RETRIEVING AND MODELLING DIELECTRIC PERMITTIVITY OF DIESEL CONTAMINATION IN TERAP RED AND SANDY SOIL USING GROUND PENETRATING RADAR

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DEDICATION

To my beloved husband, abah, late mom, son, daughters, brothers and sister.
Many thanks to Allah for all forgiveness and grace.

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ABSTRACT

Ground Penetrating Radar (GPR) is a non-destructive, full-wave electromagnetic (EM) measurement tool for quantitative imaging to describe dielectric permeability distributions. It is an efficient technique for detecting diesel contamination in soil tomography problems. However, dielectric permittivity relies entirely on variance moisture content facilitated by diesel fuel reaction soil, which determines GPR velocity. Difficulties in interpreting GPR reflection configuration are complex qualitative features limited to noisy or nonlinear relations problems. Consequently, positioning and depth determination would be misleading due to severe polarization and velocity mismatch in traveling-wave typically in Terap Red soil as silty-clay soil. Therefore, this study aims to determine the mathematical model for dielectric permittivity prediction and investigate the GPR signal segmentation algorithm model to map the diesel contamination plume in Terap Red soil. The calibration icon function of the GPR signal was quantified by dielectric permittivity prediction. The research approach was divided into 4 phases. The investigation commenced with an evaluation of the GPR propagation signal from a simulated diesel contamination plume of Terap Red and sandy soils concerning the results of geotechnical measurements using BS 1337: 1992. Next, the dielectric permittivity using the GPR velocity in modeling the empirical relationship between dielectric permittivity and moisture content was determined using statistical analysis. Additionally, cross-validation was performed using existing literature, Vector Network Analyzer (VNA) and in-situ measurements before the GPR signal images were segmented and categorized using a Support Vector Machine (SVM). Finally, ten-fold cross-validation and Logistic Regression (LR) classification were used to evaluate the spatial distribution classification mapping of GPR signals. The result shows the best prediction on Terap Red soil from third-order polynomial using ANOVA yielded a strong positive correlation (R2=0.9892, N=24, $P < 0.05$) and a standard error of 0.076. The accuracy of dielectric permittivity in terms of root mean square error (RMSE) and mean absolute error (MAE) was obtained at 9.772E-14 and 0.049, respectively. The best-fitting relationship does exhibit some degree of textural bias that should be considered in the choice of petrophysical relationship with uncertainty mean differences via VNA validation for Terap Red and sandy soil were only 2.706 % and 1.985 %, compared to over 3.608% and 15.990 % for the existing model. The accuracy of the spatial distribution classification map generated by the SVM classifier is encouraging, with RMSE of 0.139, kappa statistics of 0.888, and correct instances classified (CIC) of nearly 100 % for both SVM and LR. In conclusion, the study results on dielectric permittivity prediction of contaminated soils for Terap Red and sandy soils indicate that the empirical relationship model is only applicable to specific soils with similar properties. Additional supervised data is recommended to achieve better classification outputs.

ABSTRAK

Radar Penembusan Tanah (GPR) adalah alat pengukuran tanpa kerosakan, pengukurannya berasaskan gelombang elektromagnetik gelombang penuh (EM) untuk pencitraan kuantitatif bagi menerangkan taburan ketelusan dielektrik dan teknik yang cekap mengesan pencemaran diesel dalam masalah tomografi tanah. Walau bagaimanapun, ketelusan dielektrik bergantung sepenuhnya pada kepelbagaian kelembapan yang didorong oleh tanah reaksi bahan bakar diesel, yang mana digunakan untuk menentukan halaju GPR. Penafsiran konfigurasi refleksi GPR adalah sukar kerana ciri kualitatif yang kompleks, yang mana terhad kepada masalah hingar atau hubungan tidak linear. Oleh sebab itu, kesilapan penentuan kedudukan dan kedalaman mungkin berlaku disebabkan polarisasi yang teruk dan ketidaksepadan halaju dalam perjalanan-gelombang terutama pada tanah Terap Red sebagai tanah halus-liat. Maka, kajian ini bertujuan untuk menentukan model matematik untuk meramal permitiviti dielektrik dan menyiasat model algoritma bagi segmentasi isyarat GPR untuk memetakan kosentrasi pencemaran diesel di tanah Terap Red. Ramalan permitiviti dielektrik telah digunakan sebagai fungsi penentukuran isyarat GPR. Pendekatan kajian dibahagikan kepada empat (4) fasa. Penyiasatan dimulakan dengan penilaian isyarat penyebaran GPR daripada simulasi pencemaran diesel tanah Terap Red dan tanah berpasir berhubung dengan keputusan pengukuran geoteknikal menggunakan BS 1337: 1992. Seterusnya, penentuan ketelusan dielektrik menggunakan halaju GPR dalam memodelkan hubungan empirikal antara ketelusan dielektrik dan kandungan lembapan menggunakan instrumen analisis statistik. Selain itu, pengesahan silang dilakukan menggunakan literatur sedia ada, Penganalisis Rangkaian Vektor (VNA) dan pengukuran di tapak sebelum imej isyarat GPR disegmenkan dan dikategorikan menggunakan Mesin Vektor Sokongan (SVM). Pengesahan 10 kali ganda dan pengelasan Regresi Logistik (LR) telah digunakan untuk menilai pemetaaan klasifikasi taburan spatial isyarat GPR. Keputusan menunjukkan ramalan terbaik pada tanah Terap Red daripada polinomial tertib ketiga menggunakan ANOVA menghasilkan korelasi positif yang kuat ($R2 = 0.9892$, $N = 24$, $P < 0.05$) dan ralat piawai 0.076. Ketepatan permitiviti dielektrik dari segi ralat punca min punca (RMSE) dan ralat mutlak min (MAE) diperoleh masing-masing pada 9.772E-14 dan 0.049. Hubungan model yang paling sesuai menunjukkan tahap kecenderungan tekstur harus dipertimbangkan dalam memilih hubungan petrofisik melalui perbezaan min ketidaktentuan daripada pengesahan VNA untuk tanah Terap Red dan berpasir hanya 2.706% dan 1.985%, berbanding melebihi 3.608% dan 15.990% untuk model sedia ada. Ketepatan peta klasifikasi taburan spatial menggunakan pengelas SVM adalah memberangsangkan, dengan RMSE, 0.139, statistik kappa, 0.885 dan Perkelasan Contoh Betul (CIC) pada kadar hampir 100% untuk kedua-dua SVM dan LR. Kesimpulannya, hasil kajian ramalan kebolehtelapan dielektrik bagi tanah tercemar bagi tanah Terap Red dan berpasir menunjukkan bahawa model hubungan empirikal hanya terpakai untuk tanah tertentu dengan ciri-ciri yang sama. Data diselia tambahan yang lebih banyak disarankan untuk mencapai hasil kejituan klasifikasi yang lebih baik

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LIST OF ABBREVIATIONS

AGC	-	Automatic Gain Control
AI	-	Artificial Intelligence
ANOVA	-	Analysis of Variance
ANN	-	Artificial Neutral Network
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CO2	-	Carbon Dioxide
CH4	-	Methane
CO	-	Common-offset
CMP	-	Common Mid-Point
CRIM	-	Complex Refractive Index Model
DEPs	-	Diesel Exhaust Particles
DNAPLs	-	Dense Non-Aqueous Phase Liquids
ERT	-	Electrical Resistivity Tomography
EM	-	Electromagnetic
GWC	-	Gravimetric Water Content
GPR	-	Ground Penetrating Radar
IPCC	-	Intergovernmental Panel on Climate Change
IARC	-	International Agency for Research on Cancer
LFL	-	Lower Flammability Limit
LNAPL	-	Light Non-Aqueous Phase Liquid
LR	-	Logistic Regression
MAE	-	Mean Absolute Error
NAPL	-	Non-Aqueous Phase Liquids
N2O	-	Nitrous Oxide
NRSME	-	Normalise Root Mean Square Error
PM2.5	-	Particulate Matter 2.5
PCB	-	Polychlorinated Biphenyl Oil
PVC	-	Polyvinyl Chloride
RMSN	-	Root Mean Square Noise

RMS velocity	-	Root Mean Square Velocity
SARS-CoV-2	-	Severe Acute Respiratory Syndrome Coronavirus 2
SMO	-	Sequential Minimal Optimization
SNR	-	Signal-to-noise Ratio
SVM	-	Support Vector Machine
TDR	-	Time Domain Reflectometry
USDA	-	United States Department Of Agriculture
VOCs	-	Volatile Organic Compounds
VNA	-	Vector Network Analyzer
WARR	-	Wide-Angle Reflection And Refraction

LIST OF SYMBOLS

w	-	Moisture Content Expressed as A Percentage (%)
m_2	-	Weight of the container + weight of moist soil or wet soil (kg)
m_3	-	Weight of the container + weight of the dry soil (kg)
m_1	-	Weight of the container (kg)
W_t	-	Wet weight of contaminated soil (kg)
W_d	-	Dry weight of contaminated soil (kg)
m	-	Oil residual after drying
n	-	Oil content before drying
I_p	-	Plasticity index,
w_L	-	Result of liquid limit, and
w_p	-	Result plastic limit
ρ_s	-	Particle density (g/cm^3)
ρ_b	-	Bulk density.
M_s	-	Oven-dried soil (mass of only soil) in gram (g)
m_{p1}	-	Mass of pycnometer and cap assembly (in gram),
m_{p2}	-	Mass of pycnometer, cap and soil (in gram),
m_{p3}	-	Pycnometer, cap, soil and water (in gram)
m_{p4}	-	Mass of pycnometer, cap and water (in gram).
V_s	-	Total volume in cm^3.
V_l	-	Volume of liquid
V_g	-	Volume of gas.
φ	-	Porosity of the soil
v	-	Velocity of GPR electromagnetic wave (m ns−1),
c	-	Speed of light in a vacuum (0.3 m/ns)
ε	-	Dielectric permittivity
$\delta / \omega\varepsilon$	-	Attenuation factor, $\omega = 2\pi f$ in rad s^{-1}

μ	-	Magnetic permeability
$v_{LNAPL-soil}$	-	Velocity of LNAPL contaminated
d	-	Depth
f_s	-	Sampling frequency step
T	-	Required unambiguous time duration
y	-	Distance (m) in a vertical line,
x	-	Horizontal line's distance (m).
A	-	Amplitude,
k	-	Wavenumber (in *radian/m*) which comes by $k = {}^{2\pi}/_{\lambda}$
ω	-	Angular frequency in (*radians/s*)
$\emptyset$	-	Phase constant.
ε_{sw}	-	Dielectric permittivity of the only soil-water mixture,
ε_s	-	Dielectric permittivity of soil particles,
ε_w	-	Dielectric permittivity of water,
ε_a	-	Dielectric permittivity of air,
ε_{sNAPL}	-	Dielectric permittivity of the soil-NAPL mixture,
$\varepsilon_{sw-NAPL}$	-	Dielectric permittivity of the soil-water-NAPL mixture
S	-	Degree of saturation, ϕ is the porosity of the soil
R	-	Correlation coefficient
r^2	-	Variance (correlation coefficient),
Y	-	Dependent variable from regression and
Y_p	-	A predicted value of Y from linear regression and
$\overline{Y}$	-	Dependent variable's mean
t	-	T-test value,
$\overline{x}_1$	-	Score mean
σ_1^2	-	Variance of group
$f(k)$	-	Signal or amplitude of the raw data containing noise at a given scale level k to N, N is the length of the electromagnetic signal
$r(k)$ I	-	De-noised signal or amplitude
x_i, x_j	-	Vectors in the input space

$x_i^T.x_j$	-	A scalar product of the vectors in the input,
α	-	Inner product based on some mapping in a feature space
γ	-	Parameter that is inversely proportional to the Gaussian kernel's width.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Diesel fuel which is part of hydrocarbon, is a distilled fuel oil used in motor vehicles and electricity generation derived from crude oil and biomass composites (Gad, 2014; Latif et al., 2021). Diesel fuel contains sulfur, which can induce carcinogenic air pollution emissions in humans, according to the International Agency for Research on Cancer (IARC), obtained by Gad (2014) and Mueller et al. (2021). Carcinogenic substances are chemicals or chemical mixtures that have the potential to cause cancer in humans (Hentz, 2010; Mueller et al., 2021). Several studies, including Mustafa et al. (2020) and Mueller et al. (2021), have associated diesel exhaust particles (DEPs), a key element of atmospheric particulate matter <2.5μm (PM2.5), as a mechanism of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) risk, which tends to increase inflammation and severe lung damage as shown in Figure 1.1. In summary, contamination of diesel fine Particle Matter 2.5 (dPM2.5) provides an appropriate medium for keeping" and carrying" the SARS-CoV-2 during respiratory air transportation, as illustrated in Figure 1.1. Figure 1.1 also depicts multiple routes of virus replication into the human pulmonary system, such as type II pneumocytes expressing Angiotensin-converting enzyme 2 (ACE2) receptors, which allow SARS-CoV-2 with dimensions of 70–90 nm to enter and spread over host cells

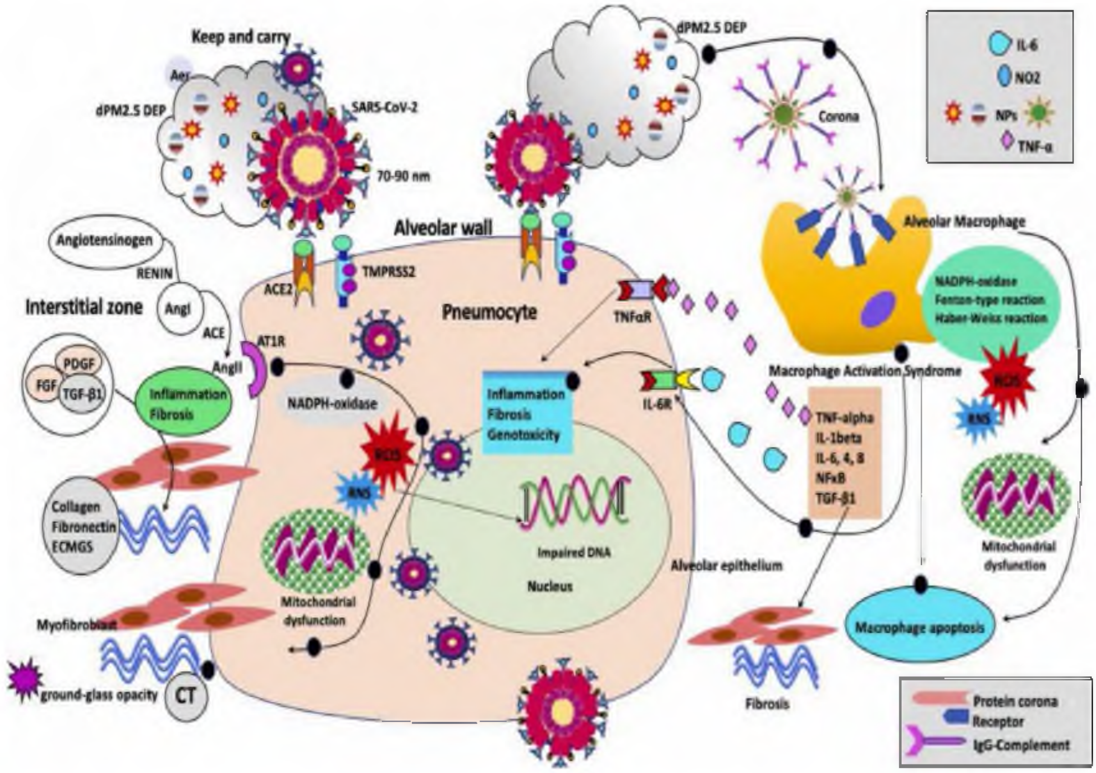

Figure 1. 1 The molecular mechanism of typical pulmonary lesions induced by DEP and SARS-CoV-2 exposure in the environment, adopted from (Mustafa et al., 2020)

In the energy industry, the emission factor from diesel, particularly Carbon dioxide (CO2) emissions, which can produce greenhouse effects, is also relatively high, as reported by Intergovernmental Panel on Climate Change (IPCC) in Table 1.1, as stated by Latif et al. (2021). Consequently, the use of diesel for power energy in Malaysia began to decline in 2014, with the potential substitute of renewable energy such as solar energy, as illustrated in Figure 1.2 reported by Latif et al. (2021).

Meanwhile, diesel as a soil contaminant can be toxic to plants and soil microorganisms and contaminate groundwater. Diesel fuel can reduce the bioconcentration index of nitrogen, phosphorus, calcium, and potassium as in corn, as well as negatively impact the physical properties of the soil. Influence on the physical properties of soils, such as water retention and unsaturated hydraulic conductivity, caused by diesel contamination depends on the characteristics of the soil contaminated. In addition to the effects on soil properties and water, the retention of diesel and diesel vapor in the soil can induce flames and explosions when mixed with air since diesel fuel is classified as a flammable liquid with a flame point below 60°C (Karim, 1980).

Table 1. 1 Emission factor for stationary combustion in the energy sector based on kg of greenhouse gas per TJ on a Net Calorie Basis, according to the IPCC report (Latif et al., 2021)

Fuel Type	**CO2 (kg/TJ)**	**CH4 (kg/TJ)**	**N2O (kg/TJ)**
Natural gas	56,100	1	0.1
Residual fuel oil	77,400	3	0.6
Diesel fuel	74,100	3	0.6
Other bituminous coal	94,600	1	1.5
Sub-bituminous coal	96,100	1	1.5
Industrial waste (Biomass)	143,000	30	4
Other biogas	54,600	1	0.1

*CH4: Methane, N2O: *Nitrous oxide*

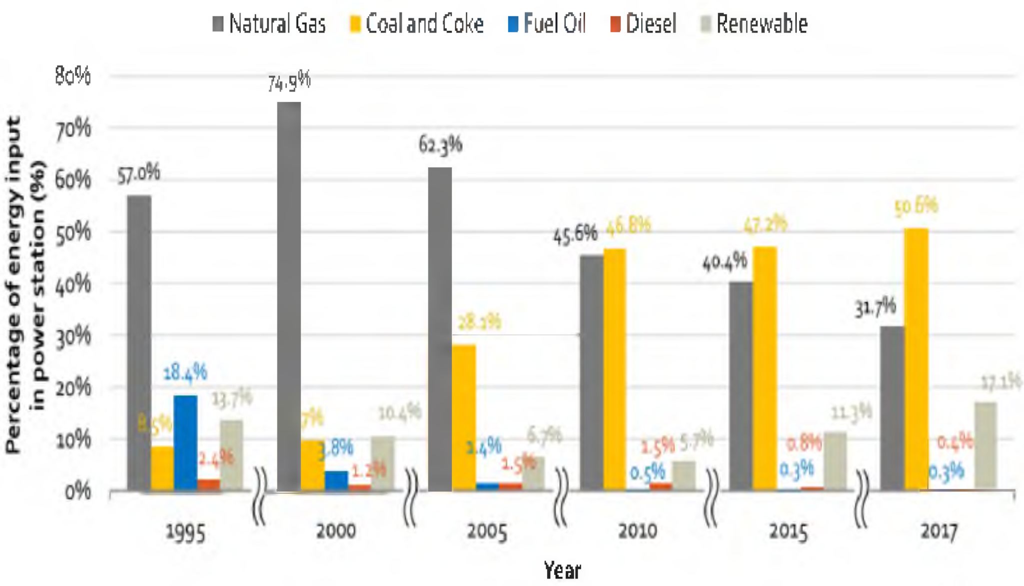

Figure 1. 2 Percentage of energy source inputs used in power plants (Latif et al., 2021)

Since diesel retention in this soil depends on soil properties such as particle size and porosity, measurements for environmental risk assessment and remediation are essential, and many studies have been conducted (Kia & Abdul, 1990). With this awareness, fuel-related safety laws have been enforced, such as in Malaysia, governed by Act 302 - Petroleum (Safety Measures) Act 1984. Since 1980, various approaches to diesel contamination detection studies in soil, including laboratory and field studies, have been introduced to satisfy legal and safety requirements on health and the environment. Some common methods that have been introduced include geotechnical studies such as moisture content test, liquid limit test, direct shear test, and grain size distribution to assess the retention effects of diesel (Hernández-Mendoza, García Ramírez, & Chávez Alegría, 2021). In addition, the geophysical technique is frequently used to map diesel-contaminated soils in situ. Geophysical methods include neutron probes and Time Domain Reflectometry (TDR), Electrical Resistivity Tomography (ERT), and Ground Penetrating Radar (GPR).

The neutron probe and TDR methods are ground-based intrusive methods suitable for high spatial diversity of soil moisture and provide point measurements with limited sampling(Charlton, 2008). In contrast, ERT for bottom surface structure imaging is based on direct conductivity measurement on a shallow surface using electrodes with time-lapse photographic imaging (Glaser et al., 2012; Meyer et al., 2013). GPR is a non-destructive geophysical method that measures changes in the electrical properties of soil to provide a high-resolution picture of subsurface variations (Darayan et al., 1998; Lu et al., 2017).

GPR could identify bulk dielectric contrasts in varying volumetric mixtures of soil, air, water, and hydrocarbons (Glaser et al., 2012). It is based on a pulse radar system that transmits short electromagnetic pulses into a medium where some energy is reflected while the remaining travels forward (Porubiaková & Komačka, 2015). This radar's travel function is determined by electromagnetic properties such as dielectric permittivity (ε), magnetic permeability (μ), and electrical conductivity (σ) (Martinez & Byrnes, 2001). The more significant the dielectric permittivity difference between the materials on the bottom surface, the higher the amplitude of reflection produced, as calculated by the amplitude reflection coefficient (R) (Glaser et al., 2012).

Dielectric permittivity is a complex function of the capacity to store energy when an electric field alternates in free space (Klotzsche et al., 2018; Paula Castilo, 2015). Dielectric permittivity can also be defined as the ratio of an electric field's strength in a vacuum to that encountered in a material with the same charge distribution (Palneedi et al., 2021; Xu, 2016; Yalcin et al., 2015). The dielectric permittivity varies with the temperature and frequency of the electric field, depending on the material structure, composition, and lattice flexibility (Jiang et al., 2018; Palneedi et al., 2021). The dielectric permittivity can be measured using Vector Network Analyzer (VNA) in laboratory (Yalcin et al., 2015; Jafery et al., 2018; Szyplowska et al., 2018), parallel plate capacitors (Palneedi et al., 2021; Taflove & Hagness, 2005), velocity equations (Weihnacht & Boerner, 2014; Wijewardana et al., 2017; Liu et al., 2020), empirical equations (Topp et al., 1980; Curtis, 2001; Park et al., 2017; Tempke et al., 2018) and volumetric mixing formulas (Bano, 2004; Iravani et al., 2020; Roth et al., 1990; Wharton et al., 1980). Dielectric permittivity is also used in modeling the image classification of GPR signals for GPR data interpretation via artificial intelligence (AI) (Cabrera, 2015; Travassos, Avila, et al., 2021) and machine learning (Millington & Cassidy, 2010; Muniappan & Balasubramani, 2011; El-Mahallawy & Hashim, 2013; Economou et al., 2017; Giannopoulos, 2005; Liu et al., 2020 Travassos et al., 2021).

The machine learning algorithm is a subset of Artificial Intelligence (AI) based on statistical learning theory that enables automatic classification and data analysis from experience (Muniappan & Balasubramani, 2011). Support Vector Machine (SVM) is a widely used machine learning algorithm for mapping the locality of GPR image hyperbola patterns that employs the principle of supervised learning for classification and regression analysis (Pasolli et al., 2008; Muniappan & Balasubramani, 2011; Travassos et al., 2018; Zadhoush et al., 2021). SVM classifies binary data by defining a divider hyperplane in a high-dimensional feature space and obtaining the maximum margin between classes from training data via GPR data segmentation (Muniappan & Balasubramani, 2011; Nishimoto et al., 2006). In classifying GPR data, according to Muniappan & Balasubramani (2011) and Pasolli et al. (2008), SVM can achieve higher accuracy and is very useful in reducing noise in GPR signal images. As an outcome, SVM has been used in this study to improve the accuracy of the interpretation of diesel-contaminated soil from GPR data segmentation.

1.2 Problem Statement

Terap Red has clayey over clayey-skeletal, kaolinite, isohyperthermic, and typical hapludults according to the USDA Soil Taxonomy as published in Malaysia Common Soil of Peninsular Malaysia by Malaysia Department of Agriculture in 2018 and Malaysia Soil Taxonomy by Paramananthan (2020). Terap Red soil has been classified as a type of laterite-reworked soil based on the characteristics of clay and other mixtures (DOA, 2018) Terap red soil is a type of soil found throughout Peninsular Malaysia, accounting for nearly 40% of the north part of the peninsular (DOA, 2018). Due to its high water retention properties, this lateritic soil is typically used as a soil liner to retain wastewater from solid waste and petroleum substances in landfill areas in Malaysia (Syafalni et al., 2015) and India (Thankam et al., 2017) and many more. However, if the soil is in an agricultural or residential area, sudden contamination, especially from diesel machinery or vehicles or the deliberate disposal of diesel waste, is likely to pose a significant problem.

According to Hewelke et al. (2018), 60 % of soil contamination in the European Union is caused by fuel minerals and heavy metals. In Malaysia, contamination from diesel was reported in the Sungai Langat, Selangor area by Mohamed (2022) from Kosmo on 27 July 2019 and the industrial area of Tanjung Kidurong, Sarawak by Department of Enviroment Malaysia (DOE) on 29 October 2020. Apart from harming the environment, the retention of diesel fuel in soils higher than water (Kia & Abdul, 1990) and the evaporation of diesel fuel are the factors that contribute to changes in the physical properties of the contaminated soil, particularly lateritic soils. For instance, as per a study by Sharma (2014), (Hewelke et al. (2018), and Hernández-Mendoza et al. (2021), diesel's presence in sandy soils has decreased the optimal moisture content of the soil and increased its plasticity and friction angle. However, the effect of diesel fuel in the soil will be different for each type of soil because of the unique characteristics of each soil.

Therefore, numerous studies, including the evaluation of GPR wave signal, have been conducted to evaluate the impact of diesel fuel on various types of soil. As an example, Daniels et al. (1995), Bano et al. (2009), Guo et al. (2012), and Mansi et al. (2017) have successfully identified apparent GPR signal anomalies in sandy soils contaminated with diesel. Nevertheless the reflection of the GPR signal is dependent on the physical and electromagnetic properties of the soil particularly the dielectric permittivity as the diesel effect of the soil varies with soil type as mentioned by Mansi et al. (2017) and Shamir et al. (2018). Additionally, the dielectric permittivity of each soil influences the accuracy of the GPR's depth measurement and resolution. This is due to the close relationship between dielectric permittivity and velocity, which determines the depth and wavelength of the GPR (resolution).

Considering the importance of dielectric permittivity, several studies have been conducted to predict dielectric permittivity's, such as Topp's model (Topp et al., 1980) and the complex refractive index method (CRIM) model (Comegna et al., 2016). Both models are frequently employed in some GPR-based studies, but each has its limitations. Patriarca et al. (2013) revealed that Topp's model underestimates the turbulence of high-bound water, such as clay, while overestimating the turbulence of low-bound water, such as sand. While Steelman & Endres (2011) claimed that changes in the shape factor of soil texture in the CRIM model are difficult to determine, contributing to the low accuracy of dielectric permittivity prediction. As a result, it motivates establishing a new empirical relationship model for predicting the dielectric permittivity of contaminated Terap Red soils in GPR measurements. This model's establishment is also supported by Al-mattarneh et al. (2013), Rubin & Ho (2018), and Mironov et al. (2019), which explain that each dielectric prediction model is only adequate for specific soils

In addition, interpretation of the GPR signal is difficult since the amplitude of the GPR signal waveform varies depending on the dielectric permittivity. Its intrinsic image is exposed to and qualitatively constrained by noisy data or nonlinear interaction issues from other devices. This issue will complicate the mapping of the distribution of contaminated soil by diesel using GPR, owing to the uncertainty of changes in contaminated soil characteristics. As a result, many studies on the reliability of GPR signal image explanation through automatic classification mapping, such as SVM (Wu et al., 2008; Pasolli et al., 2009), have been conducted. Regrettably, the automatic classification mapping method used by researchers such as Pasolli et al. (2008) is for objects permanently buried beneath the subsurface. Consequently, studies must be conducted to classify GPR signals using machine learning techniques such as SVM for diesel contamination, a movable material that induces uncertainty in soil.

1.3 Objectives

The study aims to assess the feasibility of using high-frequency GPR to characterize and retrieve the dielectric permittivity and determine the location of contaminated Terap Red soils triggered by diesel in the subsurface. In addition, studies on sandy soils, which some researchers commonly use, are also conducted as a comparison for optimized findings. Specific objectives for this thesis are:

i. To investigate the effect of diesel presence on soil properties and retrieve the dielectric permittivity of diesel-contamination in Terap Red soil from wave velocity in GPR.
ii. To establish an empirical relationship model between dielectric permittivity and variations in soil moisture content of diesel-contamination in Terap Red soil.
iii. To assess and validate the accuracy of the proposed empirical relationship for the prediction of dielectric permittivity of diesel-contamination in Terap Red soil.
iv. To delineate and improve the mapping of diesel-contaminated soil plume output using a Support Vector Machine classifier based on GPR signal images corrected with predicted dielectric permittivity.

1.4 Significance of the Study

Terap Red soil is classified as a lateritic soil with high nutrients suitable for agricultural purposes, landfill soil liner and widespread distribution throughout Peninsular Malaysia's northwestern region. The presence of diesel spills from agricultural machinery or power generators will modify the soil nutrients, so this contaminated soil detection study is required to utilize GPR as a non-invasive and non-destructive method for the large-scale identification of diesel-contaminated soil. Since GPR is dielectric dependent, and the existing dielectric permittivity calculation study is limited to specific soils, it is essential that a dielectric calculation study for Terap Red soils is performed and compared to sandy soils.

Furthermore, the depth accuracy and resolution of GPR measurements dependent on velocity value can be improved with the prediction of the soil dielectric. Besides that, the GPR signal image is difficult to interpret due to dielectric changes caused by the presence of diesel in the soil. As a result, through automatic classification mapping, the image assessment of the GPR signal can be improved.

1.5 Scope and Limitation

This study focused solely on detecting diesel contamination in Tanah Terap obtained from agricultural areas in the state of Perlis. Diesel detection was performed on a large-scale tank simulation constructed of concrete with dimensions of 1.9m x 2.5m x 1.5m and a thickness of 5cm. The use of concrete blocks is based on high conductivity material criteria (Wu et al., 2013), which control the propagation of electromagnetic (EM) waves. It can distinguish the area between simulation sites. This model applies to field and laboratory measurements to determine the parameters for constructing empirical relationships for dielectric prediction and evaluating diesel effects in the soil. Field measurements include two procedures: high-frequency GPR measurement at 800MHz, which produces high-resolution GPR images, and soil moisture probe testing. All geotechnical laboratory tests are based on British Standard (BS) to determine the properties of Terap Red and sandy soils. Furthermore, the validation of dielectric permittivity predictions is limited to comparing existing models commonly used in validation studies and in-situ testing of the VNA. Automated classification mapping for GPR signal images only using SVM classifier with comparison using Logistic Regression (LR) in WEKA software

1.6 Thesis Outline

This thesis is divided into five chapters. The first chapter discusses the study's background, problem statement, objectives, the significance of the study, the scope of the study, and research contribution.

Chapter 2 highlights the definition of contaminated soil; the concept of GPR measurement includes dielectric permittivity parameters and GPR data processing and descriptions of geotechnical tests and statistical tests for empirical relationships. In addition, the effect of the presence of diesel on soil properties is discussed. This chapter also presents some techniques used to detect contaminated soils, including existing dielectric determination studies.

Chapter 3 describes the detailed methodology, including selecting materials for the construction of soil contamination simulation sites and soil samples suitable for the study. This chapter also includes the method of data collection, GPR data processing, empirical relationship construction, and mapping of contaminated soil classification models.

In Chapter 4, the study's findings and statistical analysis, along with a discussion of the research methodology. In this chapter, each study result, analysis, and discussion are described based on the study's objectives. Next, this chapter describes GPR signal interpretation analysis results in conjunction with geotechnical results. Furthermore, the results of establishing an empirical relationship model between dielectric permittivity and soil content and statistical results and an accuracy assessment, followed by verification results. This chapter also includes the results and analysis of contaminated soil classification mapping for GPR data using SVM and LR classifiers.

Finally, chapter 5 concludes the study's findings, referring to the study's objectives, study contribution, limitations, and recommendations for future research.

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LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Ghazali, M. D**., Zainon, O., Idris, K. M., Nor, S., Zainon, A., Karim, M. N. A., Anshah, S. A., & Talib, N. A. (2020). The Assessment of Relative Permittivity on Diesel Vapour in the Moisture Content of Terap Red Soil by Ground Penetrating Radar. *Air, Soil and Water Research*, *13*, 1–11, https://doi.org/10.1177/1178622120930661 **(Q2, IF: 0.41)**

Indexed Conference Proceedings

1. **Ghazali, M. D**., Zainon, O., Mohsin, R., Idris, K. M., & Mustafa, N. (2020). Estimated relative permittivity of contaminated laterite soil: An empirical model for GPR waves. *IOP Conference Series: Earth and Environmental Science*, *540*(1). https://doi.org/10.1088/1755-1315/540/1/012056 **(Indexed by SCOPUS)**

2. Halimshah, N. N., Yusup, A., Mat Amin, Z., & **Ghazali, M. D.** (2015). Visual Inspection Of Water Leakage From Ground Penetrating Radar Radargram. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *2*(2W2), 191–198. https://doi.org/10.5194/isprsannals-II-2-W2-191-2015 **(Indexed by SCOPUS)**

List of Innovation Award

1. Gold Award
   Title: Modelling Dielectric Diesel Contamination in Laterite Soil on GPR
   International Innovation, Invention, Creation Exhibition, 2019.

2. Silver Award

Title: Empirical Model of Relative Permittivity for Diesel Contamination in Laterite Soil on the GPR

Ipoh International Summit on Professionalism, Research and Education, 2019.

3. Silver Award

Title: Disposable Hand Made Face Shield for Front Liners

The 5th International Innovation, Design and Articulation (IIDEA 2020)

4. Gold Award

Title: Disposal Hand Made Face Shield Front Liners

The 10th Seminar on Innovation and Creativity (SIC 2021)

5. Silver Award

Title: Disposal Hand Made Face shield

4th International Malaysia-Indonesia-Thailand Symposium on Innovation and Creativity (IMIT-SIC 2021

List of Grant Award

1. Fundamental Research Grant Scheme (FRGS) -1/2021

Grant Award: RM103,848.00

Role: Leader

Title: Geo-Radar Signatures Segmentation for Laterite Soil Wastewater Tomography: Petrophysical Relationship and Cluttering Algorithms Model.

2. Fundamental Research Grant Scheme (FRGS) -1/2020

Grant Award: RM 91,800.00

Role: Member

Title: Geotechnical characterization based on antireflection meta surfaces technique for detection and characterization of sinkhole in Malaysia.