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Statistical Prediction of Environmental Gamma Radiation Doses, in Perak, Malaysia

(Ramalan Statistik Dos Sinar Gama Sekitaran, Perak, Malaysia)

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ABSTRACT

The concentrations of Naturally Occurring Radioactive Material (NORM) and their corresponding terrestrial gamma radiation have been shown to be associated with certain lithology and soil types. A possible relationships among gamma radiation levels, and the lithology and soil types make it possible to predict ionizing radiation level of an area that cannot be directly measured. A study was carried out to statistically predict and validate environmental gamma radiation dose rates based on actual field measurements using a sodium iodide detector. Results obtained showed that the predicted dose rate (D_p) may be determined using a multiple correlation regression equation, $D_p = 0.35D_L + 0.82\ D_s – 0.02$, that integrates dose rates contributed by different lithological structures (D_L) and soil types (D_s). Statistical analysis on 32 different lithology and soil type combinations showed that more than 50% of the predicted data were not significantly different from the data measured in the field. A predicted isodose map was subsequently plotted base on 4 dose rate classes ranging from 0.1 – 0.3 μSv h^{-1}.

Keywords: GIS; isodose map; Malaysia; NORM

ABSTRAK

Kepekatan bahan radioaktif tabii (NORM) yang terdapat dalam tanih dan aras gama terestrial berkaitan dipengaruhi oleh litologi dan jenis tanih. Kemungkinan wujudnya perhubungan antara aras sinar gama dan litologi serta jenis tanih ini memungkinkan ia digunakan untuk meramal aras sinaran mengion sesuatu kawasan yang tidak boleh diukur aras sinarannya secara langsung. Satu kajian telah dilakukan untuk meramal dan mengesahkan secara statistik kadar dos sinar gama sekitaran berdasarkan bilangan pengukuran sebenar di lapangan dengan menggunakan pengesan natrium iodid. Hasil kajian mendapati bahawa kadar dos ramalan (D_p) boleh ditentukan melalui persamaan regresi korelasi berganda, $D_p = 0.35D_L + 0.82\ D_s – 0.02$, yang menyepadukan kadar dos sumbangan struktur litologi (D_L) dan jenis tanih (D_s) yang berlainan. Analisis statistik terhadap 32 kombinasi litologi dan jenis tanih yang berlainan mendapati lebih daripada 50% data ramalan adalah tidak berbeza secara signifikan dengan data yang diukur di lapangan. Sebuah peta isodos ramalan telah dibangunkan berdasarkan 4 kelas kadar dos antara 0.1 – 0.3 μSv h^{-1}.

Kata kunci: GIS; Malaysia; NORM; peta isodos

INTRODUCTION

Tin mining areas have been known to have higher concentrations of naturally occurring radioactive materials (NORM) as compared to non-mining area. The mining of tin and processing of *amang* (a local name for tin tailing) for valuable minerals, has stirred occupational and environmental radiological concerns due to the technological enhancement of naturally occurring radioactive materials (Azlina et al. 2003; Khairuddin et al. 2000). Large areas of former tin mining land are now being rejuvenated and developed for housing, industries and recreational areas. Such activities have caused concern on radiological risk to its occupants. Ramli et al. (2003) have also shown that different lithology and soil types yielded different levels of external gamma radiation.

The first step in estimating environmental radiological risk is to map out the dose rates distribution of the areas of interest. One method of mapping is to carry out *in situ* measurements. Although accurate and reliable, such traditional method of estimating environmental risk by measuring radiation levels at the area of interest are time consuming, costly and in some cases the areas are inaccessible for measurement. Ramli et al. (2003) proposed predicting external gamma radiation dose rates by averaging the means of radiation dose rates associated with geological structure and soil types in Kota Tinggi, Johor. Ismail et al. (2004) made a similar attempt to validate Ramli et al. (2003) finding using different lithology and soil combinations found in the districts of Kinta and Batang Padang, Perak but found that the direct 1:1 correlation between lithological structures – soil types combination and predicted dose rate proposed by Ramli et al. (2003) does not hold true for all combinations.

This study hypothesized that dose rates associated with lithological structures and soil types do not necessarily contribute equally towards the predicted dose rates. Consequently a multiple correlation regression integrating both dose rates associated with different lithological structures and soil types must be considered together to predict the overall environmental gamma radiation dose rates. This objective of this study was to propose and validate the use of statistical approach integrated with visualization technique and spatial analysis in GIS environments in mapping the environmental gamma radiation isodose map of Perak.

METHOD

The area map of Perak was divided into 1 km^2 grid lines. The points of intersections of the 1 km^2 grid line represent the number of proposed (population) required to develop an isodose map. These areas consist of different soil types with varying underlying lithological structures. Figures 1 and 2 show the lithology and soil types of Perak.

External terrestrial gamma dose rates were measured using a sodium iodide detector (Ludlum Measurement Inc. Model 4421-2). Measurements were made about 5 cm from the surface of the ground. Five readings within an area of 1 m^2 were taken at each sampling location and their values averaged. The numbers of areas measured were largely

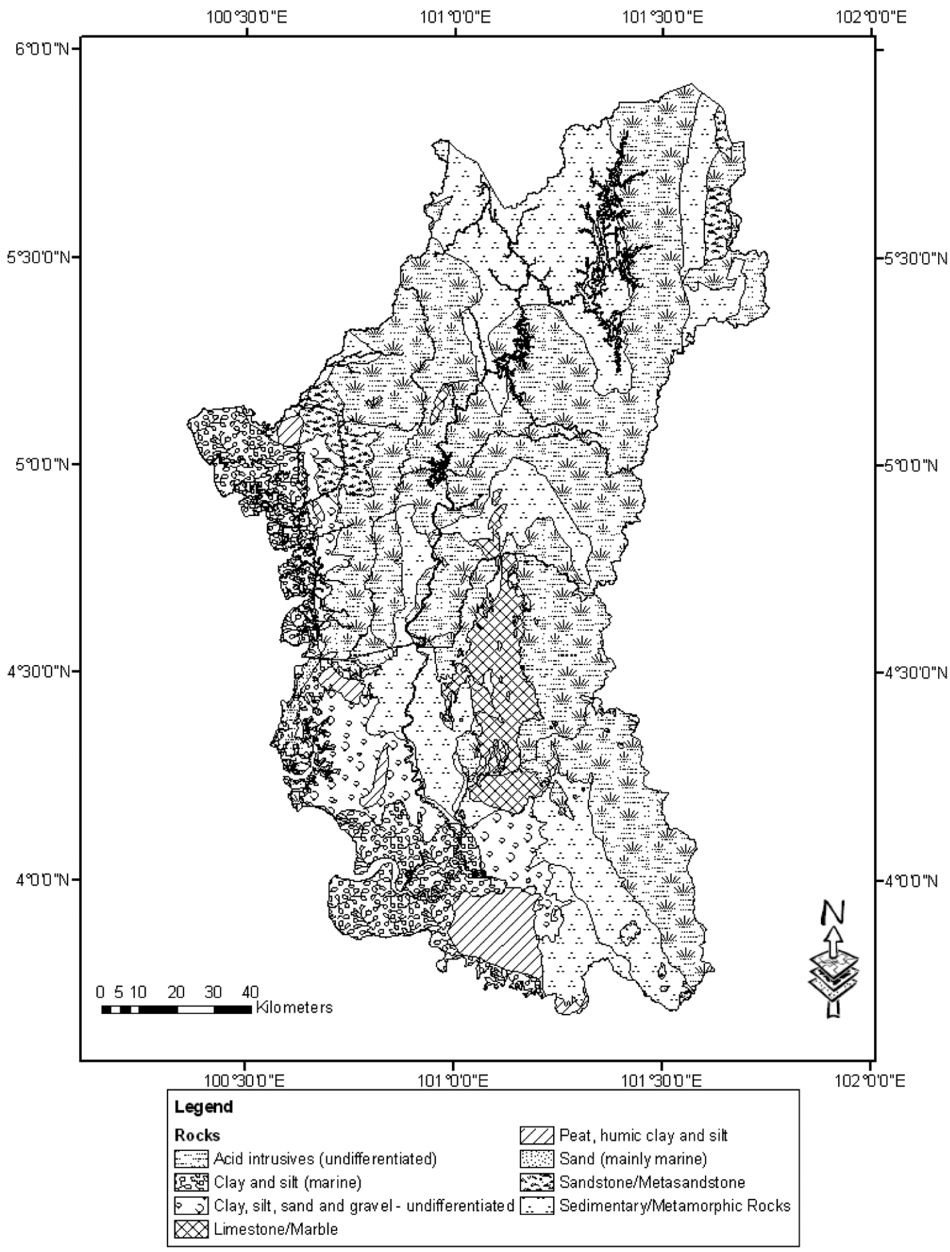

FIGURE 1. Lithological structures of Perak

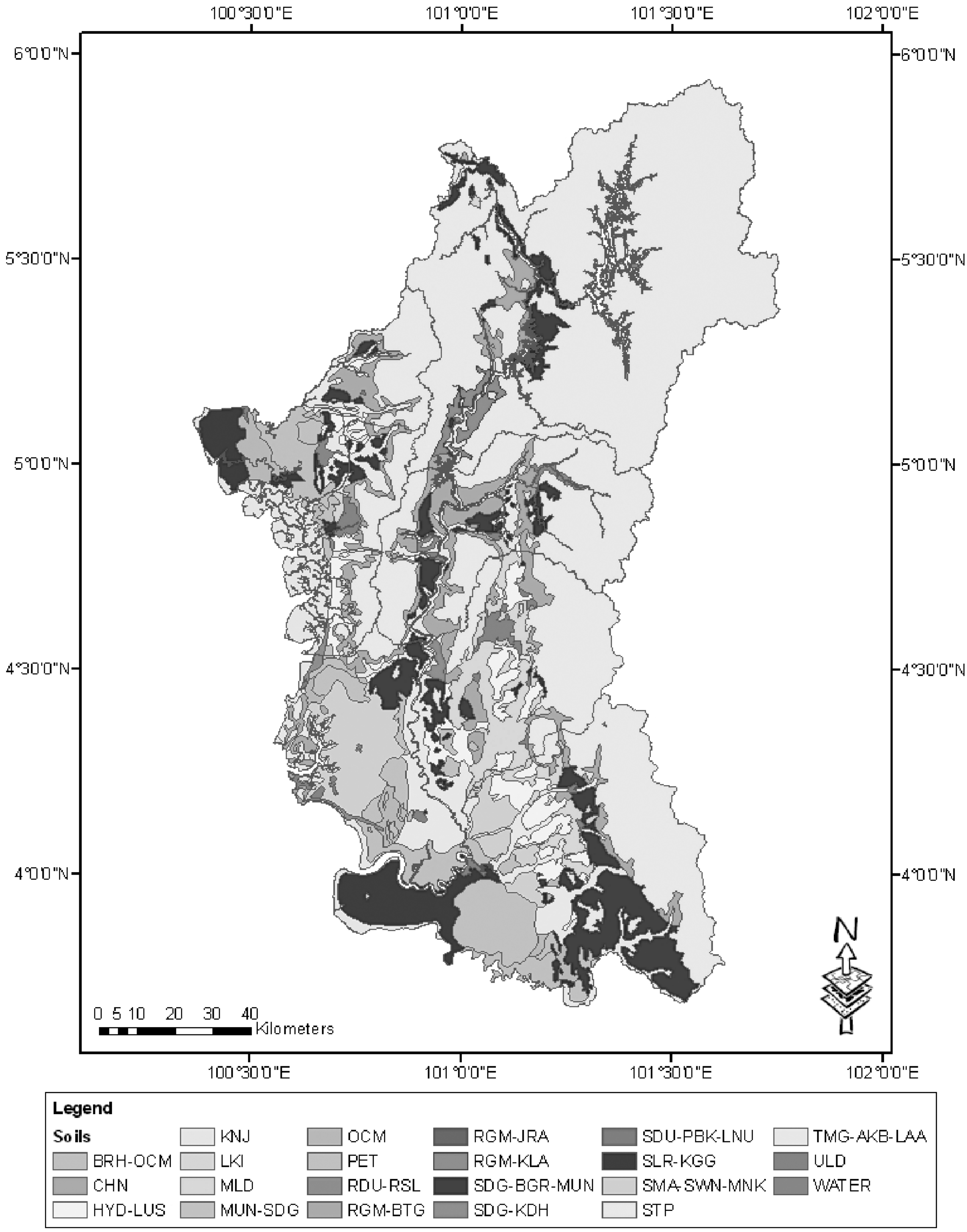

FIGURE 2. Soil types of Perak

determined by their accessibility, and their locations were pinpointed using GeoXM Explorer (Trimble Navigation Ltd) with an accuracy of 1-5 m.

A statistical method was used to predict gamma radiation dose rates based on a significantly represented number of actual dose rates measurements of the area underlying lithology and soil types (Ismail et al. 2004). The predicted dose rate (D_P) was estimated based on an equation derived from a multiple correlation regression of the actual mean dose rates for different lithology (D_L) and soil types (D_s).

The environmental radiation isodose map of Perak was plotted using the integrated visualization technique and spatial analysis in GIS environments. Every extrapolated dose rate point on the map was calculated by averaging a total of 15 adjacent radiation dose rate readings points using Inverse Density Weighted (IDW) interpolation technique in spatial analysis. A predicted isodose map drawn was based on a proposed 4 dose rate classes, ranging from 0.10 – 0.30 μSv hr^{-1}.

Results and Discussion

A significant number of actual dose rates measurement of areas with different underlying lithology and soil types were made. The dose rate readings for each soil type and lithological structure were averaged (Table 1). A multiple correlation regression carried out on the actual mean dose rates for different lithology (D_L) and soil types (D_s) gave a mathematical equation for predicted dose rate (D_P), i.e. $D_P = 0.35\ D_L + 0.82\ D_S - 0.02$, with an $r^2 = 0.736$. Such mathematical relationship suggested that D_L and D_S does not contribute equally towards the overall calculation of predicted dose rates as suggested by Ramli et al. (2003). D_L and D_S contributed differently towards the overall predicted dose rates, D_p.

Table 1 shows the predicted dose rates (D_P) based on all the different lithological structures and soil types combinations present in the state of Perak. Data obtained showed that a combination of acid intrusives and Steepland

TABLE 1. Average measured radiation dose rates of different lithological structures and soil types, and the predicted dose rates (μSv h^{-1}) of Perak calculated based on different lithological and soil types combinations

No	Lithology	Soil types	Dose Rates (μSv h^{-1})		
			D_L (Average value for lithology)	D_S (Average value for soil)	D_P (Predicted using equation)
1	Acid Intrusives	MLD	0.266	0.182	0.218
2	Acid Intrusives	RGM-BTG	0.266	0.271	0.291
3	Acid Intrusives	SDG-BGR-MUN	0.266	0.142	0.186
4	Acid Intrusives	STP	0.266	0.276	0.295
5	Acid Intrusives	TMG-AKB-LAA	0.266	0.252	0.276
6	Clay & Silt (marine)	BRH-OCM	0.204	0.198	0.210
7	Clay & Silt (marine)	KNJ	0.204	0.198	0.210
8	Clay & Silt (marine)	OCM	0.204	0.265	0.264
9	Clay & Silt (marine)	SLR-KGG	0.204	0.156	0.176
10	Clay & Silt (marine)	SMA-SWN-MNK	0.204	0.195	0.207
11	Clay & Silt (marine)	TMG-AKB-LAA	0.204	0.252	0.254
12	Clay, silt, sand & gravel	HYD-LUS	0.220	0.175	0.197
13	Clay, silt, sand & gravel	PET	0.220	0.114	0.147
14	Clay, silt, sand & gravel	SMA-SWN-MNK	0.220	0.195	0.213
15	Clay, silt, sand & gravel	TMG-AKB-LAA	0.220	0.252	0.260
16	Clay, silt, sand & gravel	ULD	0.220	0.236	0.247
17	Limestone/Marble	HYD-LUS	0.174	0.175	0.181
18	Limestone/Marble	MLD	0.174	0.182	0.186
19	Limestone/Marble	ULD	0.174	0.236	0.230
20	Peat, humic clay & silt	BRH-OCM	0.094	0.198	0.171
21	Peat, humic clay & silt	PET	0.094	0.114	0.102
22	Sand (mainly marine)	KNJ	0.262	0.237	0.262
23	Sand (mainly marine)	RDU-RSL	0.262	0.223	0.250
24	Sandstone/Metasandstone	RGM-BTG	0.226	0.271	0.277
25	Sandstone/Metasandstone	SDG-BGR-MUN	0.226	0.142	0.171
26	Sandstone/Metasandstone	TMG-AKB-LAA	0.226	0.252	0.262
27	Sedimentary/Metamorphic Rocks	CHN	0.145	0.160	0.158
28	Sedimentary/Metamorphic Rocks	HYD-LUS	0.145	0.175	0.170
29	Sedimentary/Metamorphic Rocks	SDG-BGR-MUN	0.145	0.142	0.143
30	Sedimentary/Metamorphic Rocks	SMA-SWN-MNK	0.145	0.195	0.187
31	Sedimentary/Metamorphic Rocks	TMG-AKB-LAA	0.145	0.252	0.233
32	Sedimentary/Metamorphic Rocks	WATER	0.145	0.108	0.116

Legend:
Soil types;

BRH-OCM	: Briah-Organic Clay and Muck	RGM-BTG	: Rengam-Bukit Temiang
CHN	: Chenian	RGM-KLA	: Rengam-Kala
HYD-LUS	: Holyrood-Lunas	SDG-BGR-MUN	: Serdang-Bungor-Munchong
KNJ	: Kranji	SDG-KDH	: Serdang-Kedah
LKI	: Langkawi	SLR-KGG	: Selangor-Kangkong
MLD	: Mined Land	STP	: Steepland
MUN-SDG	: Munchong-Serdang	TMG-AKB-LAA	: Telemong-Akob-Local Alluvium
OCM	: Organic Clay and Muck	ULD	: Urban Land
PET	: Peat	WATER	: Water
RDU-RSL	: Rudua-Rusila		

(STP) yielded the highest dose rate. For lithology types, acid intrusives yielded the highest dose rate while peat, humic clay and silt yielded the lowest dose rate. For soil types, Steepland yielded the highest dose rate while PET yielded the lowest dose rate.

The validity of the multiple correlation regression equation, $D_P = 0.35\ D_L + 0.82\ D_S - 0.02$, $r^2 = 0.736$ in predicting environmental gamma radiation was tested using t-test (Table 2). Results of t-test between actual dose rates (measured in the field) and their predicted values showed that 56% of the combinations were not significantly different at $p<0.05$.

Based on the validity of equation to predict dose rate and with comprehensive statistical analysis of spatio-temporal data, an isodose rates map of the environmental gamma radiation rates was produced (Figure 3). The predicted dose rates region were classified into 4 dose rates classes, ranging from 0.1 – 0.3 μSv hr^{-1}. Table 3 shows the area size covered by four categories of radiation dose rates. Dose rates between 0.25 – 0.3 μSv hr^{-1} cover the biggest area (i.e. 58.5 % of the total state of Perak). Only 6% of the area is in the category between 0.10 – 0.15 μSv hr^{-1}.

Using a direct 1:1 measured dose rate to predicted dose rate conversion, Ramli et al. (2003) reported that radiation levels in Kota Tinggi district, Johor were between 20 – 270 nGy hr^{-1} which is equivalent to 0.01 – 0.19 μSv hr^{-1} (using conversion factor of 0.7 Sv/Gy (UNSCEAR 2000)). The environmental external gamma radiation dose rates in Kota Tinggi, Johor were relatively lower than that observed in Perak. Such differences may be attributed to the different set of lithology and soil combinations and the presence of tin and amang processing plants in the current study area. However, Omar and Hassan (2002) reported that the radiation dose rates in Langkawi Island, Kedah ranged between 0.07 and 0.60 μSv hr^{-1}, which was approximately similar to those recorded in Perak. The high-end reading was attributed to a high concentration of ilmenite in Langkawi Island's Pantai Pasir Hitam. Langkawi Island also has a large formation of acid intrusive.

TABLE 2. T-test of difference between actual and predicted gamma dose rates for different lithology and soil types combinations

No	Lithology	Soil	t	Degree of Freedom	Significant (2-tailed)
1	Acid Intrusives	MLD	-2.855	48	0.006
2	Acid Intrusives	RGM-BTG	-1.531	64	0.131
3	Acid Intrusives	SDG-BGR-MUN	-2.101	42	0.042
4	Acid Intrusives	STP	-4.697	431	0.000
5	Acid Intrusives	TMG-AKB-LAA	2.390	20	0.027
6	Clay & Silt (marine)	BRH-OCM	-0.846	71	0.400
7	Clay & Silt (marine)	KNJ	-0.940	33	0.354
8	Clay & Silt (marine)	OCM	0.726	32	0.473
9	Clay & Silt (marine)	SLR-KGG	-2.238	104	0.027
10	Clay & Silt (marine)	SMA-SWN-MNK	0.201	7	0.847
11	Clay & Silt (marine)	TMG-AKB-LAA	2.588	29	0.015
12	Clay, silt, sand & gravel	HYD-LUS	-3.945	23	0.001
13	Clay, silt, sand & gravel	PET	-1.350	15	0.197
14	Clay, silt, sand & gravel	SMA-SWN-MNK	-0.449	103	0.654
15	Clay, silt, sand & gravel	TMG-AKB-LAA	-2.189	75	0.032
16	Clay, silt, sand & gravel	ULD	-0.173	13	0.866
17	Limestone/Marble	HYD-LUS	-2.194	70	0.032
18	Limestone/Marble	MLD	-1.995	167	0.048
19	Limestone/Marble	ULD	-4.731	16	0.000
20	Peat, humic clay & silt	BRH-OCM	0.790	8	0.452
21	Peat, humic clay & silt	PET	-2.797	89	0.006
22	Sand (mainly marine)	KNJ	0.813	4	0.462
23	Sand (mainly marine)	RDU-RSL	-0.726	5	0.501
24	Sandstone/Metasandstone	RGM-BTG	-1.274	6	0.250
25	Sandstone/Metasandstone	SDG-BGR-MUN	1.239	8	0.250
26	Sandstone/Metasandstone	TMG-AKB-LAA	-0.933	10	0.373
27	Sedimentary/Metamorphic Rocks	CHN	0.143	6	0.891
28	Sedimentary/Metamorphic Rocks	HYD-LUS	1.150	5	0.302
29	Sedimentary/Metamorphic Rocks	SDG-BGR-MUN	-3.010	125	0.003
30	Sedimentary/Metamorphic Rocks	SMA-SWN-MNK	-0.863	10	0.409
31	Sedimentary/Metamorphic Rocks	TMG-AKB-LAA	-2.369	29	0.025
32	Sedimentary/Metamorphic Rocks	WATER	-0.700	9	0.501

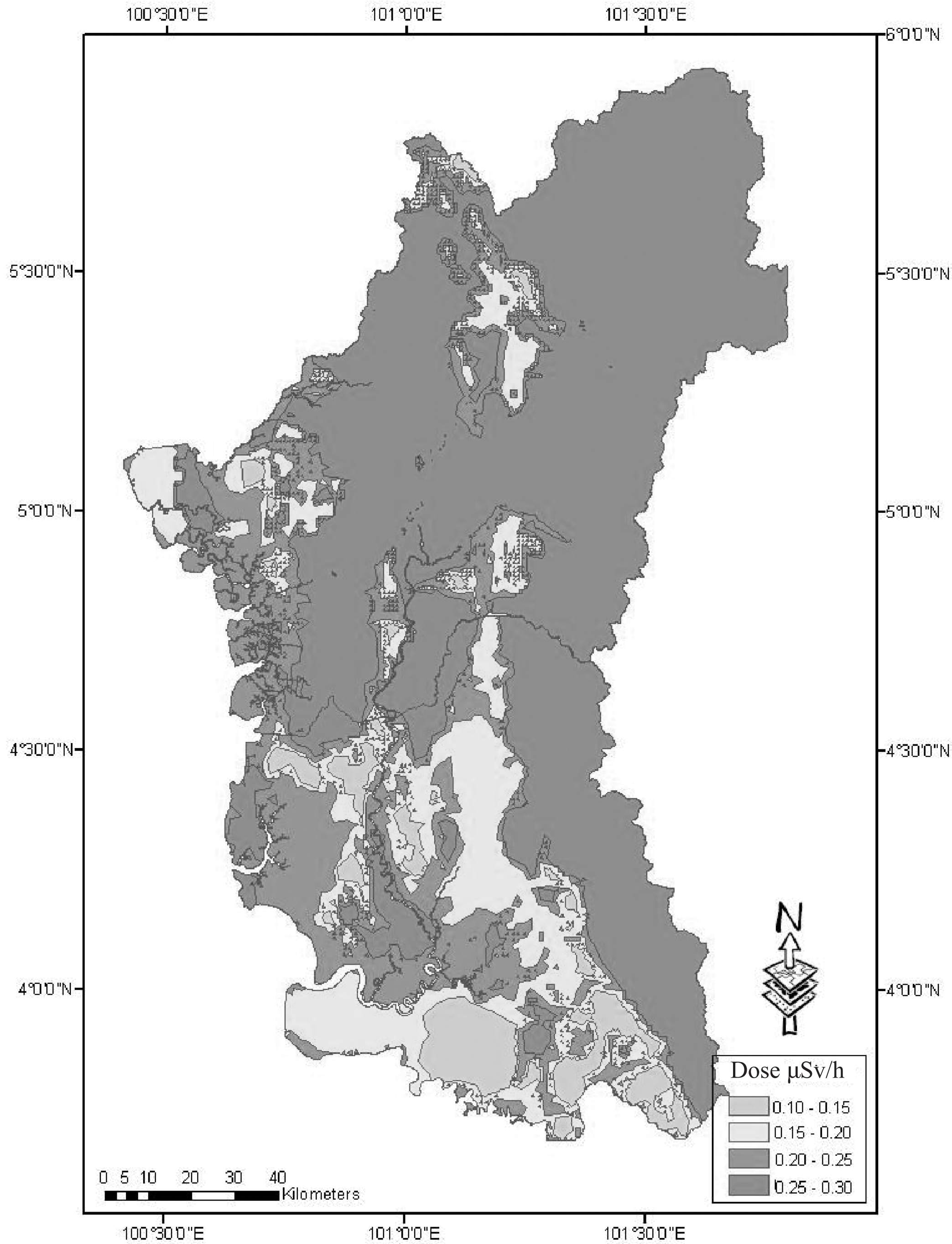

FIGURE 3. Environmental gamma radiation isodose map of Perak drawn from predicted dose rates multiple correlation regression equation

TABLE 3. Percent distribution of areas in Perak according to four radiation dose rate levels

Radiation Dose Rates Range (uSv/hr)	Area (km^2)	Percentage (%)
0.10 - 0.15	1142.8	5.5
0.15 - 0.20	3510.9	17.0
0.20 - 0.25	3905.1	19.0
0.25 - 0.30	12082.6	58.5
Total	20641.4	100.0

CONCLUSION

An attempt was made to propose and validate the use of statistical approach integrated with visualization technique and spatial analysis in GIS environments to map out the environmental gamma radiation isodose map. Results obtained showed that a multiple correlation equation incorporating dose rates based on the area underlying lithological structures and soil types, $D_P = 0.35\ D_L + 0.82\ D_S - 0.02$, with an $r^2 = 0.736$ may be used to predict and map environmental gamma radiation of the state of Perak.

Validity testing of the equation using t-test showed that 56% of the predicted dose rates were not significantly different from those measured on site. Results obtained also showed the validity of using lithological structures and soil types as parameters in predicting environmental gamma radiation dose rates.

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REFERENCES

Azlina, M.J., Ismail, B., Samudi, M.Y., Syed Hakimi Sakuma & Khairuddin, M.K. 2003. Radiological Impact Assessment of Radioactive Minerals of Amang and Ilminite on Future Land use Using RESRAD Computer Code. *Applied Radiation Isotopes* 58: 413-419.

Ismail, B., Othman M. & Soong H.F. 2000. Effect of tin dragging on the concentrations of arsenic, chromium and radium-226 in Soils and Water. *Jurnal Sains Nuklear Malaysia* 18(2): 111-119.

Ismail, B., Monawarah, N.M.Y., Hng, P.W., Sharifah Mastura, S.A. & Abdul Hadi, H.S. 2004. Statistical prediction of environmental gamma radiation doses based on geological structure-soil types in Kinta and Batang Padang districts, Perak. *Prosiding Seminar Bersama FST, UKM-FMIPA, UNRI* ke-3. 223-227.

Khairuddin, M.K., Hakimi, S.H.S.A. & Omar, M. 2000. Assessment on radiological doses associated with the disposal of amang. *Malaysian Science and Technology Congress*, Symposium B. 16-18 October, Perak, Malaysia.

Omar, M. & Hassan, A. 2002. The accurance of high concentration of natural radionuclides in black sand of Malaysian beaches. *Jurnal Sains Nuklear Malaysia* 20(1&2): 30-36

Ramli, A.T., Taufek A.A.R. & Lee, M.H. 2003. Statistical prediction of dose rate based on geological features and soil types in Kota Tinggi district, Malaysia. *Applied Radiation Isotopes* 59: 393-405.

UNSCEAR. 2000. Sources and effects of ionizing radiation. *United Nations Scientific Committee on the Effects of Atomic Radiation, 2000 Report*. New York: United Nations.

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