouneersaleh@yahoo.com, muneeraziz@utm.my, muneeraziz@petroleum.utm.my (M.A. Saleh).

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all pairs of geological formations or soil types. Ramli et al. (2003) have predicted the gamma dose rate assuming that the contribution of geological formation is equal to the contribution of soil type. While Apriantoro (2008) has assumed fifty-nine of percent of the contribution is from the geological formation and the rest from soil types. The predicted gamma dose rates were compared with the measured values using statistical hypothesis z-test.

This study was based on 3873 gamma measurements taken from different locations in Johor State, Malaysia. The data obtained were classified to 118 pairs of geological formations and soil type based on their variation of gamma dose rate. The statistical models for dose rate prediction will be derived from the data obtained. The hypothesis test was conducted to examine the model. The models could be used to estimate and predict doses in areas difficult to access.

2. Materials and methods

2.1. The study area

Johor state is situated in the southern part of Peninsular Malaysia. It shares borders with Malacca and Negeri Sembilan States to the Northwest, Pahang State to the North, South China Sea to the East, Malacca Straits to the West and the Republic of Singapore to the South. It has a tropical climate. Most of the land in the state is utilized for agriculture, mainly oil palm and rubber plantations. It covers a total land area of 19,210 km^2. It is the fifth largest state in Malaysia; it had a population of about 3,233,434 as of 2010 (Department of Statistics Malaysia, 2010).

2.2. Geological formations

Johor state has six main geological formations underlying the soil (Ramli et al., 2001) as shown in Table 1, they are as follows: Quaternary, Tertiary, Cretaceous-Jurassic, Triassic, Permian, Intermediate Intrusive, Acid Intrusive and Devonian as shown in Fig. 1 (Department of Geological Survey, 1982).

2.3. Soil types of Johor state

Johor state is overlain by twenty three soil types as classified by FAO/UNESCO (Department of Agriculture Peninsular Malaysia, 1973; FAO, 2001) as shown in Fig. 2 and Table 2. The soils of Johor can be classified, according to their parent material, into three broad groups: sedentary, alluvial and miscellaneous soils. On the basis of similar characteristics, of which the parent material is the most important, these soils have been differentiated into soil series and associations. The distribution pattern of these soil series and associations reveals a close relation with those of different geological lithologies within the state (Department of Agriculture Peninsular Malaysia, 1973).

2.4. Measurements of gamma radiation dose

The gamma radiation dose measurements were made at the cross points of the latitudinal and longitudinal lines as far as possible, using two survey meters manufactured by Ludlum Model (Ludlum Model 19 and Ludlum Model 2241 USA). The readings were taken until they stabilised (Ramli, 1997; Saleh et al., 2013a). At least two measurements were taken around the measuring point using each of the two detectors. Fig. 3 shows the external dose rate measurement locations. The measurements were conducted in the state of Johor with total 3873 measured points which covered all geological formations, soil types and mukims (parishes).

The meter display was in microroentgen per hour ($\mu R\ h^{-1}$) and the instruments have a linear energy response to gamma radiation between 0.08 and 1.2 MeV (Ludlum instruction manual, 1993 and 2011; Knoll, 2010). This range covers the majority of gamma radiations emitted from natural radiation sources. The detector's response to gamma rays from cosmic rays is very low due to the detector's low response to high energy cosmic radiation (Ramli, 1997). The instrument was calibrated at higher dose rates by Nuclear Malaysia, which is recognized by the IAEA as a Secondary Standards Dosimetry Laboratory (SSDL).

Table 1
The main superficial geological formations in Johor State (Department of Geological Survey, 1982).

Label	Geological name	Composition	Lithology
G 1	Quaternary 1	Continental and marine deposits	Unconsolidated deposits with sand (mainly marine)
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 7	Tertiary 7	Isolated continental basin deposits of late Tertiary age: Shale, sandstone, conglomerate and minor coal seams.	
G 10	Cretaceous-Jurassic 9	Thick, cross – bedded sandstone with subordinate conglomerate and shale/mudstone.	
G 10	Cretaceous-Jurassic 10	Cretaceous-Jurassic (9)	Sedimentary and metamorphic rocks with sandstone/metastone
G 15	Triassic 14	Interbedded sandstone, siltstone and shale; widespread volcanics, mainly tuffs of rhyolitic to dacitic composition in central Peninsula	
G20	Permian 20	Phyllite, shale and slate with subordinate schist and sandstone.	
G21	Permian 21	Permian (20)	Unconsolidated deposits of ignimbrite
G 38	Acid Intrusive 38	Intrusive rock	Undifferentiated with igneous rock
G 39	Intermediate Intrusive 39	Intrusive rock	Undifferentiated with igneous rock
G 40	Devonian 40	Phyllite, schist and slate; limestone and sandstone locally prominent	