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Research Article

Soil Parameters Model Prediction via Resistivity Value Limit to Shallow Subsurface Areas

Muhammad Noor Hisyam Jusoh,[1] Deprizon Syamsunur,[1,2] Norinah Abd Rahman,[3] Emmanuel Olisa,[4] Abdur Rahim ,[5] and Nur Izzi Md Yusoff [3]

[1]*Faculty of Engineering, Technology and Built Environment, UCSI University Kuala Lumpur, 56000 Cheras, Kuala Lumpur, Malaysia*
[2]*Postgraduate Studies, Universitas Bina Darma Palembang, Kota Palembang 30111, South Sumatera, Indonesia*
[3]*Department of Civil Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia*
[4]*Geosyntec Consultants, 211 Wheeler Street Saskatoon, Toronto, Saskatchewan S7P 0A4, Canada*
[5]*Department of Transportation Engineering and Management, University of Engineering and Technology, Lahore, Pakistan*

Correspondence should be addressed to Nur Izzi Md Yusoff; izzi@ukm.edu.my

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Geotechnical engineering design necessitates a study of soil parameters for calculation purposes. As a complement to the conventional method, a resistivity survey can give preliminary results in a short amount of time. This study uses a statistical analysis program to show a correlation and regression for predicting soil parameters based on the resistivity value. Sixty-six data points for each soil parameter and resistivity were used for statistical analysis from six profiles of the study area as a part of the investigation. The soils are sampled by drilling the borehole up to a depth of 3 meters. The Wenner array was applied to conduct a resistivity survey. The collected data were utilized to establish a correlation between resistivity (ρ) and soil parameters such as moisture content (w), clay content (clay), plasticity index (PI), friction angle (ϕ), bulk density (γ), and porosity (n). The generated statistic model was improved through several iterations for each correlation. For the ρ-w, ρ-clay, ρ-PI, ρ-ϕ, ρ-γ, and ρ-n relationship, the total iterations are 5, 4, 7, 6, 5, and 4 for each correlation, respectively. Resistivity and moisture content showed a significant power correlation, followed by a modest relationship between resistivity and porosity. Between resistivity and other parameters, relationships such as clay content, bulk density, friction angle, and plasticity index were found to have very weak or no association. However, some trends can be seen clearly. This study aims to offer the geotechnical engineer a quick preliminary way of obtaining the associated soil parameters for various geotechnical calculations employing the resistivity approach based on the developed numerical equation.

1. Introduction

An engineering design requires an accurate assessment of soil parameters for calculating purposes. For geotechnical engineering design, several factors must be addressed, including density, friction angle, and other factors like water level, consolidation rate, and settlement [1]. These factors are critical in engineering design, especially for evaluating soil-bearing capacity and slope stability [2]. As a result, every geotechnical engineer's responsibility is to offer a constructive design for construction assessment based on soil parameters data.

A resistivity survey, which is a geophysical approach, has been discovered to be an alternate mechanism for determining probable subsurface characteristics without disturbing the soil structure [3]. It has been used in various engineering disciplines, such as mining, tunneling, and construction. Engineers will be able to estimate geotechnical parameters based on resistivity values as preliminary and supporting data for geotechnical design by using a reliable connection between soil parameters and resistivity values, bridging the gap between geotechnical and geophysical surveys [4]. The idea behind this study is that soil parameters may be calculated based on resistivity measurements by substituting them into correlation equations.

Many studies have attempted to investigate the phenomena of soil resistivity and its connection to other soil parameters. However, it should be noted that studies conducted by the researchers came globally, which is only applicable to their local region. Therefore, this study focuses on the author's local region, Perak, Peninsular Malaysia. Although it is still in an early phase, this study tends to utilise this approach to determine soil parameters based on electrical resistivity use for geotechnical calculation purposes such as soil-bearing capacity and slope factor of safety (FOS). Moisture content versus resistivity is one of the metrics that many studies have correlated effectively. The findings did not contradict resistivity-moisture content correlations established in soil science literature [5].

Siddiqui and Osman [6] studied the correlation between resistivity and plasticity index (PI). The correlations were poor in all soil types, such as silty sand and sandy soil, while Bery and Saad, 2012, obtained a moderate relationship on clayey sand soil. Akinlabi and Adeyemi [7] discovered that when the plasticity index rose, the resistivity values dropped. The researchers determined that soil with more clay or less granular particles had a varied range of plasticity index and impacted the resistivity related to moisture content [8–12]. This is because clay-rich soil serves as a filter, reducing water penetration via soil particles collected inside the soil while increasing moisture content and conductivity [13]. The effect of clay percentage attributes to change the soil porosity. Porosity rose when clay and moisture content rose, resulting in low resistivity value [14]. However, if the clay is compacted or very dense, tortuosity will develop instead of porosity, increasing the resistivity value since the current cannot readily pass through conduction water, increasing resistance [15, 16].

Researchers found connections between friction angle and resistivity values using empirical formulas reported in publications [17–19]. Siddiqui and Osman [20] investigated the relationship between resistivity and friction angle in sandy soil, finding modest and significant correlations, respectively. According to them, the mechanism underlying these weak and robust connections has to be investigated further through rigorous testing, which is not included in their study. However, they concluded that as the resistivity increased, so did the friction angle value.

Researchers used the correlation of resistivity and density to determine the connection and assess the reliability of the correlation. Syed and Zuhar [21] measured resistivity using the Wenner configuration and correlated it to the bulk density of soil obtained from borehole samples at various depths. The soil samples comprised sandy silt, clayey silt, and silty sand. The plotted data indicated that bulk density is proportional to resistivity, and the resulting correlation revealed a significant relationship between the chosen parameters. They assumed increased bulk density was due to higher soil moisture content and porosity, but no evidence was presented.

Several attempts have been made in the present study to develop such correlations for the general soil type of the local region. From the statistical analysis modelling, through correlation and regression, the developed equations may theoretically be utilized to calculate the geotechnical parameters by simply incorporating the resistivity value, which would have been difficult to determine otherwise by using the conventional approach yet limited under certain circumstances. These limitations of the conventional approach disturb soil structure, limited data coverage, accessible area, and regular monitoring process. Hence, another quick and less expensive way of obtaining soil parameters as supporting information of the conventional approach is required to enable rapid and comprehensive measurement and computation of geotechnical design at various places either in the ground or slope.

This study aims to investigate the behaviour of soil resistivity on soil properties through an electrical resistivity survey, laboratory measurement, and statistical analysis approach. The development of statistical models for predicting soil parameters from the resistivity value through regression includes fitting tests. The correlations and equation produced from the analysis can be useful in estimating soil parameters for geotechnical calculation purposes including soil-bearing capacity and slope factor of safety (FOS).

2. Methodology

2.1. Site Description. In this study, the resistivity survey and soil sampling were carried out at six locations which are located in Seri Iskandar, Tronoh, Pinji, Parit, Sungkai, and Hutan Melintang area of Perak, Malaysia. All locations including coordinate are denoted as Profile "a" (N04°22′52.9″E100°57′54.2″), Profile "b" (N04°31′21.9″ E101°4′33.6″), Profile "c" (N04°25′45.1″E100°57′54.2″), Profile "d" (N04°32′30.23″E100°55′14.19″), Profile "e" (N03°59′32.35″E101°18′48.91″), and Profile "f" (N03°53′19.4″E100°57′07.4″). Generally, the Perak area consists of silty and medium to coarse type sand with minimal fine contents. The area in Seri Iskandar, Parit, Tronoh, Pinji, and Sungkai is mostly dominated by clay, silt, sand, and gravel, whereby the obtained samples are consistent with produced deposits as mentioned in the geological map. The soil deposits in the Hutan Melintang area are marine clay and silt. Although some areas are open, cut, and agricultural, the consistency of the obtained samples is still the same as the produced deposits.

2.2. Sampling. Samples were obtained by boring the boreholes at predetermined sites with a petrol-powered percussion drilling set (CobraTT, Atlas Copco) equipped with a 1 meter core sampler. Boreholes were bored in a comparable area to perform field resistivity. Boreholes were drilled at a maximum depth of 3 meters. The sampling tube was installed in the core sampler before drilling to allow for a simple and smooth recovery of soil samples from the core barrel. To avoid moisture loss, the undisturbed samples were then preserved with a capped plastic and sealed at both edges of the sampling tube. The samples were then labelled according to depth and location. The samples were returned to the laboratory for soil parameters analysis.

2.3. Resistivity Survey. At the exact location where the boreholes were drilled and sampled, a two-dimensional (2D) resistivity survey was performed. As shown in Figure 1, electrodes were placed at a consistent distance apart (GEOTOMO, 2002). ABEM SAS 4000 Terrameter and Electrode Selector ES-464 were used to collect 2D resistivity data using Wenner configuration. Before this investigation, the 2D resistivity equipment was connected to two electrical wires. Based on available space and 1 m, 1.5 m, and 2 m electrode spacing, the profile lengths in this investigation varied from 40 meters to 80 meters. The data were transferred, and the apparent resistivity data were kept in ".dat" files.

The obtained data was processed through the inversion technique by using Res2Dinv software [23]. The inversion technique offers additional information for resistivity value and pseudosection of the subsurface layer in the 2D resistivity survey, resulting in an accurate result [22]. A forward modelling program was found for calculating apparent resistivity values and optimizing a nonlinear least-squares system [24]. This system's synthetic data, which would theoretically be produced if the measurement was performed on the first raw model, is calculated. That synthetic data are then compared to what was collected in the field. Finally, optimizing the initial raw model minimizes the mismatch between the data obtained in the field and the synthetic data generated from the raw model. This process is called iteration, which is done three to four times on average but might be fewer or more. Each iteration is allocated a certain percentage known as the root mean square.

Root mean square (RMS) is a statistical measure of how closely field data matches synthetic data. Without considering noise and calculation mistakes, the allowable error percentage that may be considered, in general, should be less than 6% [25]. Accepting the produced pseudosection based on the RMS error alone is insufficient to validate the quality of the findings. The model with the lowest RMS error can exhibit huge and unnatural fluctuations in model resistivity values and may not always be the "optimal" model from a geological aspect. The most prudent approach is to select the model at the iteration when the RMS error does not considerably change [26].

2.4. Statistical Analysis. Before analysing pertinent data in this study, it was paramount to understand the features and factors exhibited that could affect the magnitude of soil resistivity. It should be taken to note that the soil components influence the resistivity of a certain portion at different degrees, some peculiarly at a greater degree as compared to others. A certain parameter could still establish the variance, and also the fact that these parameters influence one another could make it more complicated to establish a different unique independent correlation of resistivity with a particular soil parameter. For instance, high moisture content theoretically has a porosity, which somehow could affect the soil's strength parameter, but the degree of these parameters' influence varied, either towards the soil resistivity value or soil parameters. This is why a desktop study is essential in the geotechnical area before site investigation and survey is conducted so that the information of the proposed area, regardless of any purposes such as construction, slope assessment, and mitigation, can be obtained as part of the preliminary assessment.

The correlation and regression of obtained data of resistivity and soil parameters value were performed through statistical analysis software. It should be noted that the study of correlation and regression was used to determine broad trends for general soil types. This is because the behaviour of resistivity with soil parameters in particular soil types may be less informative and considerably different from general relationships [27, 28]. The produced statistical model from OriginPro version 2019b was assessed and the correlated variables' reliability was evaluated. Hence, descriptively define the data through numerical procedures. Through fitting analysis, this statistical model involved power allometric one function using the classical Freundlich Model, and the Levenberg–Marquardt algorithm was used for the iteration algorithm. The quality of the fitted data model is determined based on the R, R^2, adjusted R^2, and the standard error of the estimate [29]. However, in this paper, the standard error of the estimate will not be discussed. The relationship between variables and the produced value is denoted as the correlation of the coefficient, R [30]. The correlation coefficient is a statistical metric used to assess the strength and direction of data classification, data analysis, clustering, decision-making, financial analysis, biological research, engineering statistics, and other data-related activities [31]. The correlation coefficient is determined by dividing the covariance of X and Y by the standard deviation, which is expressed as follows [32]:

$$r = \frac{\sum\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{\left[\sum\left(X_i - \bar{X}\right)^2 \sum\left(Y_i - \bar{Y}\right)^2\right]^{1/2}}, \quad (1)$$

where $\bar{X}$ and $\bar{Y}$ are the mean averages of X and Y, and the correlation coefficient, often known as the amount of association between specified variables, determines whether the relationship is positive or negative. From negative correlation (−1) to no correlation (0) to positive correlation (+1) and the value range (1) are all shown in Figure 2.

The basis of the correlation coefficient, R, can be interpreted as meaningful by squaring the R known as the coefficient of determination, R^2. It is a statistical measurement or summary of data that approaches near the fitted regression line of multiple regressions [34]. The R^2 is a number that ranges from 0 to 1, indicating that the model created may be explained by the variability of the data

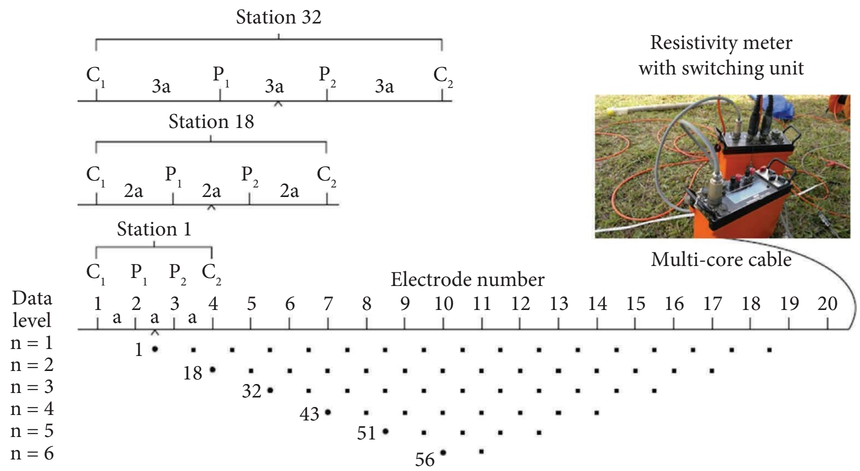


FIGURE 1: The schematic diagram for 2D resistivity survey and sequence measurement using Wenner configuration [22].

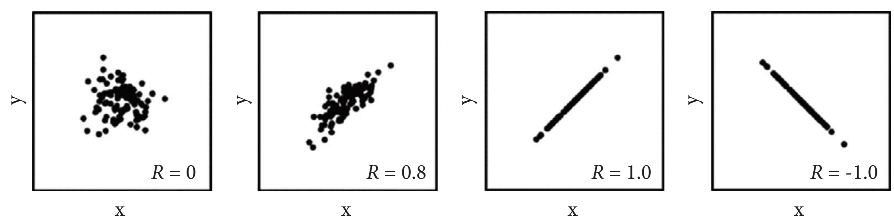


FIGURE 2: Sets of data generated based on correlation coefficients: $R = 0$, uncorrelated data; $R = 0.8$, strongly positively correlated; $R = 1.0$, perfectly positively correlated; and $R = -1$, perfectly negatively correlated [33].

response. Due to the apparent functional dependency between X and Y, the value of R^2 demonstrated that R is a relevant measurement from the fitting regression.

Nonetheless, a low or high R^2 value is acceptable, and it does not necessarily suggest that the model is well fitting. The acceptable criterion for R^2 for validation purposes is typically set to 0.6 [35–37]. It is entirely expected that the R^2 value will be low in some categories since it is more challenging to predict behaviour such as physical processes, human behaviour, or soil behaviour [38]. The success of the fitted model, which the changes in the set data may describe, will be validated by an acceptable generated regression model [39]. As a result, the R^2-based correlation characteristic description's conclusion is ambiguous or undefined. The purpose of regression analysis is to determine the relative influence of a predictor variable on the outcome. It entails the use of a dependent variable and independent variables to construct an empirical formula or equation [33]. The interaction between the factors and the responses was also obtained from the numerical analyses of the data by using the ANOVA test to analyse the variance. The P value was used to evaluate model terms with a 95% confidence level. The linear model with a P value of (0.0001) was significant enough to suggest a probability of error of less than 0.05.

3. Results and Discussion

3.1. Soil Analysis. A borehole sampling initially obtained the soil samples up to 3 m. The samples were examined and evaluated to determine the index and engineering parameters of the soil. The samples were examined and assessed in the laboratory according to British Standard (BS). In general, clayey sand (SM) type mixes of sand and clay were discovered in profiles *b*, *c*, *d*, and *e* up to a depth of 3 m. The soil profile "*a*" location revealed poorly graded sands, gravelly sands, and little or no fine particles (SP). The soil type of profile "*f*" is inorganic silt (MH), which includes inorganic silts, micaceous or diatomaceous, fine sandy or silty soils, and elastic silts. Table 1 shows the unified soil classification system's profile and soil type parameters.

3.2. Resistivity Profile. The pseudosection of the resistivity survey is depicted in Figure 3. As illustrated in the figure, the profiles of the soil sampling up to 3 meters in depth are shown in the six pseudosections. Figure 3(a) indicates the resistivity value, ρ, where the soils were sampled ranging from 60 Ω.m to 110 Ω.m. The composition of profile Figure 3(a) was described as silty sandy clay with a high water level. The resistivity values of the soil of the pseudosection in Figure 3(b) ranged between 300 Ωm and 1200 Ωm. The area indicated that the subsurface material was dominated by sand and fine soils. In Figure 3(c), the resistivity values ranged between 500 Ωm and 1400 Ωm. Similar to Figure 3(b), the profile of Figure 3(c) was interpreted to comprise loose and fine material, such as sand and clay. A similar interpretation was applied to Figures 3(d) and 3(e), where the resistivity values ranged from 200 Ω.m to1000 Ω.m and 100 Ω.m to800 Ω.m, respectively. The resistivity value of profile *f* (Figure 3(f)) was found to range

Table 1: Range value of study soil parameters.

Profile	USCS group symbol	Moisture content, w (%)	Clay content, clay (%)	Plasticity index, PI (%)	Friction angle, ϕ	Bulk density, γ (g/cm^3)	Porosity, n (%)
a	SP	11–19	1–7	17–20	22–27	1.3–1.8	40–60
b	SC	10–30	18–45	20–60	14–25	1.9–2.3	30–42
c	SC	13–28	2–27	3–19	34	1.4–2.3	7–60
d	SC	10–30	2–23	6–20	8–35	0.8–2.4	29–77
e	SC	8–45	2–44	22–34	9–32	1.2–1.9	40–64
f	MH	60–160	32–60	19–30	5–35	1.3–1.5	68–81

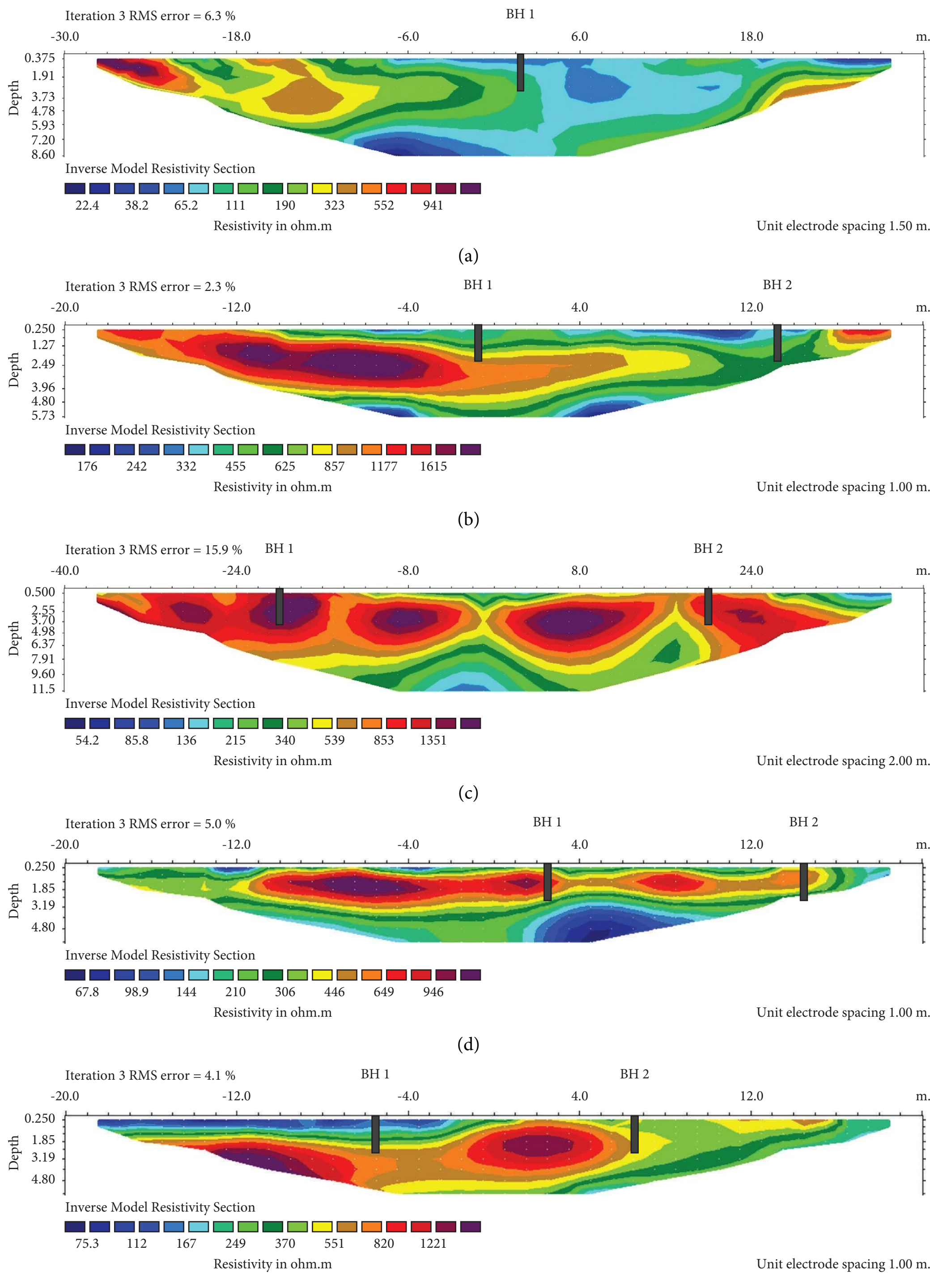
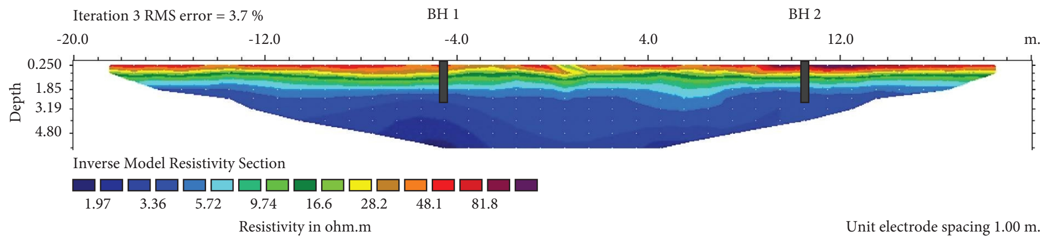


Figure 3: Continued.



(f)

Figure 3: (a)–(f) Pseudosections of resistivity survey for profile.

from 2 Ω.m to 28 Ω.m. The subsurface material of this profile comprises silty sandy clay. The resistivity values obtained from these profiles were used for correlation and regression with soil parameters, followed by evaluation using a statistical model.

3.3. Statistical Model and Regression Analysis. The statistical model of data resistivity and soil properties values are tabulated in Table 2. The total number of points in this statistic model before refining was 66, and each parameter's degree of freedom value varied. For each interrelation between resistivity and soil parameters, the generated statistic model went through a number of iterations. These numbers are 5, 4, 7, 6, 5, and 4 for ρ-w, ρ-clay, ρ-PI, ρ-ϕ, ρ-γ, and ρ-n relationship, respectively. From reduced chi-squared values, the statistical model shows that the fit testing is 100% converged with a chi-square tolerance value of $1E-9$ that is reached. The prediction quality of the soil parameters from resistivity is based on multiple correlation coefficients, R. The R values were found between 0.0692 and 0.9382.

However, the R value is supported by the coefficient of determination, R^2 (COD). This R^2 is the proportion of variance in the dependent variable that the independent variable can explain. From the correlation between resistivity and soil parameters, the R^2 values varied from perfect/strong to no association of the size of the correlation. The R^2 of interrelation between resistivity and moisture content (w), clay content (clay), plasticity index (PI), friction angle (ϕ), bulk density (γ), and porosity (n) was found to be 0.8802, 0.4093, 0.0048, 0.2292, 0.3028, and 0.5717, respectively. The adjusted R^2 was found to be lower than R^2, which indicates the model's usefulness for the better fit of the regression line [29]. Thus, the adjusted R^2 will be employed for the correlation reliability.

The F-ratio in the ANOVA, as tabulated in Table 3, was analysed to identify the data fitness for the overall regression model. According to the analysis, the table shows that the independent variables statistically and significantly predict the dependent variable, where at the 0.05 level, the fitting function is significantly better than the function $y=0$. The regression model of ρ-w relationship F (2, 64) = 487.4, p ($1.86E-39$) < 0.05 is a good fit of the data. Similar patterns happened to other relationships with F (2, 64) values of 113.94, p ($8.15E-22$); F (2, 64) 64.58, p ($4.45E-16$); F (2, 46) 227.44, p ($1.41E-24$); F (2, 63) 999.76, p ($1.89E-48$); and F (2, 64) 778.11, p ($1.23E-45$) for ρ-clay, ρ-PI, ρ-ϕ, ρ-γ, and ρ-n relationship, respectively. In general, the relationship between soil parameters and resistivity shows that independent variables statistically and significantly predict the dependent variable.

Figure 4(a) illustrates the correlation between resistivity and soil moisture content. The moisture content ranges from 10% to 150%, whereas resistivity values vary from 1 Ω.m to 1500 Ω.m. The power regression shows a perfect/strong correlation with an adjusted R^2 of 0.8784. According to several studies, as moisture content increases, the resistivity value falls. Based on the current tendency, soil moisture acts as a channel for the current flow. As a result, a decrease in moisture content caused by ion mobility in pore water would diminish electrical current conduction while increasing resistance to current flow. Previous investigations have revealed a similar tendency, with resistivity values decreasing as soil moisture content increases [40]. Although moisture content is the principal cause of resistivity variations, other variables or soil characteristics should be addressed since they may also impact resistivity, including plant roots and soil temperature. According to Ni et al. [41], higher root length, higher conductivity (lower resistivity), and high moisture content can be detected due to the fact that low soil temperature could increase the water flow resistance through the soil-plant-atmosphere continuum that leads to an increase in root length density or root surface area.

The behaviour of resistivity correlated with the percentage of clay shows a decreasing power regression, as illustrated in Figure 4(b). It can be said that the percentage of clay content is high at low resistivity and vice versa. Clay content also attributed low or high resistivity value to the surface conduction in the double layer of clay mineral particles, which is more prominent in higher or lower ionic concentration fluids, thus influencing soil moisture content [42]. Although the concept of resistivity related to moisture content is widely known, more research into the medium of water adsorbent is required. This is since some materials, such as clay, may function as a water adsorbent. In this study, the clay particle imitates the moisture content and adds to the resistivity behaviour [8]. From the regression, the relationship was found to be weak, with an adjusted R^2 0.4001. A reduction in resistivity value is attributed to a rise in clay percentage, as many researchers have claimed [9–12].

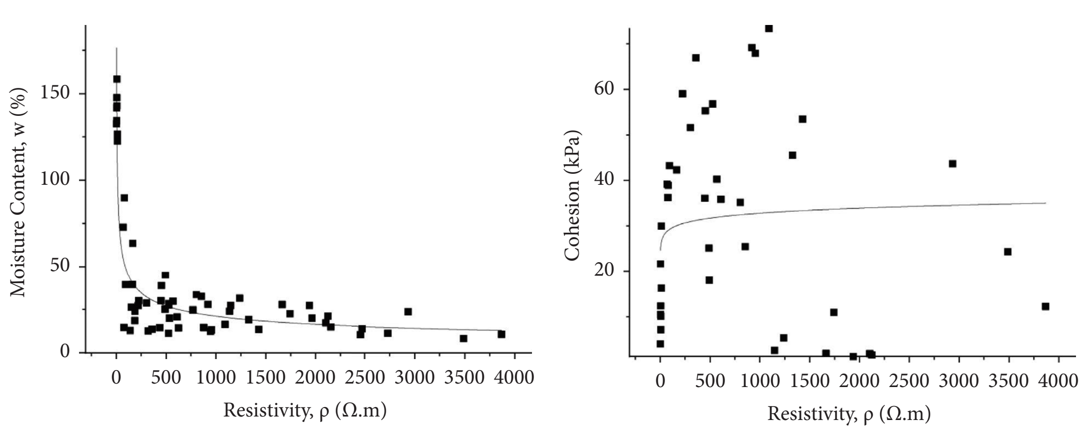
The relationship between resistivity and plasticity index (PI) values of soil is shown in Figure 4(c). The results show that there is no correlation between the two parameters.

Table 2: Summary statistical analysis for soil parameters with resistivity.

Parameters	Moisture content, w	Clay content	Plasticity index, PI	Friction angle, ϕ	Bulk density, γ	Porosity, n
Number of points	66	66	66	48	65	66
Degrees of freedom	64	64	64	46	63	64
Reduced chi-square	195.02	183.76	192.27	52.14	0.09	118.83
Residual sum of squares	12481.16	11760.85	12305.48	2398.34	5.79	7605.22
R-value	0.9382	0.6398	0.0692	0.4787	0.5503	0.7561
R-square (COD)	0.8802	0.4093	0.0048	0.2292	0.3028	0.5717
Adj. R-square	0.8784	0.4001	−0.0108	0.2124	0.2917	0.5650
Root-MSE (SD)	13.96	13.56	13.87	7.22	0.30	10.90
Number of iterations	5	4	7	6	5	4
Fit status	Succeeded (100)	Succeeded (100)	Succeeded (100)	Succeeded (100)	Succeeded (100)	Succeeded (100)

Table 3: Analysis of soil parameters using the ANOVA test.

Parameters	Model	DF	Sum of squares	Mean square	F value	Prob > F
Moisture content, w	Regression	2	190103.21	95051.60	487.40	$1.86E-39$
	Residual	64	12481.16	195.02		
	Uncorrected total	66	202584.36			
	Corrected total	65	104217.66			
Clay content	Regression	2	41876.66	20938.33	113.94	$8.15E-22$
	Residual	64	11760.85	183.76		
	Uncorrected total	66	53637.51			
	Corrected total	65	19911.53			
Plasticity index, PI	Regression	2	24835.31	12417.66	64.58	$4.45E-16$
	Residual	64	12305.48	192.27		
	Uncorrected total	66	37140.79			
	Corrected total	65	12364.62			
Friction angle, ϕ	Regression	2	23716.89	11858.45	227.44	$1.41E-24$
	Residual	46	2398.34	52.14		
	Uncorrected total	48	26115.23			
	Corrected total	47	3111.47			
Bulk density, γ	Regression	2	183.67	91.83	999.76	$1.89E-48$
	Residual	63	5.79	0.09		
	Uncorrected total	65	189.46			
	Corrected total	64	8.30			
Porosity, n	Regression	2	184928.47	92464.24	778.11	$1.23E-45$
	Residual	64	7605.22	118.83		
	Uncorrected total	66	192533.69			
	Corrected total	65	17755.98			



(a) (b)

Figure 4: Continued.

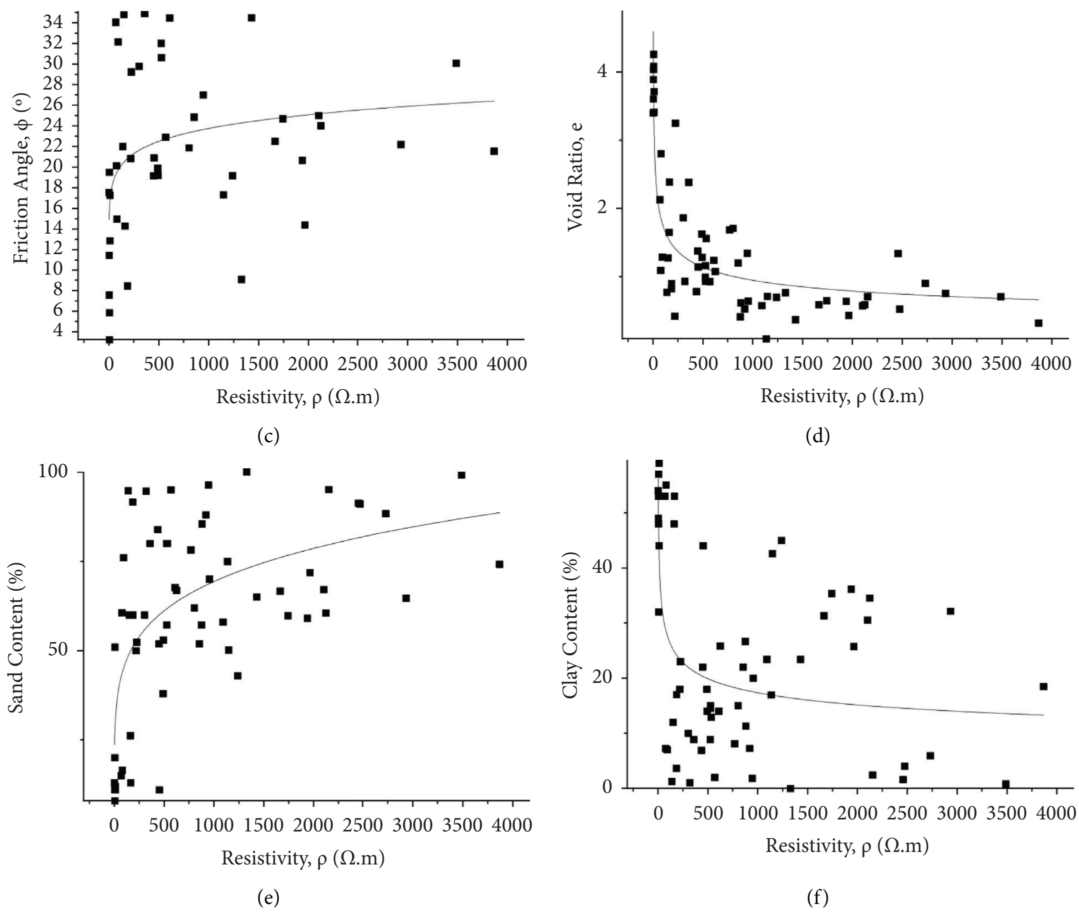


FIGURE 4: Correlation resistivity in equation $y = ax^b$. (a) Against moisture content; (b) against clay content; (c) against plasticity index; (d) against friction angle; (e) against bulk density; (f) against porosity.

However, the trend or pattern of the regression line can be observed in the image, which shows that the PI decreases as the resistivity increases [43]. The decrement of PI in the soil is due to coarse particles (less clay) dominating the percentage in soil and thus increasing the ρ.

The relationships between resistivity, ρ, and friction angle, $ø$, values of soil are depicted in Figure 4(d). The relationship between ρ and $ø$ produces adjusted $R^2 = 0.2124$, demonstrating that the variables are unrelated, although the trend suggests that resistivity rises as the friction angle rises. The reduction in moisture content is one probable reason for the rise in friction angle. Osman and Siddiqui [17] discovered a similar trend for all soil types in the ρ-$ø$ relationship and explained that soil shear strength increases as moisture content decreases.

The correlation of resistivity, ρ, with bulk density, γ, was successfully established for all soil types, as shown in Figure 4(e). The relationship shows a weak correlation with an adjusted $R^2 = 0.2917$. The rising regression lines between these two variables may be seen in the correlation. The resistivity value of soils increases as they get denser, whereas the moisture content decreases [44]. The only rational explanation for why bulk density rises when resistivity rises (in both sandy and clayey soil) is that the volume of voids in the soil reduces, resulting in a drop in moisture content. The rise in resistivity is because of the decrease in moisture content.

Figure 4(f) illustrates the relationship between resistivity (ρ) and porosity (n) for all soil types, indicating that the produced regression line is moderate with adjusted R^2 equal to 0.5650. It can be shown that as porosity increases, the ρ decreases and the findings of this relationship demonstrate that porosity is inversely related to resistivity [45]. A soil that contain a high percentage of moisture content and clay content produced high porosity, which caused the ρ to be low [46]. Since the porosity is calculated based on the void ratio, studies reveal that the relationship of ρ-n resembles the relationship between resistivity and the void ratio [47].

The generated equation was derived from correlation and regression. Although several of the produced equations are suspected owing to their flaws and inability to relate the variables, the regression trends demonstrate the possibility for a probable correlation. Table 4 listed the unstandardized coefficient denoted as "a" and "b" for the general form of the equation to predict soil parameters based on the power model.

Table 4: Equation model $y = ax^b$ for interation between resistivity with soil parameters values.

Plot	Moisture content, w	Clay content	Plasticity index, PI	Friction angle, ϕ	Bulk density, γ	Porosity, n
a	216.05 ± 10.83	68.82 ± 8.27	23.13 ± 6.07	12.91 ± 2.47	1.07 ± 0.10	95.50 ± 5.57
b	-0.36 ± 0.02	-0.22 ± 0.03	-0.03 ± 0.05	0.09 ± 0.03	0.08 ± 0.02	-0.12 ± 0.01

4. Conclusion

The soil parameters, namely moisture content, clay content, plasticity index, friction angle, bulk density, and porosity, were correlated with the resistivity value obtained from the field survey using Wenner configuration. The obtained samples were limited up to a depth of 3 meters. A total of 66 data points for each parameter were correlated with resistivity and analysed through a statistical analysis model. The analysis model indicates that the relationship between soil parameters and resistivity shows that independent variables statistically and significantly predict the dependent variable when at the 0.05 level, and the fitting function is significantly better than the function $y = 0$. Although the fitting model has shown its functionality, the acceptance of the relationship is based on the value of the correlation of coefficient (R), coefficient of determination (R^2), and adjusted R^2.

The power allometric statistical model indicates the correlations for each parameter with resistivity were found to vary. A power regression shows a perfect/strong correlation with an adjusted R^2 equal to 0.8784. Further, the resistivity (ρ) and porosity (n) correlation for all soil types exhibited regression line is moderate, with adjusted R^2 equal to 0.5650. However, between resistivity and clay content, friction angle, bulk density, and plasticity index, the relationship was observed to be very weak or with no association. The adjusted R^2 was found to be 0.4001, 0.2124, 0.2917, and −0.0108, respectively. Although these values are low or not, showing any significant correlation based on adjusted R^2, the regression trends show the possibility for a probable correlation. The limitation of the developed numerical equation is only applicable to shallow subsurface up to a depth of 3 meters. Furthermore, the sample size used for statistical analysis is relatively small. Therefore, further studies are suggested to analyse the correlation and regression with massive data and extend the depth of sampling. This study is still considered a preliminary stage, the established equations from correlation resistivity with soil parameters will be practical to obtain the parameter value of a soil for engineering design by applying a resistivity survey. Hence, we support the information obtained through the conventional approach.

Data Availability

The data presented in this study are available upon request from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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