TERRESTRIAL GAMMA RADIATION DOSE RATE AND RADIOLOGICAL HEALTH RISK ASSESSMENT OF WESTERN REGION OF SARAWAK

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DEDICATION

This thesis is a gift for my mother.

Thank you for believing in my potential

and allowing me to pursue my own path as I saw fit.

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ABSTRACT

Terrestrial gamma radiation (TGR) is one of the contributors for ionizing radiation exposure to society. In this study, the baseline TGR dose rate measurement and radiological health risk assessment of west Sarawak were made. The study area covers 5 divisions; Kuching, Samarahan, Serian, Sri Aman and Betong, for a total area of 20,259.2 km^2 using random sampling method as data point selection. The outdoor measurements were performed at approximately 1 meter above ground level, avoiding human infrastructures, using Ludlum 19 micro R meter NaI(Tl) scintillation detector. Twenty-nine soil samples were taken across the 5 divisions covering combinations of 9 geological backgrounds and 7 soil types. A hyper-pure Germanium spectrometer was then used to detect the samples' ^{238}U, ^{232}Th, and ^{40}K radionuclides concentrations producing a correction factor C_f = 0.544 from linear fitting of $y = 0.544x + 8.13$. Excluding 2 outliers, a total of 239 data were corrected with C_f producing a mean of 47 ± 1 nGy h^{-1}, with a range between 5 nGy h^{-1} – 103 nGy h^{-1}. A multiple regression analysis was conducted between geologically-respective mean dose and soil types-respective mean dose against TGR dose rate, generating $D_{G,S} = 0.847D_g + 0.637D_s - 22.313$ prediction model with a normalized beta equation of $D_{G,S} = 0.605D_g + 0.395D_s$. The model showed 100% acceptance of sign test null hypothesis when used against TGR dose rate readings. Calculations of radiological health risk assessment produce annual effective dose equivalent of AEDE = 0.058 mSv $year^{-1}$, radium equivalent dose Raeq = 140.52 Bq kg^{-1} and external hazard index $H_{ex} = 0.4$. An isodose map was generated using kriging spatial analysis in ArcGIS 10.3 software.

ABSTRAK

Sinar gama daratan (SGD) merupakan salah satu penyumbang kepada dedahan sinaran mengion terhadap masyarakat. Dalam kajian ini, pengukuran kadar dos SGD asas dan pentaksiran risiko kesihatan radiologi di kawasan barat negeri Sarawak telah dilakukan. Kawasan kajian meliputi 5 bahagian; Kuching, Samarahan, Serian, Sri Aman, dan Betong, merangkumi keluasan 20,259.2 km^2 dengan menggunakan kaedah persampelan rawak sebagai teknik pemilihan titik bacaan data. Pengukuran bacaan data luar bangunan dilakukan pada kira-kira 1 meter di atas permukaan tanah dan menjauhi infrastruktur binaan manusia menggunakan pengesan sintilasi Ludlum 19 micro R meter NaI(Tl). Sebanyak 29 sampel tanah telah diambil merentasi 5 bahagian merangkumi kombinasi 9 latar belakang geologi dan 7 jenis tanah. Spektrometer Germanium hiper-tulen telah digunakan untuk mengukur kepekatan radionuklid ^{238}U, ^{232}Th, dan ^{40}K, menghasilkan faktor pembetulan C_f = 0.544 daripada penyuaian linear $y = 0.544x + 8.13$. Dengan penyingkiran 2 data terpencil, sebanyak 239 data telah diperbetulkan dengan Cf menghasilkan min 47 ± 1 nGy j^{-1}, dengan julat antara 5 nGy j^{-1} – 103 nGy j^{-1}. Analisis regresi berganda dilakukan antara min dos geologi dan min dos jenis tanah terhadap kadar dos SGD, menghasilkan model jangkaan $D_{G,S} = 0.847G_g + 0.637D_s - 22.313$ yang mempunyai $D_{G,S} = 0.605D_g + 0.395G_s$ sebagai persamaan beta yang ternormal. Model ini menunjukkan 100% penerimaan ujian tanda apabila digunakan terhadap bacaan kadar dos SGD. Pengiraan risiko kesihatan radiologi pula menghasilkan nilai dos efektif setara tahunan AEDE = 0.058 mSv tahun^{-1}, kadar dos radium setara Raeq = 140.52 Bq kg^{-1}, dan indeks hazad luar H_{ex} = 0.4. Sebuah peta isodos telah dijana menggunakan analisis ruangan kriging dalam perisian komputer ArcGIS 10.3.

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LIST OF ABBREVIATIONS

ACXRP	-	Advisory Committee on X-ray and Radium Protection
GPS	-	Global Positioning System
IAEA	-	International Atomic Energy Agency
ICRP	-	International Commission on Radiological Protection
NCRP	-	National Council on Radiation Protection and Measurements
UNSCEAR	-	United Nations Scientific Committee on the Effects of Atomic Radiation

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Studies show radiation exposure to society is contributed from multiple sources. Although medical radiation exposure is one of the highest contributors, its doses and effects are regulated and monitored throughout the world. Other sources of radiation however are not as closely monitored, and the extent of the effects are vaguely known for some of them (IAEA, 1989). Terrestrial gamma radiation is one of these less apparent sources but requires attention, nonetheless.

For peninsular Malaysia, a proper baseline data for level of background radiation is already available from old airborne survey data along with ground level measurement studies made in recent years. Sarawak and Sabah states however lack such complete data throughout the 2 states. As a study for Sabah state is currently underway (Siti Fharhana et al., 2017), this natural radiological research focuses on terrestrial gamma radiation for west of Sarawak state.

1.2 Problem Statement

Natural background radiation is part of annual radiation exposure to the general population. Terrestrial gamma radiation (TGR), an external natural gamma radiation source, contributes to the overall radiation exposure and a complete baseline data of these background radiation dose is important for radiation safety monitoring of the general population. As a continuous radiation and cancer risk safety measures, a baseline data of the TGR dose rates is a critical reference for establishment of radiation safety standards.

For peninsular Malaysia (West of Malaysia), such data are available in the form of airborne dose survey by Agocs, and multiple terrestrial gamma radiation dose studies in recent years by Ramli, Apriantoro, Muneer, Garba, Sanusi, and many others (Apriantoro, 2011; Garba, 2016; Ahmad Termizi Ramli et al., 2005; Saleh et al., 2014; Sanusi et al., 2014). Sarawak state, however, lacks similar comprehensive studies of radiation safety.

This study focuses on TGR dose rate in west of Sarawak via in-situ gamma dose rate measurements complemented with radionuclide concentration study through gamma spectroscopy. A prediction model will also be constructed in respect to geological and soil distribution of the study areas for prediction of TGR dose rates in hard to reach areas of similar geological and soil components and an isodose map of the study area will be constructed for radiological referencing.

1.3 Study Objectives

1. Measuring terrestrial gamma radiation dose rate in west Sarawak,
2. Studying U^{238}, Th^{232}, and K^{40} radionuclides concentrations of soil samples taken throughout the studied areas,
3. Calculating the combined contribution of geology and soil type to gamma radiation dose rate for the study,
4. Formulating a prediction model of TGR dose rate in respect to geology and soil types present in studied areas,
5. Constructing an isodose map of the studied areas.

1.4 Research Scope

This study covers 5 divisions of west Sarawak; Kuching, Samarahan, Serian, Sri Aman, and Betong. Serian was formerly part of Samarahan division, formerly a district status, elevated to division status on 11 April 2015. These 5 divisions are located in between latitudes 0° 50’ and 2° 6’ North, and 109° 32’ and 112° 15’ East.

They cover a total of 20,259.2 km^2 and by 2010, Kuching division, where the capital of Sarawak is situated, has a population of 705,546, while the other divisions have populations of 159,023, 91,599, 94,774, and 108,225 for Samarahan, Serian, Sri Aman, and Betong divisions respectively. From diversity of geological and soil types point of view, these 5 divisions carry a more complex distribution of geology and soil types compared to the rest of Sarawak, with 9 geological backgrounds and 7 soil types.

The research focuses on natural terrestrial gamma radiation dose, mainly due to geological and soil types. In-situ measurements using a scintillation detector were collected at points determined by random sampling and ease of access throughout the 5 divisions. To determine geology and soil type contributions to the gamma radiation dose rate, a prediction model of geo-soil pairing was constructed, and the results were then compared statistically to the dose rate measurements.

Next, TGR dose rate measurements and ^{238}U, ^{232}Th, and ^{40}K radionuclide concentrations were used in radiological health risk calculations which are annual effective dose equivalent (AEDE), cancer risk probability (G_r), equivalent radium activity (Ra_{eq}), and external hazard index (H_{ex}). These data will be critical references in preparation of radiological safety standards for the studied areas in the future as baseline data to be compared in the case of radiation level changes due to human activities.

Finally, an isodose map was constructed using ArcGIS 10.3 software and geospatial interpolation Kriging was used to provide a spatial data analysis of terrestrial gamma radiation dose rate of the studied areas.

1.5 Research Significance

Sarawak lacks a comprehensive terrestrial gamma radiation dose rate data. A proper gamma radiation dose rate study is required to establish a baseline reference in annual radiation exposure to the general population.

Other than that, this research constructs a prediction model of gamma radiation dose rate in respect to geology and soil types composition relationship, providing a method for estimation of TGR dose rate in hard to reach areas with similar geology and soil compositions. Since the 5 divisions of interest comprises of a more complex geology and soil composition compared to the rest of Sarawak, the model should be able to estimate GDR data for most areas of the rest of Sarawak with similar geo-soil pair profiles.

Finally, the study will produce an isodose map of the studied areas that can be used in human infrastructure and activity planning in the future with public radiological safety standards in mind.

1.6 Chapters Layout

This thesis is comprised of 5 chapters, Introduction, Literature Review, Research Methodology, Data and Results, and Conclusion and Recommendations.

Chapter 1 of the thesis, Introduction, lays out the basis for the study to be carried out. It explains about the background, problem statement, research scope, and research significance of the study.

Chapter 2 of the thesis, Literature Review, lists out and briefly describe a few related topics used in the study. Descriptions of some basic definitions are available in this chapter, along with explanations of related lithologies of the study areas. Similar previously conducted studies done locally and internationally are also mentioned here.

Chapter 3 of the thesis, Research Methodology, describes the procedures used in carrying out the study. The area of the study is included in this chapter, followed by data measurement procedures, soil sampling procedures, statistical analysis, spatial analysis, and health risk assessment equations.

Chapter 4 of the thesis, Results and Discussions, is comprised of data obtained for the study and the corresponding possible explanations for them. The chapter also includes result of statistical analysis, spatial analysis, and health risk assessments calculated using the analayzed data.

Chapter 5 of the thesis, Conclusion and Recommendations, summarizes the findings of the study and discusses a few recommendations for future similar or related

REFERENCES

Alaamer, A. (2008). Assessment of human exposures to natural sources of radiation in soil of Riyadh, Saudi Arabia. *Env. Sci, 32,* 229-234.

Almayahi, B. A., Tajuddin, A. A., & Jaafar, M. S. (2012). Effect of the natural radioactivity concentrations and 226Ra/238U disequilibrium on cancer diseases in Penang, Malaysia. *Radiation Physics and Chemistry, 81*(10), 1547-1558. doi:https://doi.org/10.1016/j.radphyschem.2012.03.018

Al-Sulaiti, H., Alkhomashi, N., Al-Dahan, N., Al-Dosari, M., Bradley, D. A., Bukhari, S., & Santawamaitre, T. (2011). Determination of the natural radioactivity in Qatarian building materials using high-resolution gamma-ray spectrometry. *Nuclear Instruments and Methods in Physics Research Secton A: Accelerators, Spectrometers, Detectors, and Associated Equipment, 652(1),* 915-919. doi:10.1016/j.nima.2011.01.020

Andriesse, J. P. (1972). *The soils of West-Sarawak (East-Malaysia)* (Vol. 1: Text). Kuching: Department of Agriculture, Sarawak, East Malaysia - Soils Devision Research Branch.

Apriantoro, N. (2011). *Kajian radiologi alam sekitar negeri Perak dan implikasi kesihatan radiologi.* Universiti Teknologi Malaysia, Johor.

Bushberg, J. T. (2012). *The essential physics of medical imaging*. Philadelphia: London.

Dendy, P. P., & Heaton, B. (2003). *Physics for diagnostic radiology*. Bristol: Institute of Physics Pub.

Department of Standards, M. (2015). *Geographic information/geomatics - Feature and attribute codes (First revision)*. Shah Alam: SIRIM Berhad.

Directorate of National Mapping Malaysia (Cartographer). (2010). Sarawak

Eisenbud, M., & Gesell, T. F. (1997). *Environmental radioactivity: from natural, industrial, and military sources* (4 ed.). San Diego: Academic Press.

Gabdo, H., Ramli, A., Mohd Sanusi, M. S., Saleh, M., & Garba, N. (2014). Terrestrial gamma dose rate in Pahang state Malaysia. *Journal of Radioanalytical and Nuclear Chemistry, 299:,* 6. doi:10.1007/s10967-014-2928-1

Garba, N. (2016). *Natural Radiological Studies of Kelantan and Terengganu States, Malaysia*. Universiti Teknologi Malaysia, Johor.

Garmin. (2000). *Chartplotting receiver owner's manual and reference guide*. Kansas: Garmin Corporation Ins.

Gignoux, M. (1955). *Stratigraphic geology*. San Francisco: W.H. Freeman and Co.

Hani, N. Z. (2015). *Kajian Radiologi Alam Sekitar di Iskandar Malaysia Johor, Malaysia*. Universiti Teknologi Malaysia, Johor.

Harb, S. (2008). Natural radioactivity and external gamma radiation exposure at the coastal Red Sea in Egypt. *Radiation Protection Dosimetry, 130*, 376-384. doi:10.1093/rpd/ncn064

IAEA, International Atomic Energy Agency. (1989). *Measurement of Radionuclides in Food and the Environment, A Guidebook. Technical Reports Series No. 295*. Vienna: International Atomic Energy Agency.

Jabatan Pertanian Kuching Sarawak (Cartographer). (2008). Soil Maps of Sarawak

Jabatan Pertanian Sarawak. (2017). Betong Divisional Agriculture Office. Retrieved from http://www.doa.sarawak.gov.my

Kathren, R. L., & Ziemer, P. L. (1980). *Health physics, a backward glance: thirteen original papers on the history of radiation protection*. Elmsford, NY: Pergamon Press.

Knoll, G. F. (2010). *Radiation detection and measurement*. Hoboken, N.J: Wiley.

Lee, C. P. (2004). *Stratigraphic lexicon of Malaysia*. Kuala Lumpur: Malaysian Stratigraphic Central Registry Database Subcommittee, Geological Soc. of Malaysia.

Lee, S. K., Wagiran, H., Ramli, A. T., Apriantoro, N. H., & Wood, A. K. (2009). Radiological monitoring: terrestrial natural radionuclides in Kinta District, Perak, Malaysia. *J Environ Radioact, 100*(5), 368-374. doi:10.1016/j.jenvrad.2009.01.001

Ludlum. (1993). *Instruction Manual of Ludlum Model 19 Micro R Meter*. Texas: Ludlum Measurements, Inc.

Majlis Daerah Serian. (2017). Sejarah Kami. Retrieved from http://www.seriandc.sarawak.gov.my

Majlis Daerah Sri Aman. (2017). Pengenalan. Retrieved from http://www.sriamandc.sarawak.gov.my

Martin, B. R. (2012). *Nuclear and Particle Physics*. Chichester: Wiley.

Merrill, R. T. (2010). *Our magnetic Earth: The science of geomagnetism*. Chicago: The University of Chicago Press.

Meyers, L. S., Gamst, G., & Guarino, A. J. (2006). *Applied multivariate research: design and interpretation*. Thousand Oaks: Sage: SAGE Publications.

Minerals and Geoscience Department Malaysia, S. (Cartographer). (2013). Geological Map of Sarawak

Nair, R. R. K., Rajan, B., Akiba, S., Jayalekshmi, P., Nair, M. K., Gangadharan, P., . . . Sugahara, T. (2009). BACKGROUND RADIATION AND CANCER INCIDENCE IN KERALA, INDIA—KARANAGAPPALLY COHORT STUDY. *Health Phys, 96*(1), 55-66. doi:10.1097/01.Hp.0000327646.54923.11

Parry RA, Glaze SA, Archer BR. The AAPM/RSNA physics tutorial for residents. Typical patient radiation doses in diagnostic radiology. Radiographics. 1999;19 (5): 1289-302.

Penelope, A., & Jerry, W. (2007). *Farr's Physics for Medical Imaging (Second Edition)*. W.B. Saunders.

Pentadbiran Bahagian Kuching. (2017). Sejarah Kuching. Retrieved from http://www.kuching.sarawak.gov.my

Pentadbiran Bahagian Samarahan. (2017). Profile Bahagian Samarahan. Retrieved from http://www.samarahan.sarawak.gov.my

Ramli, A. T., Hussein, A. W., & Lee, M. H. (2001). Geological influence on terrestrial gamma radiation dose rate in the Malaysian State of Johore. *Appl Radiat Isot, 54*(2), 327-333.

Ramli, A. T., Sahrone, S., & Wagiran, H. (2005). Terrestrial gamma radiation dose study to determine the baseline for environmental radiological health practices in Melaka state, Malaysia. *Journal of Radiological Protection, 25*(4), 435-450. doi:10.1088/0952-4746/25/4/006

Saha G.B. (2013) Radioactive Decay. In: Physics and Radiobiology of Nuclear Medicine. Springer, New York, NY

Saleh, M. (2013). *Environmental Radiology of Johor State, Malaysia.* Universiti Teknologi Malaysia, Johor.

Saleh, M., Ramli, A., Hamzah, K., Alajerami, Y., Abu Mhareb, M., Aliyu, A., & Zati Hani Binti Abu Hanifah, N. (2014). Natural environmental radioactivity and the corresponding health risk in Johor Bahru District, Johor, Malaysia.

Journal of Radioanalytical and Nuclear Chemistry, 303. doi:10.1007/s10967-014-3631-y

Sanusi, M. S. (2014). *Kajian fizik kesihatan negeri Selangor, Wilayah Persekutuan Kuala Lumpur dan Putrajaya.* Universiti Teknologi Malaysia, Johor.

Sanusi, M. S., Ramli, A. T., Gabdo, H. T., Garba, N. N., Heryanshah, A., Wagiran, H., & Said, M. N. (2014). Isodose mapping of terrestrial gamma radiation dose rate of Selangor state, Kuala Lumpur and Putrajaya, Malaysia. *J Environ Radioact, 135*, 67-74. doi:10.1016/j.jenvrad.2014.04.004

Siti Fharhana, Y., Hassan Wan Muhamad Saridan, W., Ahmad Termizi, R., Mohd Hilmi, S., Mohd Sanusi, M. S., Basri, N. A., & Hanifah Nor Zati Hani, A. (2017). Environmental radiology assessment in Lahad Datu, Sabah. *EPJ Web of Conferences, 156*, 00008. doi:10.1051/epjconf/201715600008

Snedecor, G. W., & Cochran, W. G. (1967). *Statistical methods* (6 ed.). Ames, IA: The Iowa State University Press.

Sprent, P., & Smeeton, N. C. (2007). *Applied nonparametric statistical methods* (4 ed.). Boca Raton: Chapman and Hall/CRC.

Stabin, M. G. (2011). *Radiation protection and dosimetry: An introduction to health physics*. New York: Springer.

Stankovic JB, Milosevic NT. Osnovi radioloske fizike (Basic Principles of Radiological Physics), PTT, Belgrade, 2007

UNEP, United Nations Environment Programme. (2016). *Radiation effects and sources*. Vienna: UNSCEAR.

UNSCEAR., United Nations Scientific Committee on the Effects of Atomic Radiation. (1962). *Report of the United Nations Scientific Committee on the effects of atomic radiation*. New York: United Nations.

UNSCEAR., United Nations Scientific Committee on the Effects of Atomic Radiation (2006). *Annex E: Sources-to-effects assessment for radon in homes and workplaces*. New York: United Nations.

UNSCEAR., United Nations Scientific Committee on the Effects of Atomic Radiation. (2008). *Sources and Effects of Ionizing Radiation*. New York: United Nations.

US EPA., United States Environmental Protection Agency. (1992). *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. Washington, DC: National Service Center for Environmental Publications.

US EPA., United States Environmental Protection Agency. (2000). *US EPA Environmental Response Team Soil Sampling Standard Operating Procedures*. Washington, DC: National Service Center for Environmental Publications.

Valkovic, V. (2000). *Radioactivity in environment*. Amstermdam: Elsevier Science B. V.

Vetter, R. J. (2008). ICRP Publication 103, The Recommendations of the International Commission on Radiological Protection. *Health Physics, 95*(4).

Warner, R. M. (2008). *Applied statistics: from bivariate through multivariate techniques*. Thousand Oaks, CA: SAGE Publications.

Yii Mei, W. (2008). *Natural radioactivity in the coastal sediment of East Malaysia.* Paper presented at the Nuclear Malaysia R and D 2008 Seminar, Malaysia.