STATISTICAL PREDICTION OF ENVIRONMENTAL EXTERNAL GAMMA RADIATION DOSES OF PERAK, MALAYSIA

Zalina Rahmat*, Ismail Bahari, Muhammad Samudi Yasir , Redzuwan Yahaya, Amran Ab. Majid

Nuclear Science Programme, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
**E-mail:zalinarahmat@gmail.com, Tel: +60389213051, Fax: +60389269470*

ABSTRACT

Concentrations of Natural Occurring Radioactive Material (NORM) and terrestrial gamma radiation have been shown to be associated with certain lithology and soil types. An attempt was made to statistically predict and validate environmental gamma radiation dose rates based on limited number of actual field measurements using sodium iodide (NaI(Tl)) detector. Statistical analysis including the correlations between the actual and predicted dose were made based on 32 different lithology and soil type combinations. Results of field measurements, have shown that more than 50% of the predicted data were not significantly different from the actual measured data. The interpolation method in GIS was used to produce an isodose map based on the prediction equation. A correlation of multiple regression on the predicted versus lithology and soils dose rates gave relationships of $D_P = 0.35\ D_L + 0.82\ D_S - 0.02$, $r^2 = 0.736$. A predicted isodose map was subsequently plotted base on 4 dose rates classes, ranging from 0.1 – 0.3 $\mu Svhr^{-1}$.

ABSTRAK

Kepekatan NORM dan aras sinar gama terestrial menunjukkan bahawa ia dipengaruhi oleh litologi dan jenis tanih tertentu. Satu kajian telah dilakukan dengan meramal secara statistik dan mengesahkan kadar dos sinaran gama sekitaran berdasarkan bilangan pengukuran sebenar di lapangan yang terhad dengan menggunakan pengesan natrium iodide (NaI(Tl). Analisis statistik termasuk korelasi di antara dos sebenar dan dos ramalan dilakukan berdasarkan 32 kombinasi litologi dan jenis tanih yang berlainan. Hasil yang diperoleh dari pengukuran lapangan, menunjukkan bahawa lebih daripada 50% dari dos ramalan tidak berbeza dengan bacaan sebenar. Kaedah interpolasi dalam GIS telah digunakan untuk menghasilkan peta isodos berdasarkan persamaan ramalan. Korelasi bagi regresi berganda ramalan bagi litologi dan jenis tanih memberikan hubungan $D_P = 0.35\ D_L + 0.82\ D_S - 0.02$, $r^2 = 0.736$. Seterusnya peta dos ramalan telah diplot berdasarkan 4 kelas kadar dos dengan julat 0.1 – 0.3 μSvj^{-1}.

Keywords: NORM, GIS, isodose map, Malaysia

INTRODUCTION

Tin mining areas have been known to have higher concentrations of NORM. The mining of tin and processing of amang (a by-product of tin mining) for valuable minerals, has stirred occupational and environmental radiological concerns due to the technological enhancement of naturally occurring radioactive materials (Khairuddin *et al*. 2000; Azlina *et al*. 2003). Large areas of former tin mining lands are now being rejuvenated and developed for all sorts of man-made activities including housing, industries and recreational areas. Such activities have provided concern on radiological risk of its occupiers. Ramli *et. al* (2003) have also shown that different lithology and soil types yielded different levels of external radiation. Improvement of economic climate of Malaysia has resulted in the opening up of more lands and increase rejuvenation of ex-mining land. All these makes it more important to identify areas for development that has the lowest radiological risk.

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 dose rates distribution 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's finding using different lithology and soil combinations in Kinta and Batang Padang, Perak but had to adapt the direct 1:1 correlation between geological structures – soil types combination between measured and predicted dose rate proposed by Ramli. Ismail *et al.* (2004) regressed all predicted dose rates against the measured dose rates and apply the regression equation to predict dose rates of unmeasured areas having similar lithological structures and soil types combination.

This study adopted the method used by Ismail *et al.* (2004) and tries to integrate it with Geographical Information System (GIS) approach to map out a predicted 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. Figure 1 shows the map of the districts in Perak. The lithology and soil types of Perak are shown in Figures 2 and 3.

External terrestrial gamma dose rates were measured using 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. Numbers of areas measured were largely determined by their accessibility, and their locations were pinpointed using GeoXM Explorer (Trimble Navigation Ltd) with an accuracy of 1-5 m. The predicted dose rate was calculated as the mean of gamma radiation dose rates based on the soil types and the mean of gamma radiation dose rates based on underlying lithology types (Ramli *et al.* 2003; Ismail *et al*. 2004).

An environmental gamma radiation isodose rates map of the study area was develop based on the equation of $D_P = 0.35\ D_r + 0.82\ Ds - 0.02$ ($r^2 = 0.736$). The statistical method was developed to help predict gamma radiation dose rates based on a significantly represented number of actual measurements of a particular sites or areas (Ismail et al., 2004). A large amount of data concerning the external environmental radiation of Perak were analysed using an integrated visualization technique and spatial analysis in GIS environments. Every point was extrapolated by averaging a total of 15 points radiation dose rates reading nearby with IDW (Inverse Density Weighted) interpolation technique in spatial analysis. A predicted isodose map was drawn based on a proposed 4 dose rate classes, ranging from 0.10 – 0.30 $\mu Svhr^{-1}$.

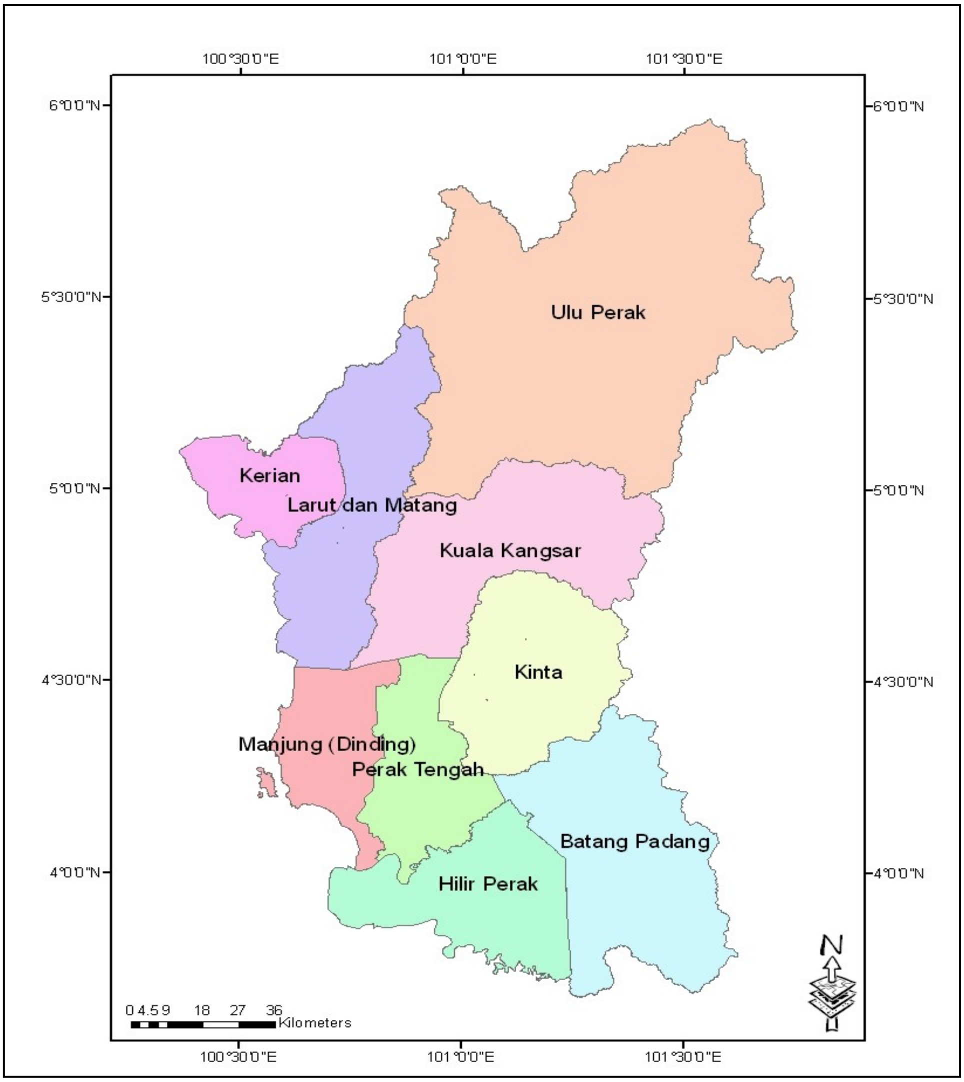

Figure 1: Districts of Perak

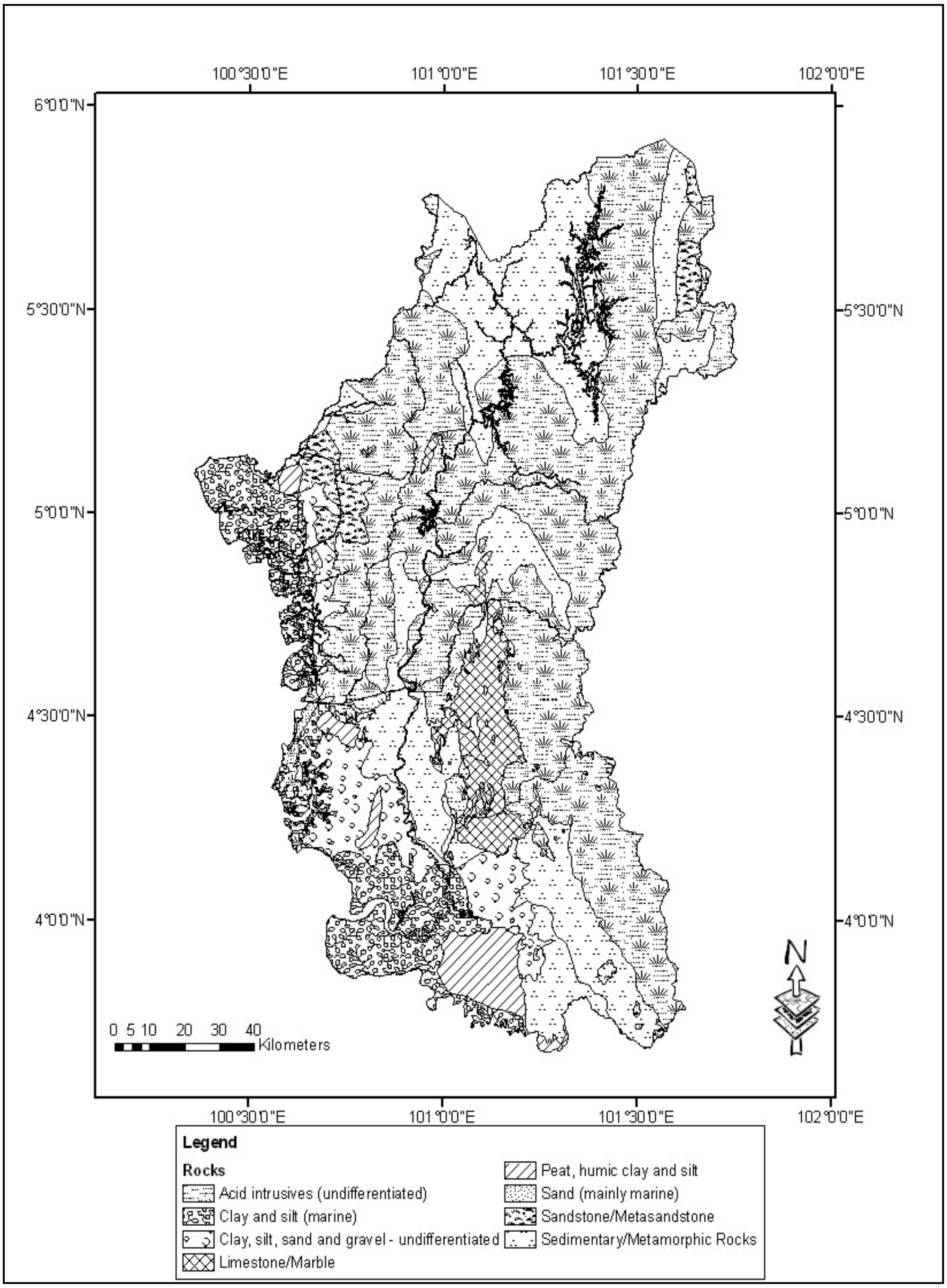

Figure 2: Lithology of Perak

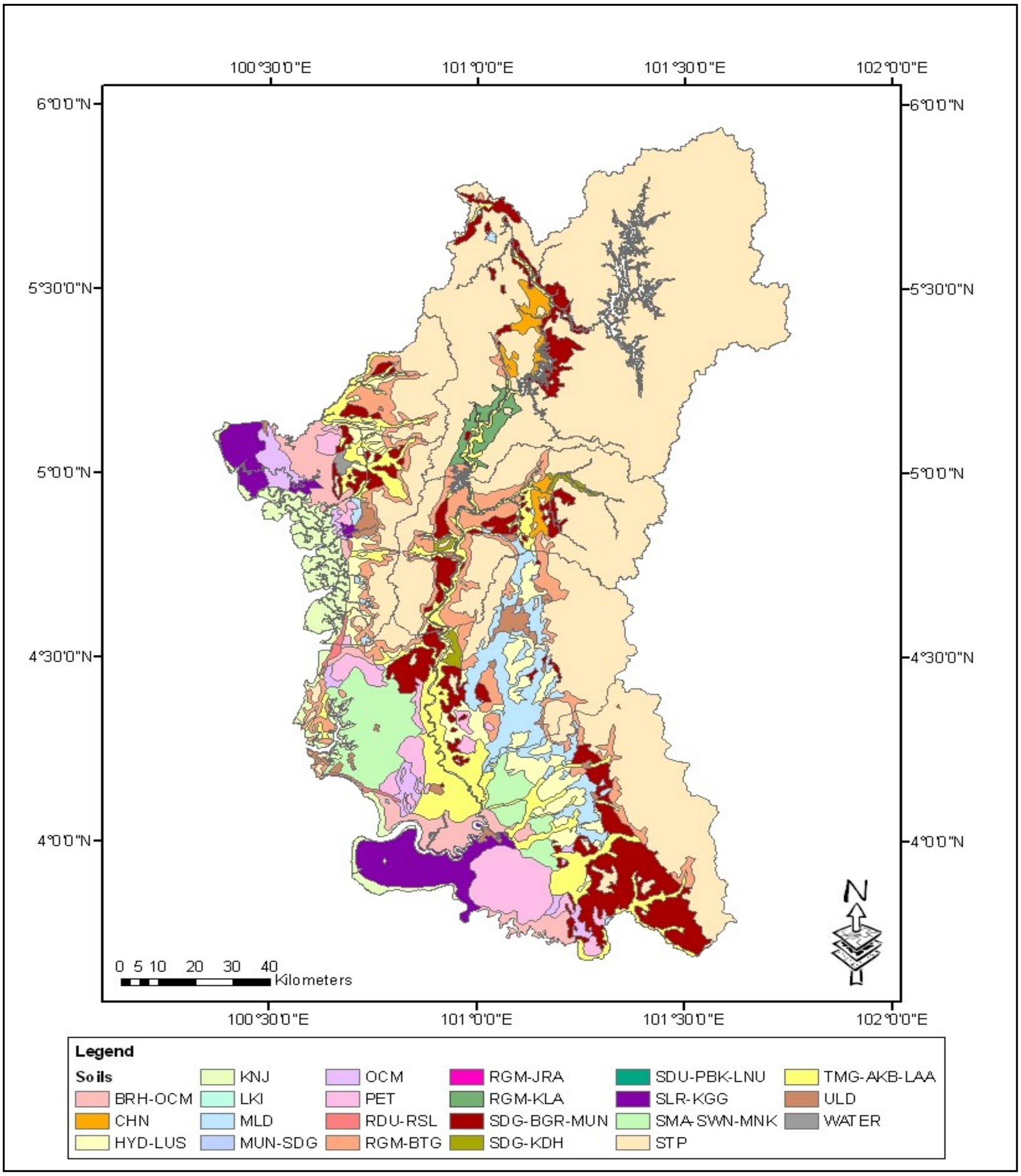

Figure 3: Soil Types of Perak

RESULTS AND DISCUSSIONS

T-tests were carried out to test any significant diffrences between the actual dose rates and their predicted values. Results of these tests were shown in Table 1. It shows that 56% of the combinations had no significant differences between the predicted and the actual mean dose rates ($p<0.05$).

Table 1: T-test of different between actual and predicred gamma dose rates for different lithology and soil types combinations using Sodium Iodide detectors.

Bil	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

Table 2 shows the predicted external dose rates for different lithological and soil types combinations. Data obtained showed that a combination of Acid intrusives and Steepland (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.

Table 2 : Predicted dose rates (μSvhr^{-1}) of Perak calculated based on different lithological and soil types combinations

			Dose Rates (μSvhr^{-1})		
No	Lithology	Soil types	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			

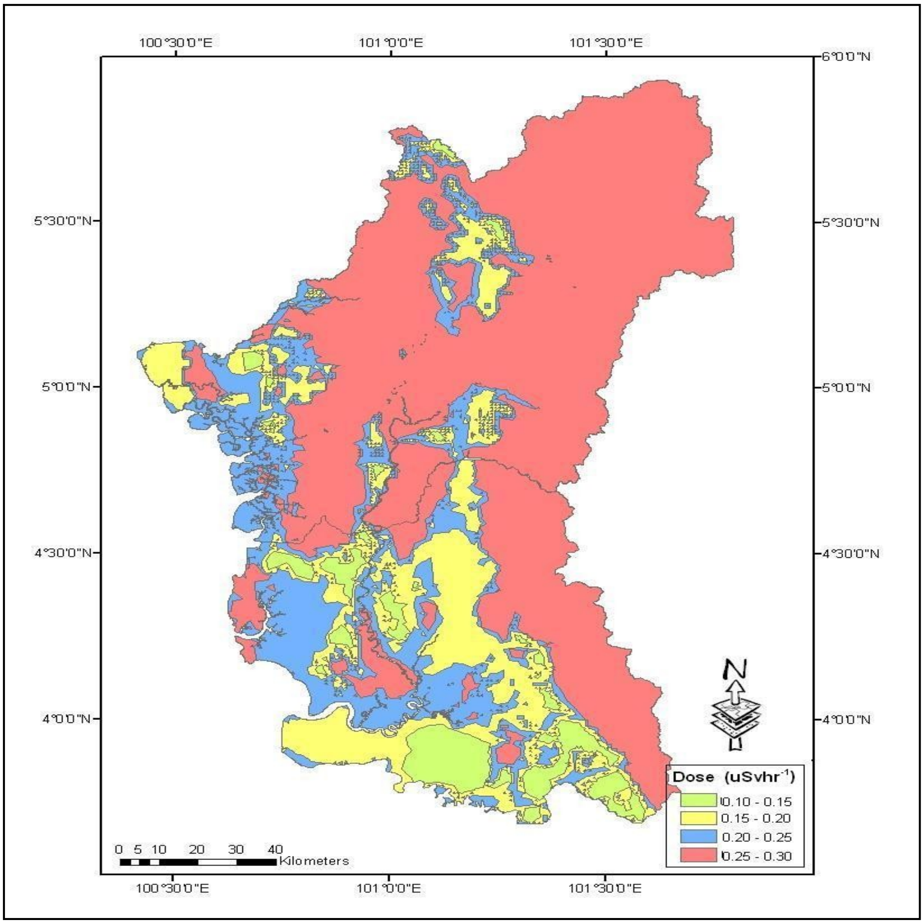

Figure 4: Map of Predicted Dose Rates of Perak

Based on the validity of equation $D_P = 0.35\ D_L + 0.82\ D_S - 0.02$, $r^2 = 0.736$ and with comprehensive statistical analysis of spatio-temporal data, an isodose rates map of the environmental gamma radiation rates was produced (Figure 4). The predicted dose rates regions were classified into 4 dose rates classes, ranging from 0.1 – 0.3 μSvhr^{-1}. Table 3 shows the area size covered by four categories of radiation dose rates. Dose rates between 0.25 – 0.3 μSvhr^{-1} cover the biggest area (i.e. 58.5 % of the total state of Perak). Only 6% of the area was in the category between 0.10 – 0.15 μSvhr^{-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 μSvhr^{-1} (using conversion factor of 0.7 SvGy^{-1} (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 ranges between 0.07 – 0.60 $\mu Svhr^{-1}$, which was approximately similar to those recorded in Perak. The high end reading was attributed to a high concentration of ilmenite in a particular beach in Langkawi. Langkawi Island also has a large formation of acid intrusive.

Table 3: Area of environmental gamma dose rates region and the population density

Radiation Dose Rates Range ($uSvhr^{-1}$)	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 statistically predict the environmental gamma radiation dose rates based on limited number of actual field measurements using Sodium Iodide detectors. The predicted isodose map was drawn through the integration of statistical dose rate prediction based on the lithology and soil types combinations. The dose rate prediction was based on a regression curve derived from statistically accepted relationship between the predicted dose rate and actual reading made for each lithological-soil types combinations. The use of a regressed equation between all these variables is recommended because it takes into considerations of other lithology and soil types combinations.

ACKNOWLEDGEMENT

The authors wish to thank the generous funding provided by the Ministry of Science, Technology and Innovation Malaysia (06-01-02SF0142) for this research.

REFERENCES

AELB, 1994a. Atomic Energy Licensing Act, 1994a. Atomic Energy Licensing (Small Amang Factories) (Exemption) Order 1994. Lebaga Perlesenan Tenaga Atom, Malaysia.

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. *Appl. Rad. Iso*t. **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, 2000, Symposium B, 16-18 October 2000, 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. *Appl. Rad. Isot*. **59**: 393-405.

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