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Spatial Distribution Analysis of Geotechnical Properties (Elastic Modulus, Cohesion, and Internal Friction Angel) in Soil Layers of Bengkulu City

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Cohesion
Soil characteristics
Geotechnical parameter

ABSTRACT

This study investigates the spatial distribution of key geotechnical parameters—namely modulus of elasticity, cohesion, and internal friction angle—in the dominant soil types of Bengkulu City, Indonesia. Given the region's complex geological structure and vulnerability to seismic activity, accurate assessment of soil characteristics is essential to support infrastructure development and mitigate geotechnical risks. Bengkulu lies between two active tectonic faults, making soil behavior analysis a crucial component of earthquake-resistant design. A total of 215 geotechnical data points were compiled from previous field investigations, covering a wide range of lithologies, including sandy soils, clay deposits, and various rock layers. The geotechnical parameters were spatially interpolated using the Inverse Distance Weighting (IDW) method to generate distribution maps that visualize the variation across different soil layers. This method was selected for its simplicity, effectiveness, and ability to provide weighted estimates based on spatial proximity. The analysis reveals that soils in the southern coastal region generally exhibit lower values of modulus of elasticity and cohesion, indicating a higher potential for deformation and shear failure. In contrast, central and northern areas tend to show higher geotechnical strength parameters, suggesting relatively stable ground conditions. The internal friction angle also increases with depth and material density, with hard rock zones showing the highest values. These findings contribute to the understanding of soil behavior in Bengkulu City and offer valuable insights for geotechnical engineers, urban planners, and disaster mitigation authorities. The spatial analysis of soil strength parameters provides a foundation for more resilient infrastructure planning and can be used as a reference for similar studies in other high-risk seismic regions.

1. Introduction

Bengkulu City is the capital of Bengkulu Province in Indonesia, located in the western region of Sumatra Island and directly adjacent to the Indian Ocean [1]. The city has significant geotechnical risks due to its complex geology and vulnerability to natural disasters such as earthquakes and landslides [2]. Two active tectonic faults flank Bengkulu Province: the Sumatra and Mentawai Fault as show in Figure 1 [3]. Terefore, it is necessary to study soil characteristics to support the design of disaster-resistant infrastructure development and minimise the risk of damage. One of the crucial aspects of geotechnical studies is understanding the spatial distribution of soil properties, such as elastic modulus, cohesion, and internal friction angle. These three parameters play an important role in determining the response of the soil to mechanical loads and its shear strength, which directly impacts the soil's stability and the safety of structures standing on it.

The modulus of elasticity describes the stiffness of the soil and its ability to return to its original shape after a load [4]. Soils with a higher modulus of elasticity will have greater stiffness. Cohesion represents the attractive force between soil particles, especially in clay soils, which plays a role in determining the ability of the soil to stay together without shear failure [5]. The friction angle measures the soil's ability to resist shear forces under load and is closely

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related to slope stability and foundation strength [6]. These three parameters have varying distributions in each region, so spatial mapping and analysis are necessary to support decisions in geotechnical planning [7].

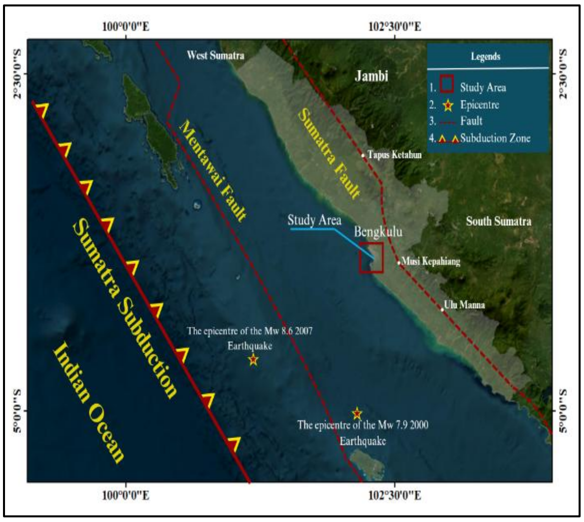

Figure 1. Seismotectonic Map of Bengkulu Province

A practical method for assessing the spatial variation of geotechnical properties is Inverse Distance Weighting (IDW). IDW is a widely used spatial interpolation technique in geotechnical analysis due to its ability to predict values at unmeasured locations based on the distance from nearby observation points [8]. In this method, points closer to the analysis site are given more weight than points farther away, resulting in a map that shows the parameter distribution smoothly and accurately [9]. This method is particularly suitable to be applied in Bengkulu City, which has a wide variety of dominant soil types. Using IDW, this research aims to map the spatial distribution of elastic modulus, cohesion, and friction angle in different areas of Bengkulu City. The mapping results are then used to identify regions with high-potential geotechnical risks.

Previous research on soil characteristics in Bengkulu has focused chiefly on seismic vulnerability and general geological studies, such as those conducted by [10], [11], and [12] In seismic vulnerability map of Bengkulu City. [13] Mapping earthquake hazards based on indicators of soil shear strain in Bengkulu City, the result is that the coastal areas of Bengkulu City are vulnerable to liquefaction due to earthquakes. [14] They Examined the hardness of rocks based on the type of geological formations of Bengkulu City. However, in-depth studies on the spatial distribution of geotechnical parameters, such as elastic modulus, cohesion, and inner friction angle of geotechnical parameters, have not been discussed in detail. Analysing the distribution of these geotechnical parameters is very important to assess the risk of soil failure and help make the right decisions in infrastructure planning in the area.

This research is expected to significantly contribute to civil engineering practitioners and decision-makers in Bengkulu City, especially in recognising areas that require special attention in infrastructure planning and design. Through accurate geotechnical parameter distribution maps and visualisation of distribution patterns with density graphs, the results of this study can help in planning risk mitigation measures against potential geotechnical disasters in the future.

2. Methods

This research was conducted in Bengkulu City, the capital of Bengkulu Province, in the western part of Sumatra Island. The city exhibits diverse topographical and geological features. The area is generally dominated by terrace deposits of Aluvium (Qat) spread from the coastal area to the central part of the city can be seen in Figure 2. These deposits mainly consist of sedimentary materials such as sand, silt, clay and gravel. Along the coastline, there is a reef limestone formation (Ql) which consists of sandy soil with coral limestone underlying. The Bintunan Formation (Qtb) is found in the border area with Central Bengkulu Regency, Seluma, and a small part of North Bengkulu, which is composed of polymict conglomerate, breccia, reef limestone, tuffaceous mudstone, and wood fossils. In the eastern part of Bengkulu City, bordering Central Bengkulu and Seluma regencies, the Andesite Formation (Tpan) is found in the highland area. Meanwhile, in the north and west of the city, there is the Swamp Sediment Formation (Qs) which consists of sand, silt, clay mud, and plant fossils. For the central area of the city, the Aluvium Formation (Qa) is found, which is composed of materials such as boulders, pebbles, sand, silt, mud and clay [15].

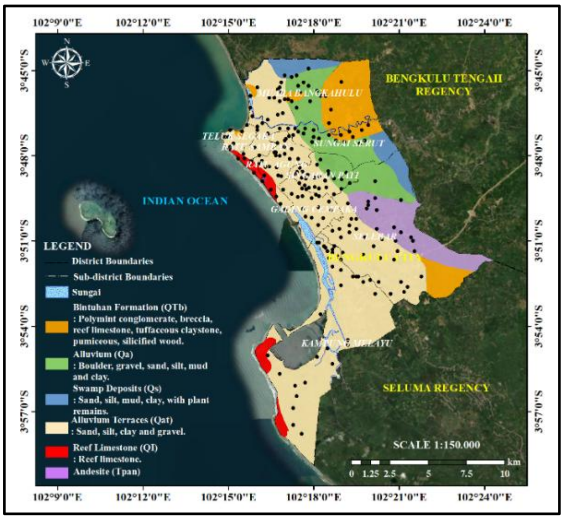

Figure `2. Geologic Condition Map of Bengkulu City

2.1 Data Availability

This study uses geotechnical data from previous research in the form of data on the modulus of elasticity (Es), cohesion (c), and friction angle (φ). Data were taken from 215 points spread throughout Bengkulu City, with evenly distributed data collection points to capture the spatial variation of the dominant soil. The geotechnical parameter data is presented as diagrams, then processed and analysed to obtain a distribution map of parameter values for each layer.

Figure 3 shows the percentage of Modulus Elasticity (Es) data for the type of sand layer with the largest data obtained in the range of 10500 - 12500 as much as 49%, in Figure 4 the percentage of Modulus Elasticity (Es) data for the clay layer with the largest data in the range of 145000 - 16500 as much as 33%, in Figure 5 the percentage of Modulus Elasticity (Es) data in the soft rock layer is dominated by the range 12500 - 14500 as much as 65%, Figure 6 shows the percentage of Modulus of Elasticity (Es) data for medium rock layers dominated by the range of 14500 - 16500 as much as 42%, and the diagram shown in Figure 7 shows a diagram of the percentage of Modulus of Elasticity (Es) data for hard rock dominated by the range 12500 - 14500 as much as 65%.

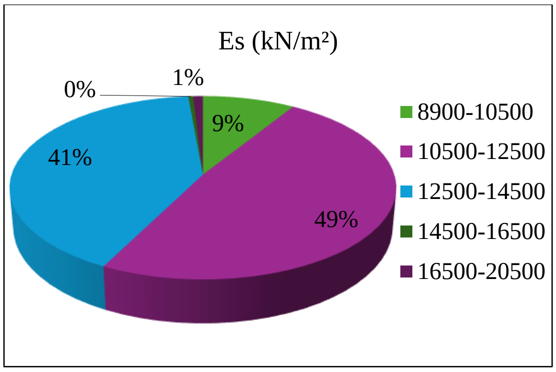

Figure 3. Percentage Chart of Modulus of Elasticity (Es) Data on Sand Layer

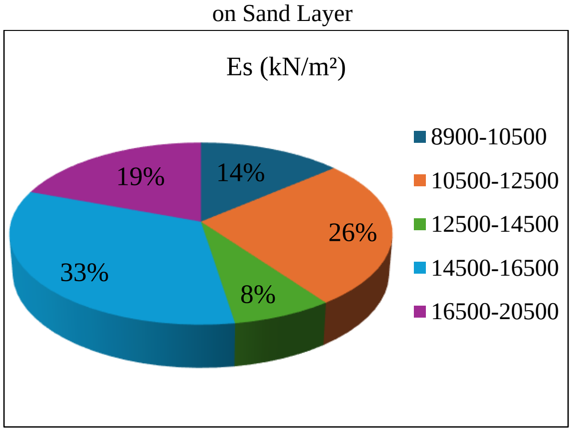

Figure 4. Percentage Diagram of Modulus of Elasticity (Es) Data on clay layer

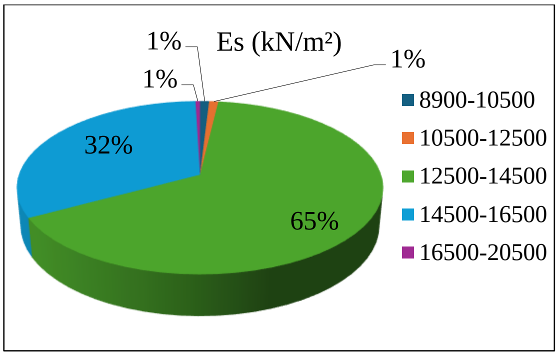

Figure 5. Percentage Diagram of Modulus of Elasticity (Es) Data on soft rock layers

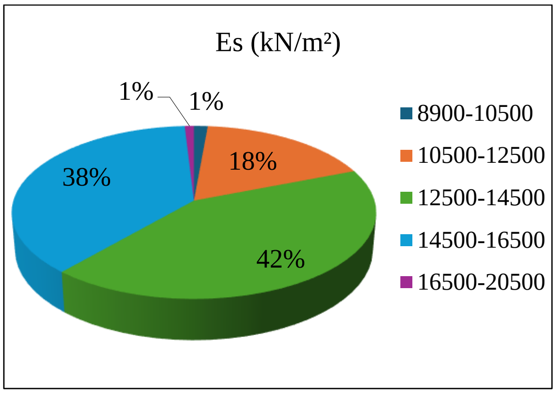

Figure 6. Data Percentage Diagram of Modulus of Elasticity (Es) in medium rock layers

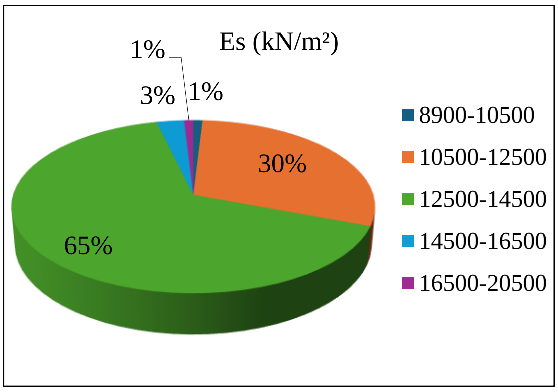

Figure 7. Percentage diagram of Modulus of Elasticity (Es) data in complex rock layers

The percentage diagram of Cohesion (C) data, which is only found in the clay layer, is presented in Figure 8, dominated by the range 341 - 441 as much as 31%. Meanwhile, the percentage of Inner Friction Angle (φ) data for the type of sand layer is shown in Figure 9 with dominated by the range of 30 - 32 as much as 47%, in the clay layer has an average cohesion value of 20% as shown in Figure 10, in the soft rock layer presented in Figure 11 is dominated by the range 34 - 35 as much as 66%, in the medium rock layer is dominated by the range 36 - 3 as much as 78% this can be seen in Figure 12, and in Figure 13 the hard rock layer is dominated in the range 41 - 42 with a value of 74%.

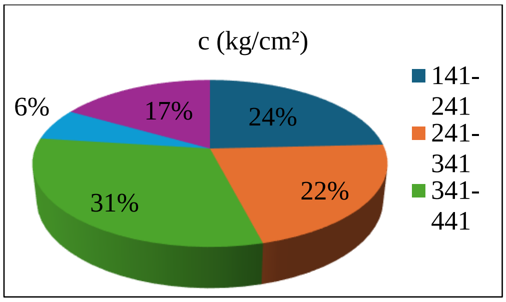

Figure 8. Percentage Chart of Cohesion Data (c) on Clay Soil

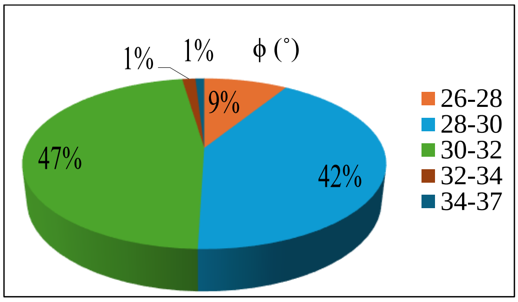

Figure 9. Percentage Diagram of Inner Friction Angle (φ) Data on Sand Layer

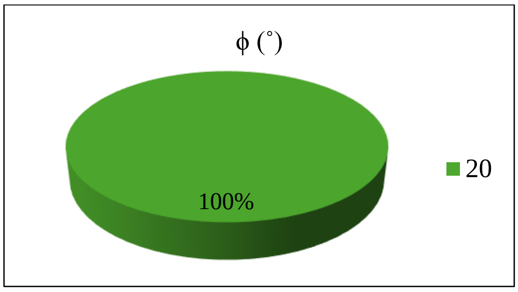

Figure 10. Percentage Diagram of Inner Friction Angle (φ) Data on Clay Layer

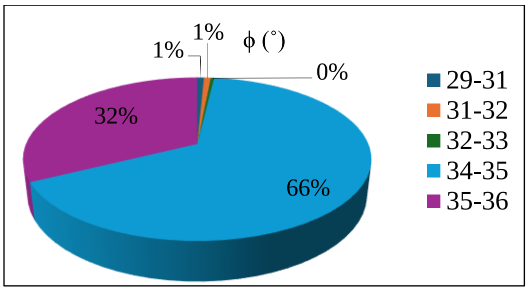

Figure 11. Diagram of Percentage Data of Inner Friction Angle (φ) in Soft Rock Layer

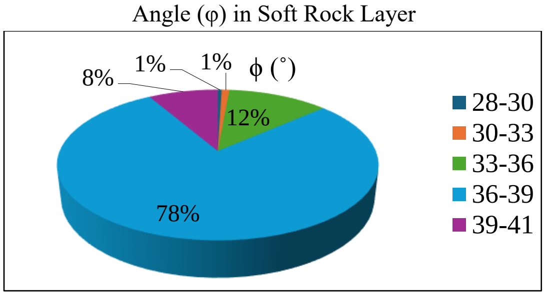

Figure 12. Diagram of Percentage Data of Inner Friction Angle (φ) in Medium Rock Layer

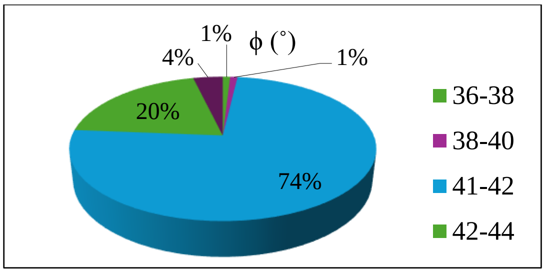

Figure 13. Diagram of Percentage Data of Inner Friction Angle (φ) in Hard Rock Layer

2.2 IDW Interpolation Method (*Inverse Distance Weighting*)

The geotechnical data were further analysed using Argcis software and Inverse Distance Weighting (IDW) interpolation to map the spatial distribution of geotechnical parameters. Inverse Distance Weighting (IDW) is an interpolation method that estimates the value of a parameter at a given location concerning values at surrounding points, where the weight is determined by distance. This technique was chosen for its simplicity and ability to produce reasonably accurate predictions, especially when geotechnical data is only available at limited measurement points [16].

According to Singh and Verma [17] the Inverse Distance Weighting (IDW) method is a non-geostatistical interpolation technique whose principle is that values at unknown locations are more influenced by nearby control points than more distant ones, the initial data is usually located on a regular grid or sometimes irregularly distributed in a region, and the interpolation process is performed on a tighter grid to produce a map. According to Yudanegara et all [18] the simplest form of this method is linear interpolation, where weights are calculated based on a linear function of the distance between the data points and the predicted location. However, this method does not have a built-in mechanism to verify the accuracy of the prediction, so the quality of the map can only be analyzed by considering validated sample points. Equation 1 is an overview of the equations used in the Inverse Distance Weighting (IDW) interpolation method according to [19]
.

$$Z(x_0) = \frac{\sum_{i=1}^{n} Z(x_i)\ .\ \lambda(x,x_i)^{-P}}{\sum_{i=1}^{n} \lambda\,(x,x_i)^{-P}} \qquad (1)$$

Where, $Z(x_0)$ is the predicted value at the study site, $Z(x_i)$ is the value measured at a point x_i, and $\lambda(x,x_i)$ is the distance between the prediction and measurement points, and p is the distance exponent adjusted to produce the interpolation that best fits the data conditions.

2.3 Research Framework

This research was conducted systematically following the flow chart presented in Figure 14. This research begins with the collection of geotechnical data from previous studies in the form of data on modulus of elasticity (E_s), cohesion (c), inner friction angle (φ) and secondary data in the form of geological maps of Bengkulu City. Data recapitulation was carried out after the data was collected to ensure completeness and consistency before analysis. The geotechnical parameter data was then analysed using the Inverse Distance Weighting (IDW) interpolation method. The study resulted in a distribution map of the values of modulus of elasticity (E_s), cohesion (c), and angle of friction (φ) in Bengkulu City that can be used to identify the dominant characteristics of the soils in the study area and their geotechnical implications.

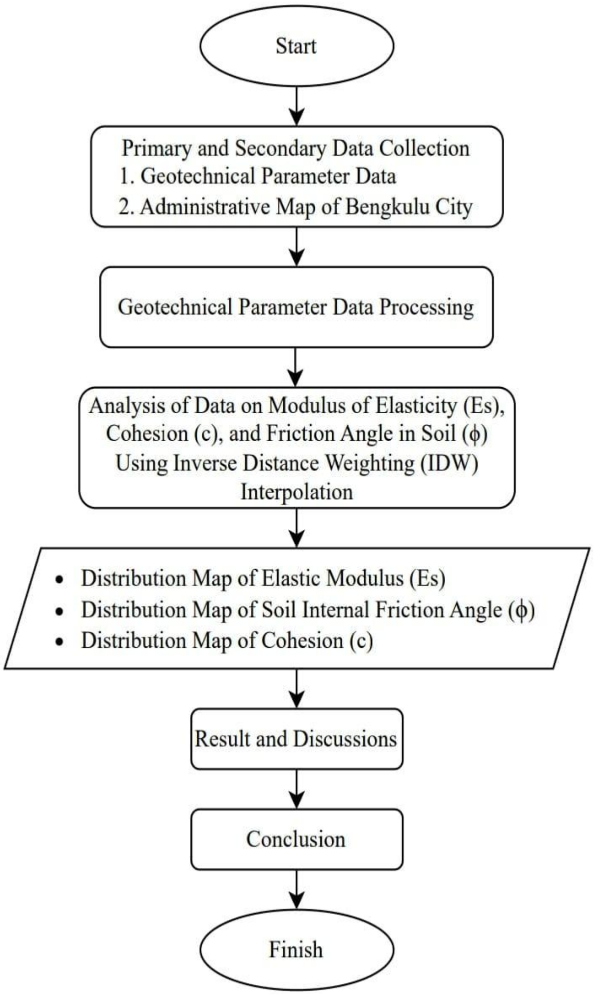

Figure 14. Research Flow Chart

The Inverse Distance Weighting (IDW) interpolation results were validated by comparing the predicted data with actual field measurements. This process involved testing several control points not included in the interpolation process to ensure the accuracy of the mapping results.

3. Result and Discussion

3.1 Modulus of Elasticity (E_s) Distribution Map

The interpolation results using the Inverse Distance Weighting (IDW) method show the spatial distribution of elastic modulus in Bengkulu City. The modulus of elasticity indicates a material's rigidity level, which means that if the material has a high modulus of elasticity value, the shape change due to a particular stress will be more minor [5]. The elastic modulus distribution map shown in Figure 15 shows significant variations in some areas; the sandy soil layer of Bengkulu City is dominated by lower elastic modulus values, ranging from 9 kN/m^2 to 14 kN/m^2, indicating that the soil in this area tends to be softer and less able to withstand load-induced deformation.

Furthermore, the distribution map in Figure 16 shows variations in the clay layer. In this layer, the Bengkulu City area is dominated in the range of 3 kN/m^2 to 9 kN/m^2, indicating that the clay layer in the Bengkulu City area tends to be soft. The distribution map in Figure 17 shows the variation in the soft rock layer, which is dominated by the range of 13 kN/m^2 to 19 kN/m^2, indicating that the soil is more rigid than the clay layer. Then, the distribution map shown in Figure 18, the modulus of elasticity in the medium rock layer in Bengkulu City is dominated in the range of 18 kN/m^2 to 26 kN/m^2 in this layer; the soil tends to be stiff and stable. This indicates the possibility of denser soil material. Figure 19 shows the distribution map of higher modulus of elasticity values dominated by the 26 kN/m^2 range to 37 kN/m^2, indicating more rigid and stable soil characteristics. This suggests the possibility of denser soil material, such as dense clay or bedrock, closer to the surface.

This map shows that the variation in elastic modulus values across different layers and regions greatly influences decisions in structural design. For example, soil reinforcement is required before erecting buildings in areas with low elastic modulus. This significant difference aligns with previous research, which found that coastal regions tend to have soils of lower geotechnical quality than areas higher up or further from the coast [7]. In addition, these results are consistent with geotechnical theory, where soils with low modulus of elasticity generally require additional reinforcement before being used for structural development [20].

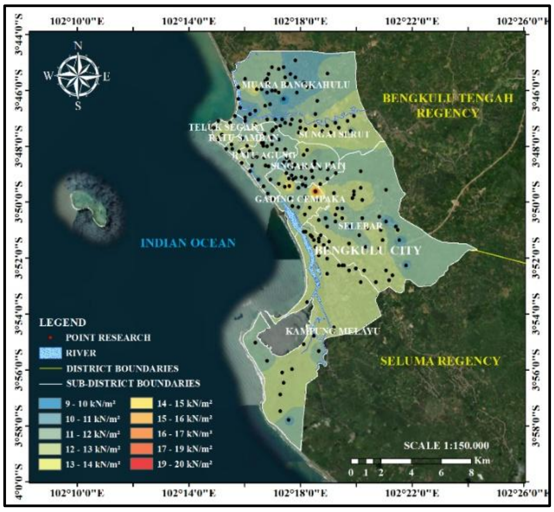

Figure 15. Distribution Map of Modulus of Elasticity (Es) Values in Sand Layer

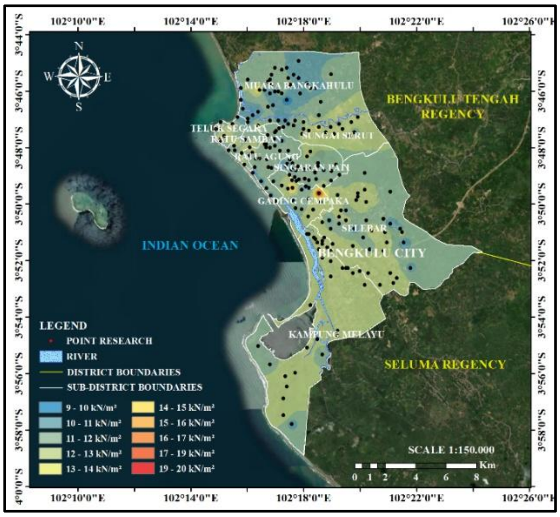

Figure 16. Distribution Map of Modulus of Elasticity (Es) Values in Clay Soil Layer

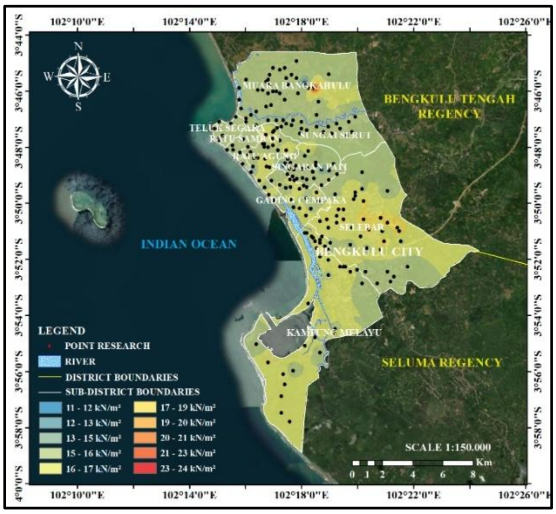

Figure 17. Distribution Map of Modulus of Elasticity (Es) Values in Soft Rock Layers

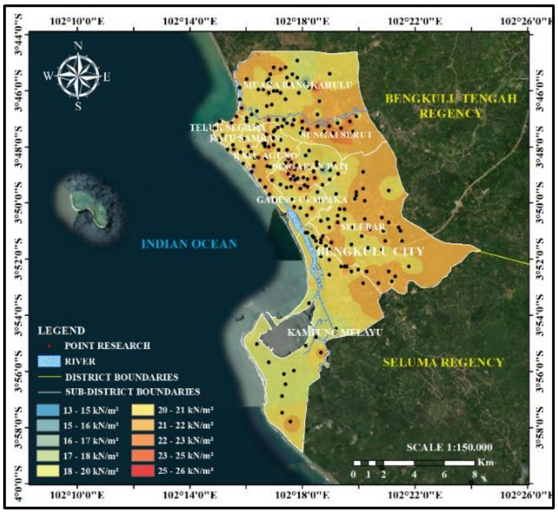

Figure 18. Distribution Map of Modulus of Elasticity (Es) Values in Medium Rock Layer

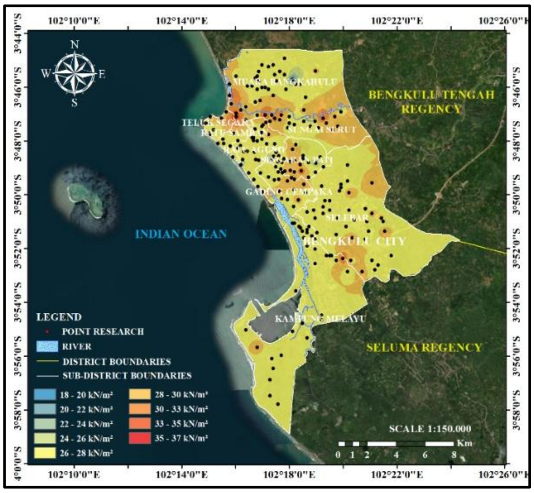

Figure 19. Distribution Map of Modulus of Elasticity (Es) Values in Hard Rock Layers

3.2 Distribution Map of Cohesion (c)

The distribution of soil cohesion in Bengkulu City is also generated through the IDW method, and the results show significant variations in different areas. Cohesion soil in this study is found in the clay layer because clay soil is a cohesive soil that consists primarily of tiny grains and has the properties of small shear force, significant compression, small permeability coefficient and a low bearing capacity [21]. Cohesion is the force of attraction between soil particles, measured in weight units per area. The cohesion value of the soil will increase as the shear strength increases. Factors that affect cohesion include the density and spacing between molecules in a material. Cohesion is positively correlated with density, so the more significant the density of a material, the higher the cohesion value [6].

Figure 20 shows the distribution map of cohesion values across Bengkulu City. The highest cohesion values are found in the city's southern area, ranging from 12 kg/cm^2 to 16 kg/cm^2. These values indicate that the soil in the area has a relatively high tensile strength, which can withstand vertical loads better. On the other hand, areas in the northern part of Bengkulu City have much lower cohesion values, ranging from 4 kg/cm^2 to 8 kg/cm^2, indicating looser soils that are potentially more susceptible to collapse. This low cohesion may be due to the high organic matter or water content in the coastal areas, which tends to weaken soil strength. This cohesion distribution is essential for infrastructure planning in high-risk areas, especially coastal areas, which may require additional soil stabilisation measures to prevent landslides or collapse due to heavy loads.

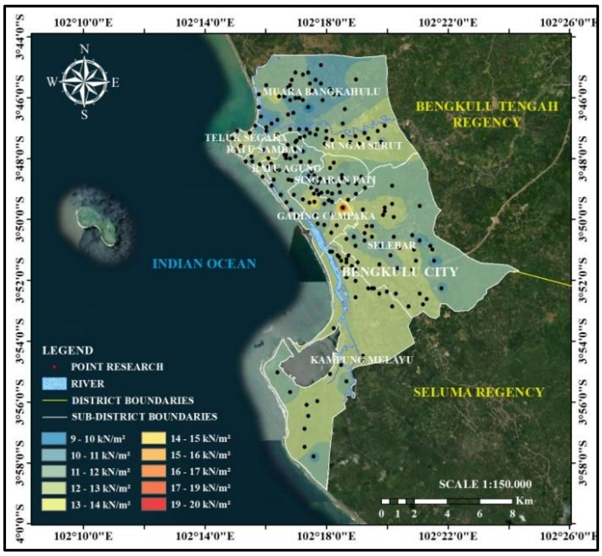

Figure 20. Distribution Map of Cohesion Value (c) in Clay Soil Layer

3.3 Distribution Map of Inner Friction Angle (φ)

The interaction between normal and shear stress in soil or rock forms the deep friction angle. The fracture angle occurs when a material is subjected to stress beyond its shear stress limit. The greater the friction angle in a material, the stronger the material resists the external stress applied to it [6]. The deep friction angle (φ), which indicates the ability of the soil to resist shear, was also mapped using the IDW method. The results presented in Figure 21 show that in the sand layer, the values of the angle of friction in Bengkulu City are dominated in the range of 26° to 30°, indicating a higher risk of soil instability, especially when the soil is exposed to heavy rainfall or earthquakes and is prone to liquefaction. The soil friction angle in the clay layer is shown in Figure 22; in the Bengkulu City area, it is dominated by a range of 20°, which is lower than the sand layer, indicating a higher risk of soil instability in this layer.

Figure 23 shows the distribution map of soil friction angle values in the soft rock layer dominated by the range of 32° to 35°, indicating that this layer has a better ability to resist shear and is more stable against potential landslides and susceptible to liquefaction. Figure 24 illustrates the distribution map of deep friction angle values in the medium rock layer dominated by the range from 34° to 40°. Figure 25 shows the distribution map of the friction angle in the hard rock layer dominated by the 40° to 46° range, which is greater than the previous layer.

Based on the analysis of the inner friction angle, the deeper the soil layer, the greater the inner friction angle. This indicates that the more profound the soil layer, the more structurally stable the soil is in withstanding horizontal loads generated by shear forces. Soils with low internal friction angles are more susceptible to liquefaction, where the soil loses its strength and stiffness due to high water pressure during seismic vibrations. The internal friction angle distribution map generated by the IDW method provides essential guidance for disaster risk planning and mitigation in coastal areas prone to soil collapse.

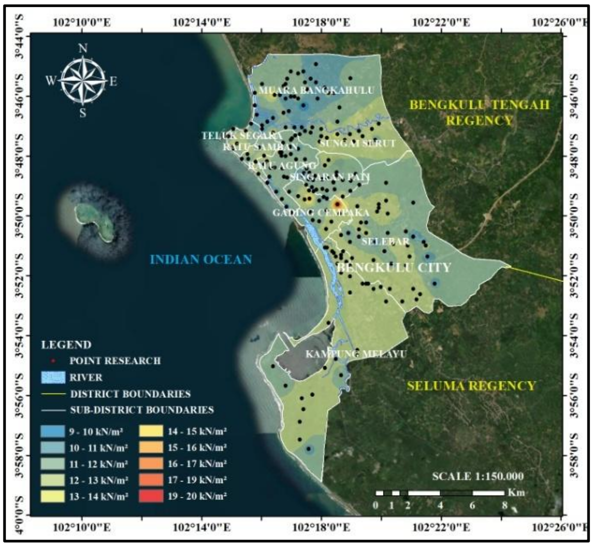

Figure 21. Distribution Map of Inner Friction Angle (φ) Values in Sand Soil Layer

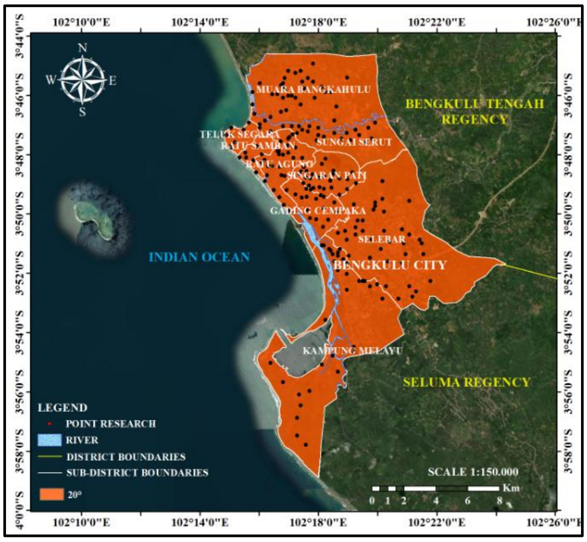

Figure 22. Distribution Map of Inner Friction Angle (φ) Values in Clay Soil Layer

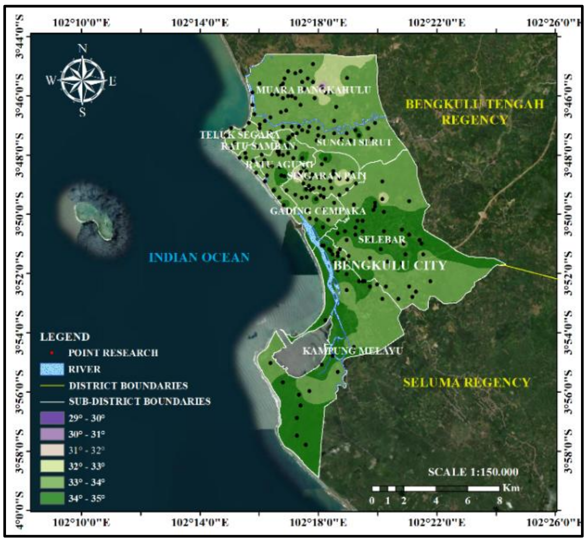

Figure 23. Distribution Map of Inner Friction Angle (φ) Values in Soft Rock Layer

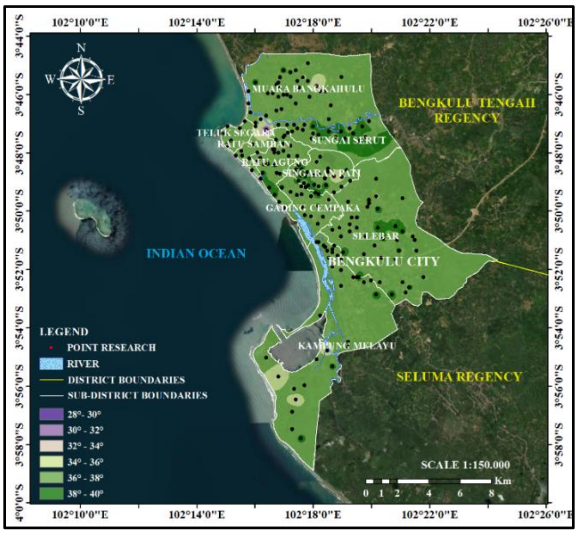

Figure 24. Distribution Map of Inner Friction Angle (φ) Values in Medium Rock Layer

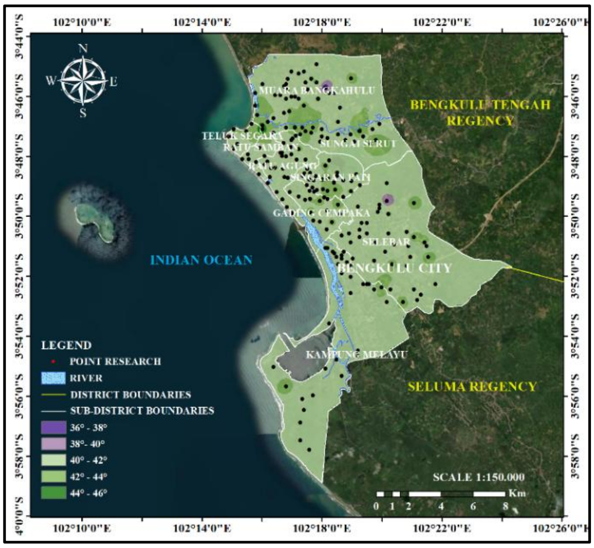

Figure 25. Distribution Map of Inner Friction Angle (φ) Values in Hard Rock Layer

3.4 Statistical Parameter

The spatial distribution results of the three geotechnical parameters analysed provide a deeper understanding of the soil characteristics in Bengkulu City. Analysis using the IDW method provides an accurate and reliable distribution map. Furthermore, the statistical analysis of geotechnical parameters was carried out to make reading the data analysed as a table easier.

Table 1 presents the results of statistical analysis of the modulus of elasticity (Es) parameter (kN/m²) range from 8935 - 18038 kN/m². Meanwhile, the average value of the Es parameter in each layer is 12084.58 kN/m² for sandy soil, 6157.34 kN/m² for clay soil, 16265.29 kN/m² for soft rock, 20942.21 kN/m² for medium rock and 28470.54 kN/m² for hard rock. The low modulus of elasticity in Bengkulu City indicates that the area is more susceptible to deformation and may require soil reinforcement techniques in development.

The results of the statistical analysis of the cohesion modulus (c) parameter (kg/cm²) presented in Table 2 show that the clay soil is in the range of 4.18-16.30 kg/cm². Meanwhile, the average value of the cohesion parameter in the clay soil is around 9.34 kg/cm². Low cohesion in the Bengkulu City area indicates loose soil and the potential for landslides or subsidence. Interventions such as soil stabilisation or special foundations may be required in the area.

Table 1. Statistical Analysis Results of Modulus of Elasticity (Es) Parameters (kN/m²)

Modulus of Elasticity (Es) (kN/m²)					
Statistical Parameters	**Sand**	**Clay**	**Soft Rock**	**Medium Rock**	**Hard Rock**
Mean	12084.58	6157.34	16265.29	20942.21	28470.54
Median	12067.00	6107.00	15955.00	20954.00	28140.00
Min	8935.00	3588.00	10842.00	13704.00	18038.00
Max	20197.00	9652.00	24426.00	26399.00	37660.00
Standard Deviation	1304.79	1747.22	1222.87	1733.80	1657.18
Variance	1694534.19	3033685.43	1488463.41	2992097.68	2733478.60
Coeff of Variation	10.80	28.38	7.52	8.28	6
Standard Error	89.19	138.13	83.40	118.24	113.02
The 95th Percentile	13545.35	9449.30	18278.80	23921.50	30380.30

Table 2. Statistical Analysis Results Parameter Cohesion (c) (kg/cm²)

Cohesion (c) (kg/cm²)	
Statistical Parameters	**Clay**
Mean	9.34
Median	9.24
Min	4.18
Max	16.30
Standard Deviation	3.48
Variance	12.05
Coeff of Variation	37.28
Standard Error	0.28
The 95th Percentile	15.90

Table 3. Statistical Analysis Results Parameter Inner Friction Angle ϕ (˚)

Inner Friction Angle ϕ (˚)					
Statistical Parameters	**Sand**	**Clay**	**Soft Rock**	**Medium Rock**	**Hard Rock**
Mean	30.40	20.00	34.50	37.88	42.27
Median	30.00	20.00	34.00	38.00	42.00
Min	26.00	20.00	29.00	28.00	36.00
Max	37.00	20.00	36.00	41.00	47.00
Standard Deviation	1.45	0.00	0.94	1.44	0.99
Variance	2.10	0.00	0.87	2.07	0.98
Coeff of Variation	4.78	0.00	2.72	3.81	2
Standard Error	0.10	0.00	0.06	0.10	0.07
The 95th Percentile	32.00	20.00	36.00	40.00	43.00

Based on Table 3, the results of statistical analysis of the friction angle parameter ϕ (˚) range from 26 to 36˚. Meanwhile, the average value of the ϕ parameter in each layer, namely, in the sand soil layer is around 30.40˚, clay soil is around 20˚, soft rock is around 34.50˚, medium rock is 37.88˚ and hard rock is 42.27˚. The lower internal friction angles in some areas of Bengkulu City confirm the need for more attention in infrastructure planning, especially against the risk of landslides that can be triggered by heavy rainfall or earthquakes.

The results of this study provide important insights for development planning in Bengkulu City. The spatial distribution of elastic modulus, cohesion and internal friction angle suggests that the southern coastal areas are more vulnerable to geotechnical risks, such as subsidence and liquefaction, especially under earthquakes or landslides.

4. Conclusion

This research aims to analyse the spatial distribution of geotechnical parameters, namely elastic modulus, cohesion, and inner shear angle (φ), on dominant soils in Bengkulu City using the Inverse Distance Weighting (IDW) method for mapping. Based on the analysis results, some main conclusions can be drawn as follows:

1. The distribution of modulus of elasticity in Bengkulu City shows a significant difference in each layer between the south-coastal and north-central areas. In the sandy soil layer, the modulus of elasticity is lower, ranging from 9 kN/m^2 to 14 kN/m^2, indicating that the soil in the area is soft and less able to resist deformation under load. The clay layer ranges from 3 kN/m^2 to 9 kN/m^2, indicating that the clay layer in Bengkulu City tends to be soft. The soft rock layer is dominated by the range of 13 kN/m^2 to 19 kN/m, h indicating that the soil is more rigid than the clay layer. The medium rock layer in Bengkulu City is dominated by the range of 18 kN/m^2 to 26 kN/m^2. In this layer, the soil tends to be stiff and stable. This indicates the possibility of denser soil material, and the hard rock layer ranging from 26 kN/m^2 to 37 kN/m^2 shows more rigid and stable soil characteristics. This difference indicates that the sand and clay layers of Bengkulu City are more susceptible to subsidence or structural collapse, so soil reinforcement is required in construction planning in this area.

2. The mapping results show that the highest cohesion values are found in the city's southern area, ranging from 12 kg/cm^2 to 16 kg/cm^2. These values indicate that the soil in the region has a relatively high tensile strength, which can withstand vertical loads better. On the other hand, areas in the northern part of Bengkulu City have much lower cohesion values, ranging from 4 kg/cm^2 to 8 kg/cm^2, indicating looser soils that are potentially more prone to collapse. The low cohesion in the coastal areas emphasises the need for soil improvement before significant infrastructure development, such as mechanical compaction or reinforcing materials.

3. The deep friction angle mapping shows that the sandy soil layer has deep friction angle values ranging from 26° to 30°, indicating a higher risk of soil instability. Furthermore, the clay layer is dominated by a range of 20° lower than the sand layer. The soft rock layer ranges from 32° to 35°, indicating that this layer can resist shear better. The medium rock layer is dominated by the 34° to 40°. And in the hard rock layer with a dominant range of 40° to 46° greater than the previous layer. Based on the analysis of the inner friction angle, the deeper the soil layer, the greater the inner friction angle. This indicates that the more profound the soil layer, the more structurally stable the soil is in withstanding horizontal loads generated by shear forces. This lower internal friction angle distribution in coastal areas must be considered in infrastructure planning to reduce the risk of soil failure during earthquakes or heavy rains.

This study confirms the importance of geotechnical parameter distribution analysis in planning safe and sustainable infrastructure development. Using the IDW method, accurate spatial distributions of elastic modulus, cohesion, and internal friction angle can be identified, providing a solid basis for geotechnical risk mitigation in Bengkulu City.

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