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Research article

Density distribution of shear wave velocity, cone resistance and corrected SPT in the dominant soils of Bengkulu City, Indonesia

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ABSTRACT

This research is essential as it discusses modelling a two-dimensional map of soil parameters in Bengkulu City, Bengkulu Province, Indonesia. The two-dimensional modelling aimed to show the distribution of soil parameter values based on the research points strategically distributed throughout Bengkulu City. These research points were chosen to represent the diverse soil conditions in the city, making the modelled soil parameters particularly helpful for engineers and construction consultants when planning construction in the study area. The parameters to be discussed include shear wave velocity, cone resistance, and corrected standard penetration test. This modelling applies Inverse Distance Weighting as an interpolation method from 215 research points. Inverse Distance Weighting is used because it helps determine the value of soil parameters around the review point, especially in two-dimensional modelling. The results showed that the distribution of the highest value of shear wave velocity of the clay layer is dominated in the Teluk Segara sub-district. The distribution of the highest value of cone resistance of the clay layer is dominant in the Kampung Melayu Sub-district. The distribution of the highest value of the corrected standard penetration test of the clay layer is also dominant in the Kampung Melayu Sub-district.

INTRODUCTION

Bengkulu Province is one of the areas on the island of Sumatra located in the intersection of tectonic plates known as the Ring of Fire path. The Ring of Fire often experiences earthquakes and volcanic eruptions with high intensity. Bengkulu City, as part of this region, is particularly significant due to its proximity to several active seismic sources, including the Sumatra Subduction, Sumatra Fault, and Mentawai Fault (**Figure 1**). **Mase (2020)** stated that seismic impacts due to subduction activities could have a more severe effect on communities in the coastal areas of Bengkulu City. **Mase et al. (2021)** noted in their study that Bengkulu Province has experienced large earthquakes with magnitudes of M_w

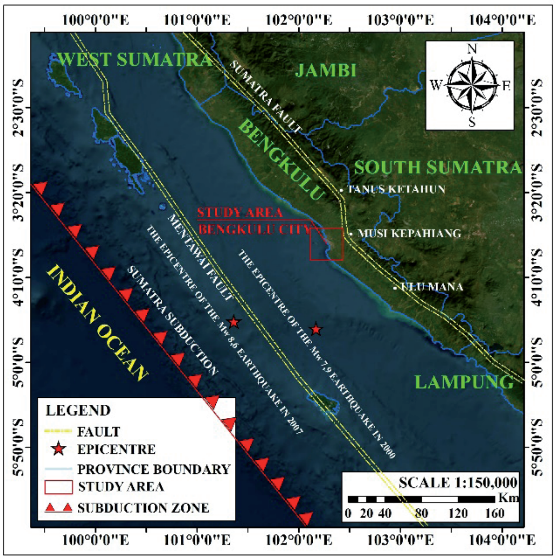


Figure 1 Seismotectonic Setting Map of Bengkulu City

7.9 and M_w 8.9 in the last 20 years. As technology develops and construction progresses in Bengkulu Province, geological data must be available to support construction planning. Minimising construction failures due to earthquakes or other natural disasters can be done by planning earthquake-resistant construction. One data needed to plan earthquake-resistant construction is soil geological data with many parameters. The soil layer is the main foundation that supports the load of a building, which is channelled through the foundation. Hard soil with more than 14.71 MPa compressive strength supports a good load. Hard soil can be known by conducting Cone Penetration Test (CPT) and Standard Penetration Test (SPT) tests directly in the field. In line with the evolution of technology, many studies have been conducted to find CPT and SPT data without having to do research directly in the field, one of which is by analysing two-dimensional distribution maps. Geological structure modelling is one of the most important fundamental aspects of earth science studies, and it plays a role in understanding the characteristics and dynamics of the earth's layers **(Wellmann and Caumon 2018)**. Various methods can be used to develop two-dimensional distribution maps; one widely used interpolation method is the Inverse Distance Weighting (IDW) interpolation method. This research discusses the distribution of shear wave velocity (V_s), cone resistance (q_c), and corrected SPT (N_{60}), which is the value of soil compressive strength at the 60th beat. The three values above will be presented as a two-dimensional distribution map using IDW interpolation.

Geological research has made significant progress in two-dimensional modelling soil parameter distribution mapping. This modelling can provide a clear and in-depth picture of the subsoil conditions at the construction project site, allowing engineers and planners to understand the geotechnical characteristics of the soil more accurately, as done by **Vollgger et al. (2015)** and **Pavicic (2018)**. **Benedetta et al. (2023)** have also presented geological distributions in two-dimensional representations, which depict various aspects of geological structures and the distribution of soil and rock layers. This representation allows for a clearer understanding of the local geological conditions and assists in further analysis of geological risks. The mapping of the distribution of soil parameters is based on research on the subsoil conducted in the study area.

This research presents a novel approach to the distribution of soil parameters. Interpolation-based two-dimensional distribution maps have not been done much, especially in the Bengkulu City area. The interpolation in question is Inverse Distance Weighting (IDW), generally used to map a value based on surrounding values. **Mase (2017, 2022)** recently studied the seismic response analysis of liquefaction-affected areas in the north coastal region of Bengkulu Province, showing that liquefaction phenomena can occur even in relatively shallow layers dominated by sand layers. **Mase et al. (2024a)** studied the soil layer in the Dendam Tak Sudah Lake area, consisting of two main layers: sand and clay. **Mase et al. (2024b)** are studying the soil layer profile along the Muara Bangkahulu River; the soil profile in the research area tends to be basin-shaped with relatively shallow bedrock. Based on the research conducted in Bengkulu City by **Mase (2017, 2022)**; **Mase et al. (2024a, 2024b)**, this study interpolates the distribution of soil parameters through shear wave velocity (V_s), cone resistance (q_c) and SPT correction (N_{60}), which are presented in the form of two-dimensional maps.

This research employs a two-dimensional modelling technique to present the distribution of soil parameter values across Bengkulu City. This technique provides a visual representation of the soil parameter values, making it easier to identify points with the highest and lowest values for each parameter. This information is crucial for planning structures and understanding the geological conditions at each research point. The technique involves integrating data from two x-y axes, such as a visual representation of the research point and value distribution based on a colour indicator. The two-dimensional modelling presented as a map will be helpful for engineers to illustrate the value of shear wave velocity, cone resistance and N-SPT correction in Bengkulu City when planning a future structure.

METHOD

Study Area

The geological conditions in the study area are presented in the form of a Geological Map in **Figure 2,** showing the geological formations of the study area. The geological formations are dominated by alluvium terraces (Qat) and alluvium (Qa) found along the coast to the centre of Bengkulu City **(Mase 2017, 2020)**. There are also four smaller formations: Bintunan formation (QTb), andesite (Tpan), swamp deposits (Qs), and reef limestone (Ql). There are 215 research points spread across nine sub-districts in Bengkulu City: Muara Bangkahulu, Teluk Segara, Sungai Serut, Ratu Samban, Ratu Agung, Singaran Pati, Gading Cempaka, Selebar, and Kampung Melayu. The research area is bordered to the north and east by Central Bengkulu Regency, to the west by the Indian Ocean, and to the east and south by Seluma Regency. Local geological formations greatly influence the distribution of interpolated soil parameter results. Factors such as rock types, soil strata and geological structures can cause soil density and

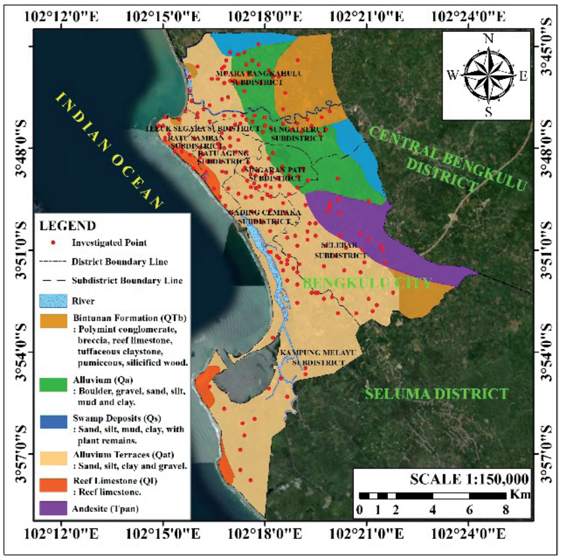
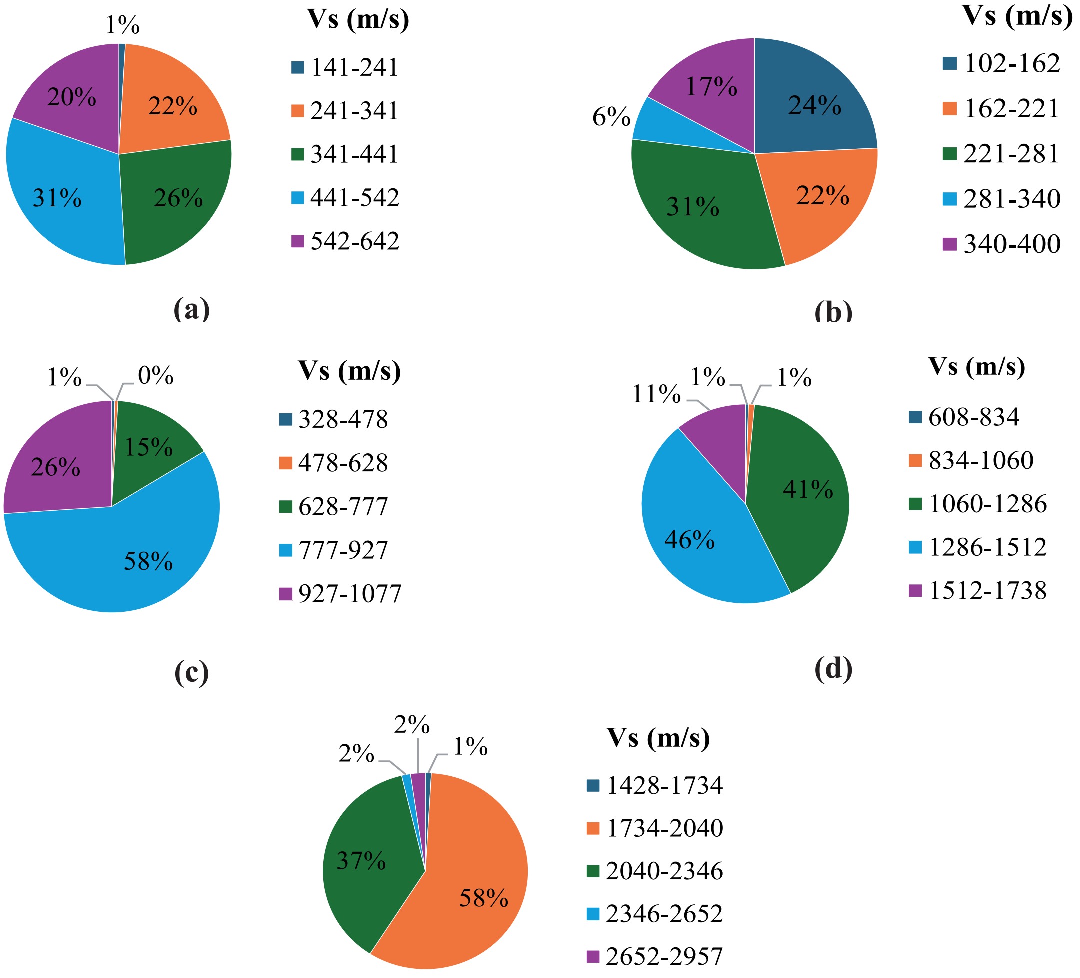


Figure 2 Geological Map of Bengkulu City

strength differences. This can result in uneven distribution patterns, so it is essential to understand the local geology to make the interpolation model more accurate and infrastructure design decisions more informed.

Data Availability

The available data describes each soil parameter spread across the investigation points according to the longitude and latitude coordinates. The parameter values are presented as pie charts consisting of three soil parameters, and each parameter consists of five pie charts representing the subsoil layers. Five layers of soil are obtained from the representative of each layer according to the type of soil and they are divided into five main layers of soil consisting of layers of sand, clay layers, soft rock layers, medium rock layers, and hard rock layers. The sand layer dominates as the uppermost layer, the clay layer is found at a depth of 29.60 m, the soft rock layer at a depth of 61.44 m, the medium rock layer at a depth of 120.31 m and the hard rock layer at a depth of 222.20 m. Based on the data presented in pie charts, the values of shear wave velocity (V_s) vary from 141 m/s to 2957 m/s, as shown in **Figure 3**. The cone resistance (q_c) values shown in **Figure 4** show values of 14 MPa to 302 MPa. **Figure 5** shows the corrected SPT (N_{60}) values, which range from 3 blows/feet to 60 blows/feet.



(a) (b)

(c) (d)

(e)

Figure 3 Shear Wave Velocity (V_s) value, **a** Sand layer, **b** Clay layer, **c** Soft rock layer, **d** Medium rock layer, **e** Hard rock layer

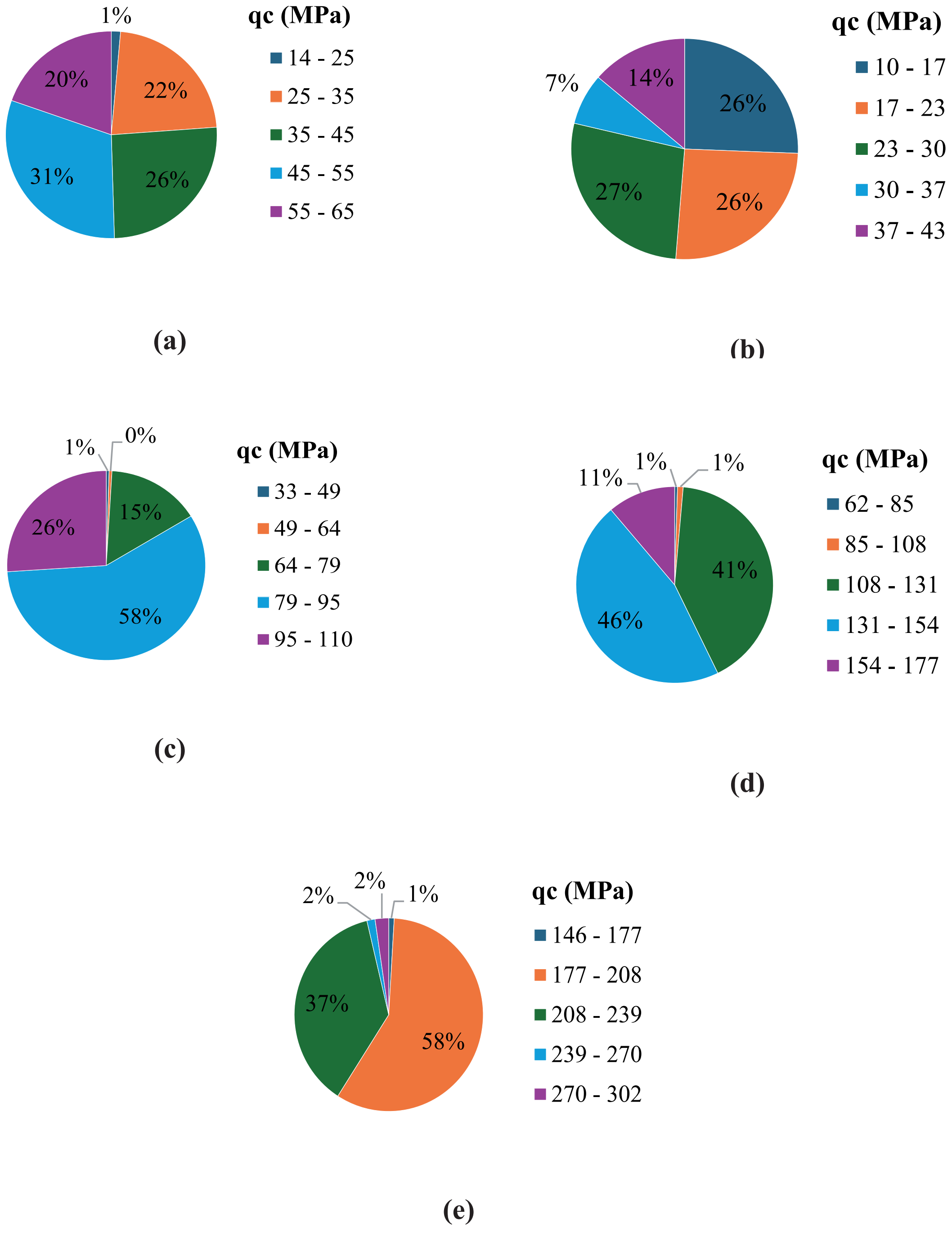
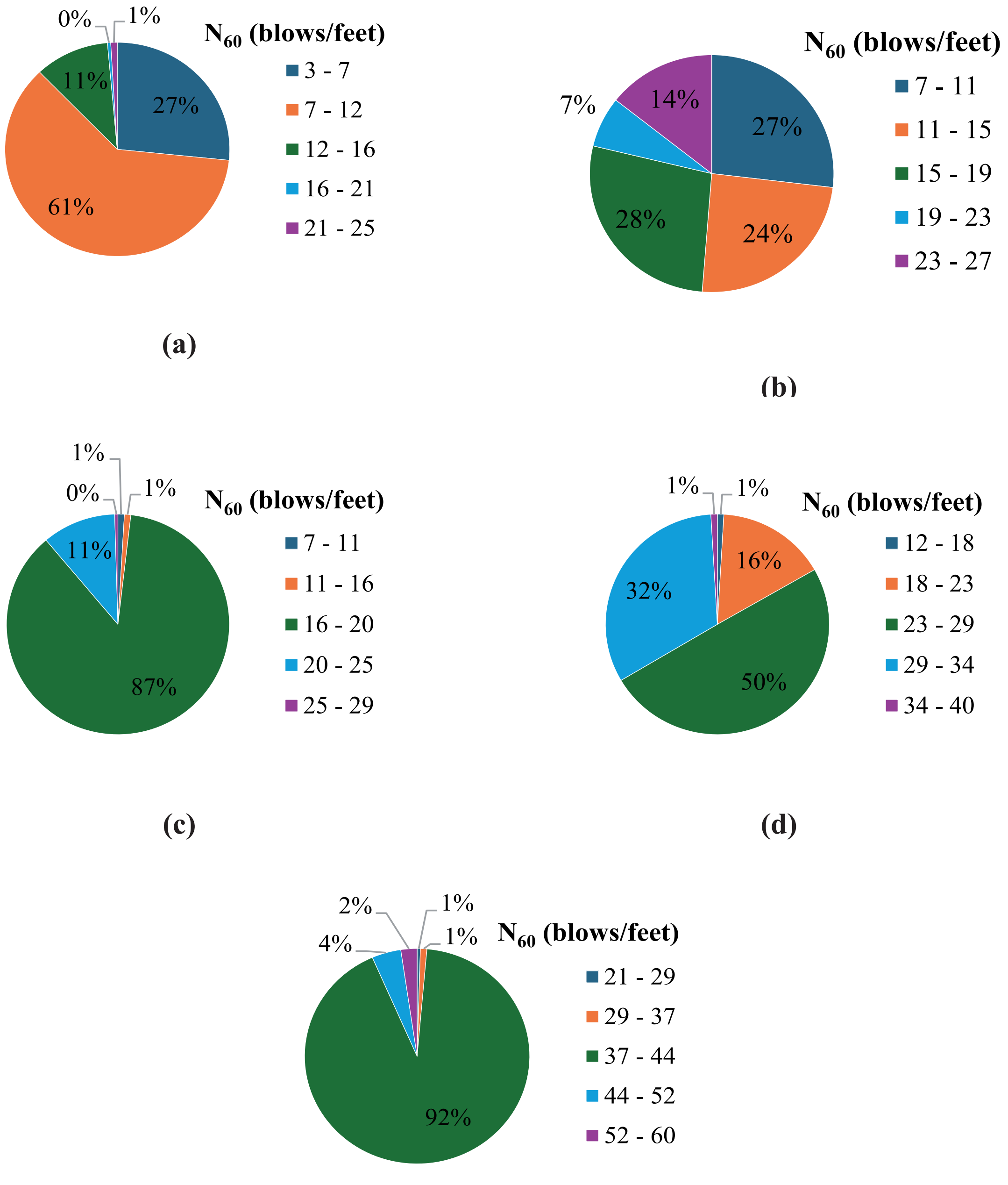


Figure 4 Cone Resistance value, **a** Sand layer, **b** Clay layer, **c** Soft rock layer, **d** Medium rock layer, **e** Hard rock layer



(a)

(b)

(c)

(d)

(e)

Figure 5 Corrected SPT (N_{60}) value, **a** Sand layer, **b** Clay layer, **c** Soft rock layer, **d** Medium rock layer, **e** Hard rock layer

Inverse Distance Weighting (IDW) Interpolation Method

Interpolation is a method of finding data values based on a known value. One of the point-based numerical interpolation methods used to determine a value is Inverse Distance Weighting (IDW) interpolation. The application of the IDW method in this research is that the research point used in the interpolation calculation is determined by finding a circle centred on the interpolated point. At least three points centred on the reference point are required to calculate the parameter value accurately. Using a search circle can significantly affect the performance of the IDW method (**Figure 6**) **(Harman et al. 2016)**. The empirical function can determine the modelled mathematical equation (1).

$$f_0 = f(x_0), f(x_1), \ldots, f_n = f(x_n) \tag{1}$$

Various studies have compared the IDW interpolation method with Krigging to determine soil layer characteristics using several parameters **(Elumalai et al. 2017)** and **(Rostami et al. 2019)**. IDW interpolation produces better distribution prediction accuracy than other interpolation methods **(Chen and Liu, 2012)**.

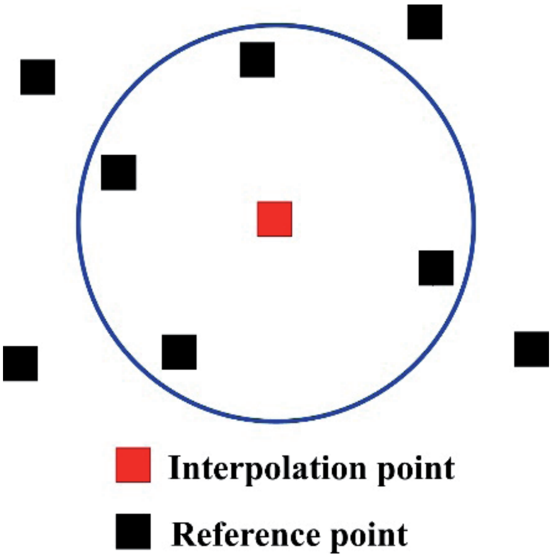


Figure 6 Circle Interpolation

Research Framework

Figure 7 presents the research framework applied in this study. It begins with reading some literature that discusses interpolation-based two-dimensional modelling. Next, data collection of soil layer profiles and V_s were recapitulated along with data on soil parameter properties such as q_c and N_{60}. The recapitulated data were analysed using the IDW interpolation method followed by two-dimensional modelling. The resulting two-dimensional modelling includes a distribution map of V_s, q_c, and N_{60} values. This research aims to understand the distribution of soil properties parameter values in the form of two-dimensional maps. The results of the map presentation can be a general description of the distribution of values in the study area.

RESULTS AND DISCUSSION

Shear Wave Velocity (V_s)

Figure 8 describes the shear wave velocity values distribution of each soil layer at the research site. The sand layer ranges from 141 m/s to 642 m/s, with the highest value at several points in the Sungai Serut Sub-district. The clay layer has values ranging from 102 m/s to 400 m/s, with the highest value

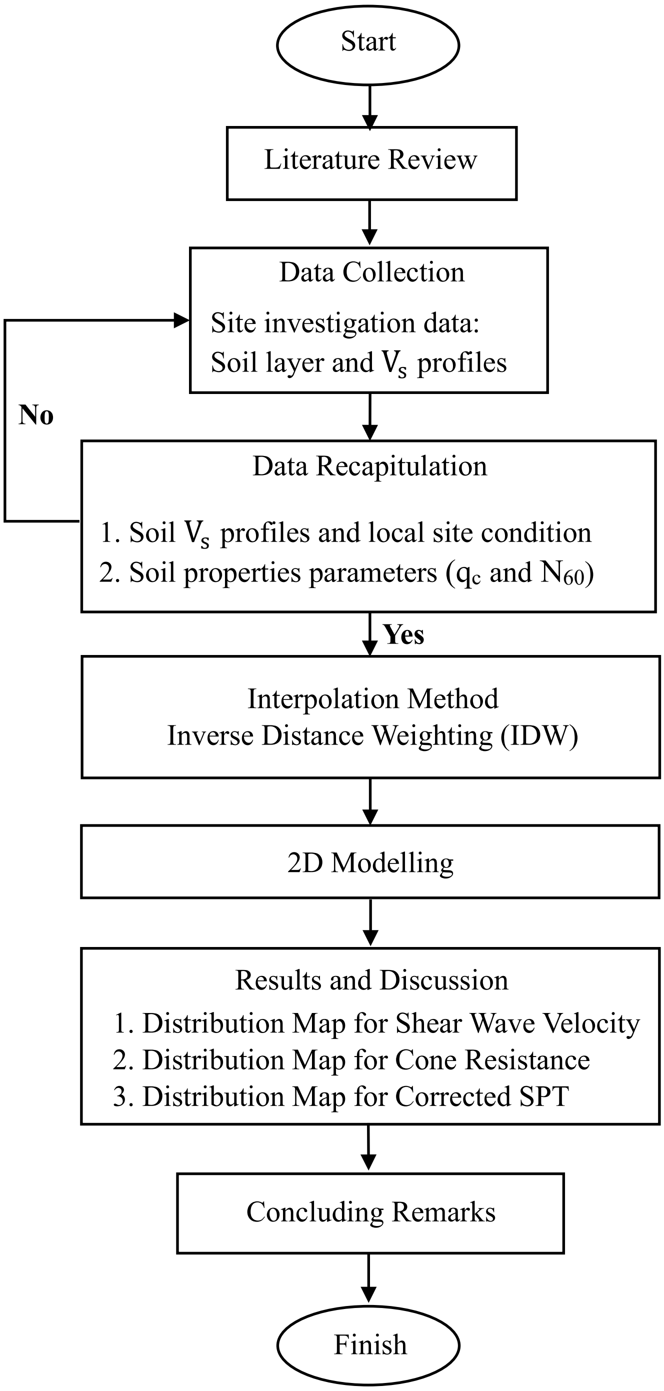


Figure 7 Research Framework

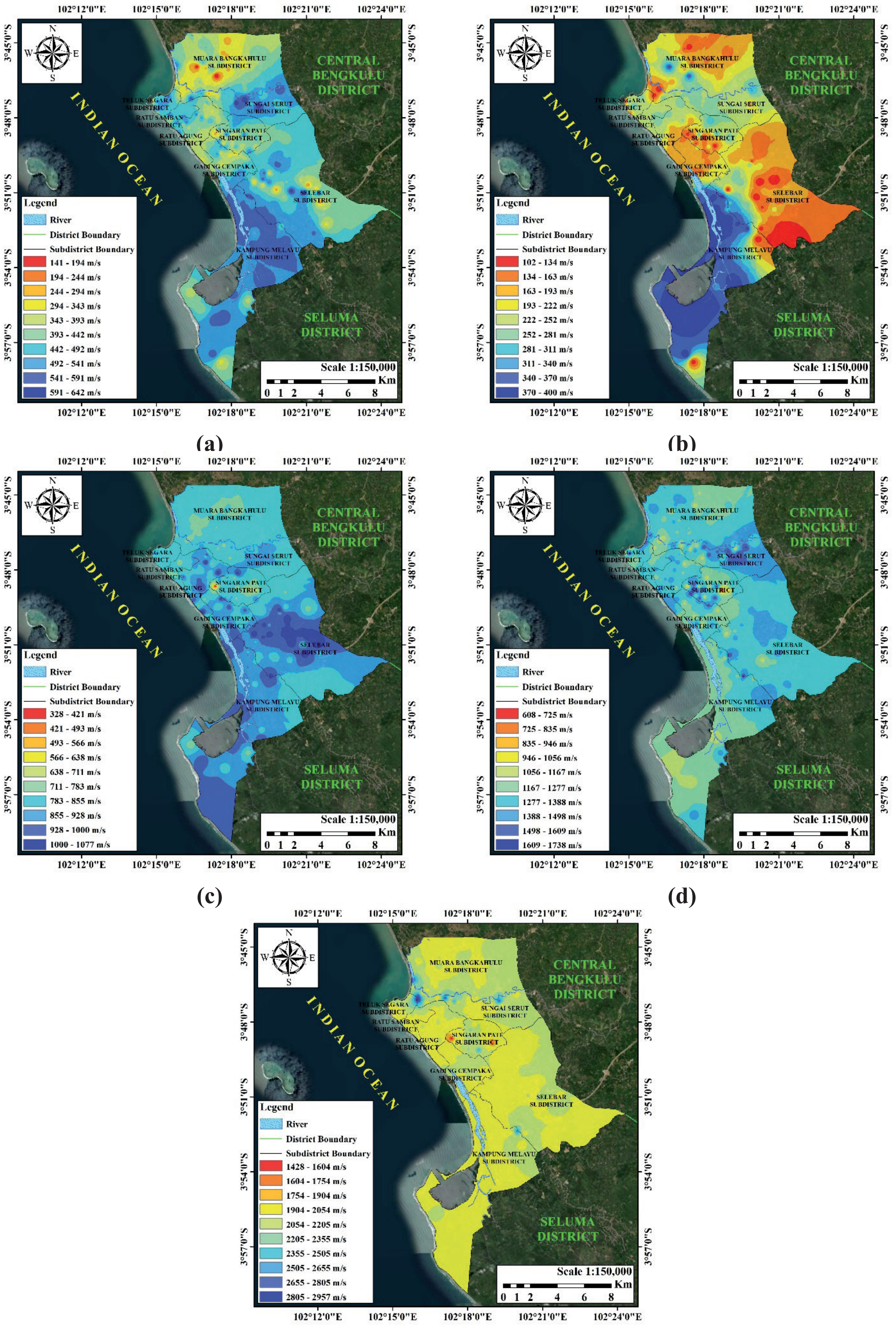


Figure 8 Distribution Map for Shear Wave Velocity (V_s), **a** Sand layer, **b** Clay layer, **c** Soft rock layer, **d** Medium rock layer, **e** Hard rock layer

in the Kampung Melayu sub-district. Selebar sub-district has the highest value with a V_s value range of soft rock layer of 328 m/s to 1077 m/s. The medium rock layer is recorded to have a value range of 608 m/s to 1738 m/s, with the highest value at the point of Sungai Serut Sub-district. The lowest layer, namely hard rock, has the highest value range of 1428 m/s to 2957 m/s, with the highest value in Teluk Segara District. A high V_s value indicates that the soil has good density and strength, making it more stable and able to withstand loads. Soils with high V_s values tend to respond better to seismic shaking and a lower risk of liquefaction. Conversely, low V_s values indicate that the soil may be softer or less dense, which can increase the risk of settlement, sliding or liquefaction during an earthquake. Soils with low V_s values may require more careful ground improvement techniques or structural design to address these potential risks. Research conducted by **Jia (2018)** states that V_s on various soil types, such as loose gravel, clay, and sand, have values ranging from 330 m/s to 1200 m/s.

Cone Resistance (q_c)

Figure 9 presents the distribution map of cone resistance values across all soil layers in Bengkulu City. As the topmost layer, the sand layer has a value range of 14 MPa to 65 MPa, while the clay layer has a value range of 10 MPa to 43 MPa. The highest value of cone resistance for the sand layer is in the Sungai Serut sub-district, while the clay layer is in the Kampung Melayu sub-district, and there are also several points in the Sungai Serut sub-district. The highest value of the soft rock layer is in the Selebar Sub-district, with a value range of 33 MPa to 110 MPa. The medium rock layer, with a value range of 62 MPa to 177 MPa, has the highest value and dominates in the Sungai Serut sub-district. Sungai Serut sub-district also has the highest value for the hard rock layer as the lowest layer, with a value range of 146 MPa to 302 MPa. A high q_c value indicates the soil has good density and strength, making it suitable for supporting heavy structures. This means the soil has good stability and a low risk of settlement or landslides. Conversely, a low qc value suggests that the soil has lower density and strength, increasing the risk of settlement, shifting or landslides if used for heavy building foundations. In this case, more profound soil improvement techniques or foundation design may be required. **Khodaparast et al. (2020)** stated that the cone retaining value in soil consisting of clay tends to be smaller when compared to soil with sand or rock composition. This is due to the difference in physical and mechanical characteristics between the three types of soil where clay, which has finer particles and is cohesive, allows easier penetration compared to sand, which is more granular and rock, which is more complex and denser.

Corrected SPT (N_{60})

The distribution map of corrected SPT values is presented in **Figure 10,** where generally, these values are obtained through direct testing in the field known as Standard Penetration Test. The sand layer has the highest value in the Gading Cempaka sub-district with 25 blows/feet, and the smallest value is three blows/feet. The clay layer with the highest value dominates in the Kampung Melayu sub-district with a value range of 24 blows/feet to 27 blows/feet and the smallest value of 7 blows/feet. The average soft rock layer values range from 15 blows/feet to 22 blows/feet, with the highest value of 29 blows/feet in the Teluk Segara sub-district. The medium rock layer is dominated by values of 21 blows/feet to 30 blows/feet, with the highest value in the Sungai Serut Sub-district being 40 blows/feet. Finally, the hard rock layer has the highest value of 60 blows/feet in the Sungai Serut sub-district, while the smallest value is 21 blows/feet. A high N_{60} value indicates that the soil is moderately dense and has good strength, to support structural loads well. Soils with high N_{60} values are more stable and have a lower settlement risk. Conversely, a low N_{60} value indicates the soil is softer or less dense, which means it is unlikely to support heavy loads without settlement or displacement. To ensure structural stability, soils with low N_{60} values may require exceptional repair of foundation design. **Wadi et al. (2021)** conducted SPT-N testing in Nigeria, showing that sandy silt clay followed by black cotton soil to a depth of 4.5-6 m has an SPT-N value of 0-26 blows/feet.

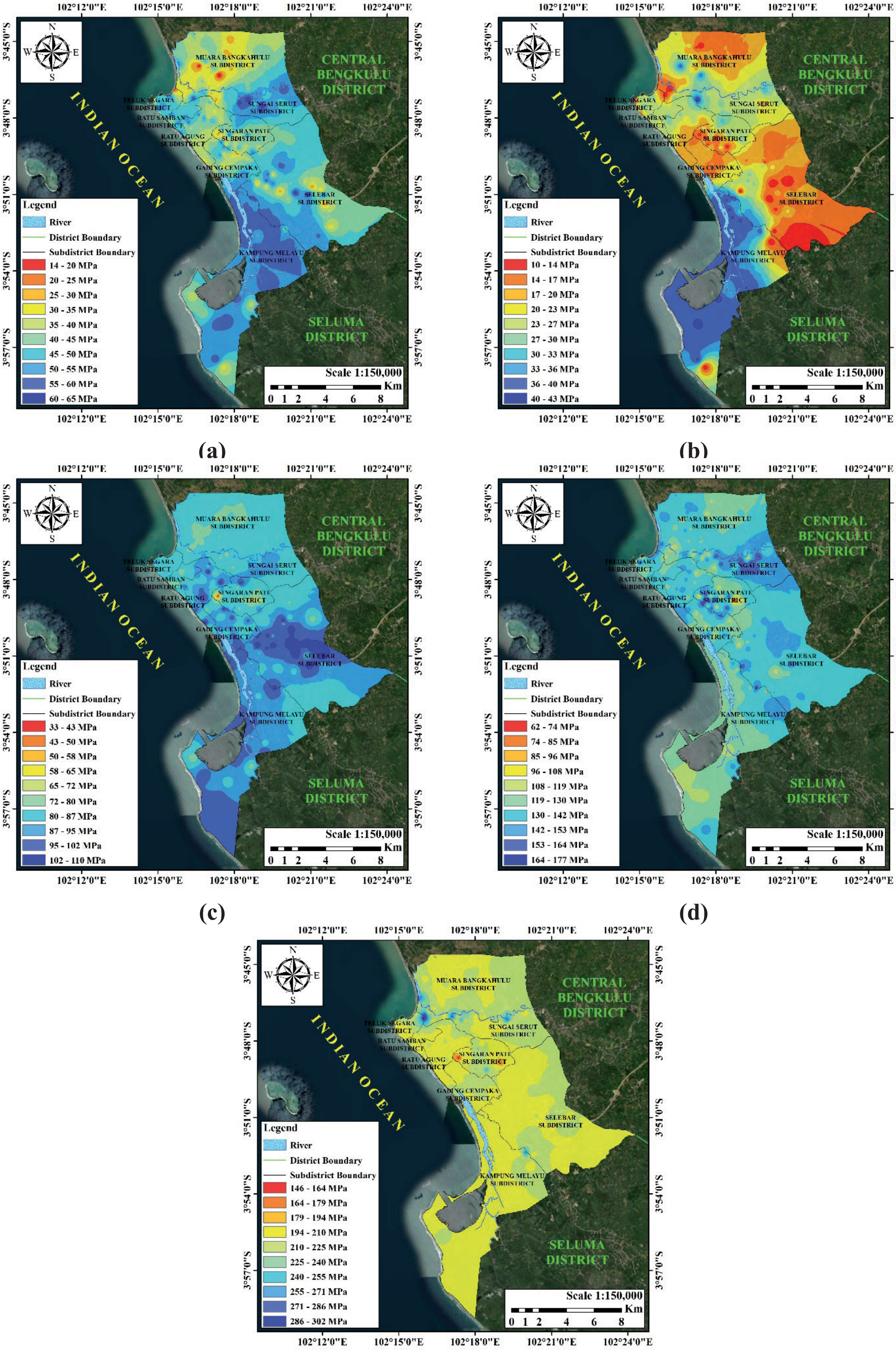


Figure 9 Distribution Map for Cone Resistance (q_c), **a** Sand layer, **b** Clay layer, **c** Soft rock layer, **d** Medium rock layer, **e** Hard rock layer

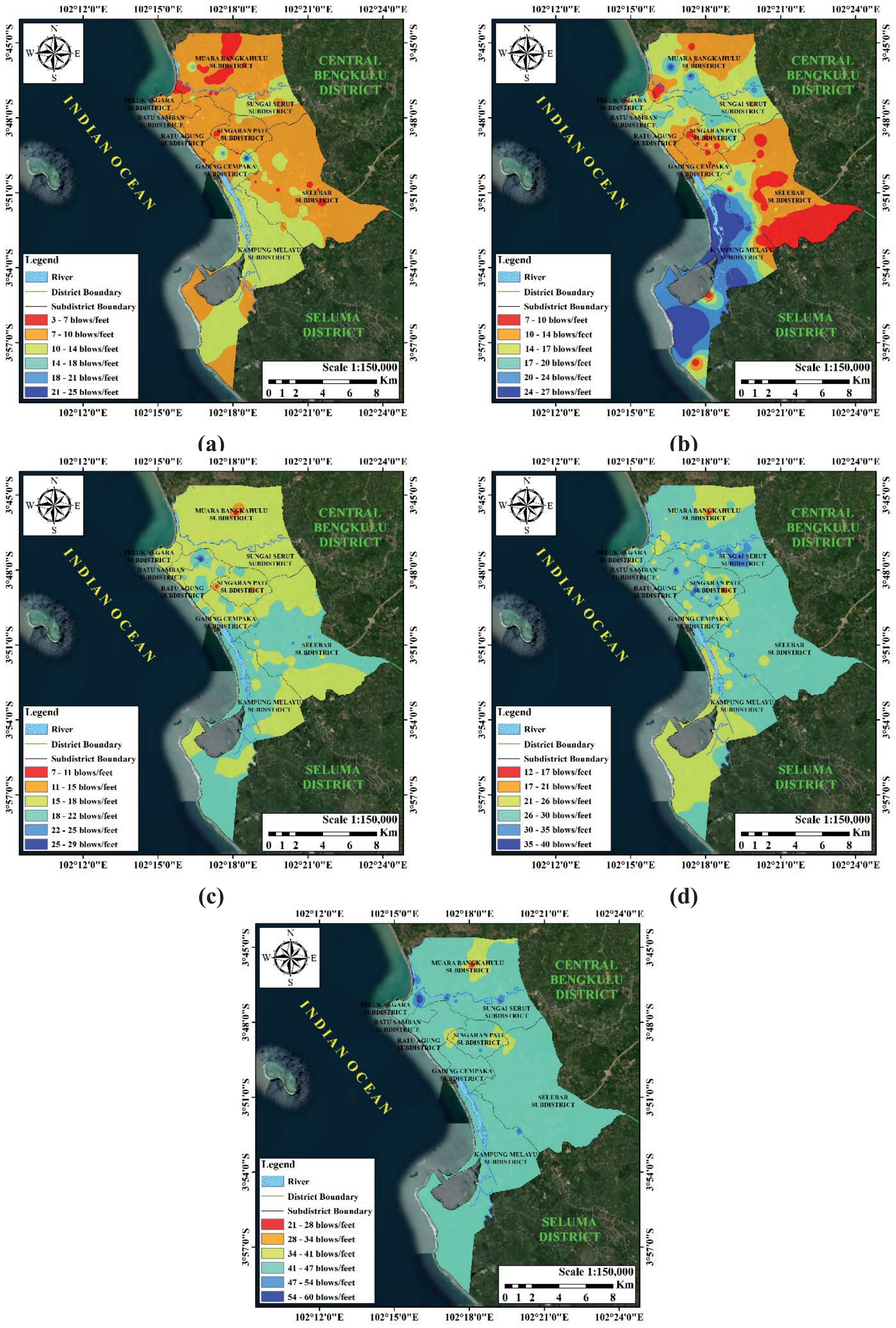


Figure 10 Distribution Map for Corrected SPT (N_{60}), **a** Sand layer, **b** Clay layer, **c** Soft rock layer, **d** Medium rock layer, **e** Hard rock layer

CONCLUSION

Conclusions that can be drawn from this research.

1. The resulting two-dimensional map provides a comprehensive overview based on interpolating of V_s, q_c, and N_{60} values around the survey points. The distribution of these parameter values can serve as an essential reference for engineers to understand the soil characteristics in the area. With this information, engineers can make more informed decisions regarding foundation design and construction strategies appropriate for the existing geotechnical conditions.
2. Through the spread map of V_s, qc, and N_{60} values, it is known that the research area consists of five main layers; sand layers, clay layers, soft rock layers, medium rock layers, and hard rock layers, with each parameter having the highest value on different layers.
3. This research focuses on the Bengkulu City area and produces a two-dimensional map showing the distribution of soil parameter values in the area. In this study, the Interpolation Distance Weighting (IDW) method was used as a data interpolation technique to illustrate the distribution of values. However, to ensure the accuracy of the data obtained, it is essential to carry out direct validation through field testing. Thus, this research can provide a more accurate and reliable picture of the soil characteristics in Bengkulu City
4. This research has the potential to be further developed where the data on shear wave velocity (V_s), q_c, and N_{60} values can be analysed in depth to identify other soil parameters. By carrying out these advanced analyses, we can gain a more comprehensive insight into the geotechnical properties of the soil, which in turn can improve our understanding when planning and designing infrastructure for greater effectiveness.

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REFERENCES

Benedetta, A., Roberto, I., Ciampi, P., Salvatore, M., Domenico, M., Federico, G., Gabriele, S. M., & Francesca, B. 2023. Engineering-geological modelling for supporting local seismic response studies: insights from the 3D model of the subsoil of Rieti (Italy). *Bulletin of Engineering Geology and the Environment*, Vol. 82(6). https://doi.org/10.1007/s10064-023-03259-4

Chen, F. W., & Liu, C. W. 2012. Estimating the spatial rainfall distribution using inverse distance weighting (IDW) in the middle of Taiwan. *Paddy and Water Environment*, Vol. 10(3), 209–222. https://doi.org/10.1007/s10333-012-0319-1

Elumalai, V., Brindha, K., Sithole, B., & Lakshmanan, E. 2017. Spatial interpolation methods and geostatistics for mapping groundwater contamination in a coastal area. *Environmental Science and Pollution Research*, Vol. 24(12), 11601–11617. https://doi.org/10.1007/s11356-017-8681-6

Harman, B. I., Koseoglu, H., & Yigit, C. O. 2016. Performance evaluation of IDW, Kriging and multiquadric interpolation methods in producing noise mapping: A case study at the city of Isparta, Turkey. *Applied Acoustics*, Vol. 112, 147–157. https://doi.org/10.1016/j.apacoust.2016.05.024

Jia, J (2018). Dynamic and Cyclic Properties of Soils. *Soil Dynamics and Foundation Modeling.* Vol. 23, 75-108. https://doi.org/10.1007/978-3-319-40358-8_2

Khodaparast, M., Rajabi, A. M., & Derakhshan, M. 2020. Development of Practical Correlations Between Cone Penetration Resistance and SPT Values for Various Types of Soils. *Iranian Journal of Science and Technology - Transactions of Civil Engineering*, Vol. 44, 471–481. https://doi.org/10.1007/s40996-019-00319-2

Mase, L. Z. 2017. Liquefaction potential analysis along the coastal area of Bengkulu province due to the 2007 Mw 8.6 Bengkulu earthquake. *Journal of Engineering and Technological Sciences*, 49(6), 721–736. https://doi.org/10.5614/j.eng.technol.sci.2017.49.6.2

Mase, L. Z. 2020. Seismic Hazard Vulnerability of Bengkulu City, Indonesia, Based on Deterministic Seismic Hazard Analysis. *Geotechnical and Geological Engineering*, Vol. 38(5), 5433–5455. https://doi.org/10.1007/s10706-020-01375-6

Mase, L. Z., Sugianto, N., & Refrizon. 2021. Seismic hazard microzonation of Bengkulu City, Indonesia. *Geoenvironmental Disasters*, Vol. 8 (1). https://doi.org/10.1186/s40677-021-00178-y

Mase, L. Z. 2022. Local seismic hazard map based on the response spectra of stiff and very dense soils in Bengkulu City, Indonesia. Geodesy and Geodynamics, Vol. 13(6), 573-584. https://doi.org/10.1016/j.geog.2022.05.003

Mase, L. Z., Amri, K., Ueda, K., Apriani, R., Utami, F., Tobita, T., & Likitlersuang, S. 2024a. Geophysical investigation on the subsoil characteristics of the Dendam Tak Sudah Lake site in Bengkulu City, Indonesia. *Acta Geophysica*, Vol. 72(2), 893–913. https://doi.org/10.1007/s11600-023-01158-6

Mase, L. Z., Irsyam, M., Gustiparani, D., Noptapia, A. N., Syahbana, A. J., & Soebowo, E. 2024b. Identifying bedrock depth along a downstream segment of Muara Bangkahulu River, Bengkulu City, Indonesia. *Bulletin of Engineering Geology and the Environment*, Vol. 83(4). https://doi.org/10.1007/s10064-024-03591-3

Pavicic I, Dragicevic I, Ivkic I. 2018. High-resolution 3D geological model of the bauxite-bearing area Crvene Stijene (Jajce, Bosnia and Herzegovina) and its application in ongoing research and mining. *Geol Q* Vol. 62(1), 100–119. https://doi.org/10.7306/gq.13

Rostami, A. A., Isazadeh, M., Shahabi, M., & Nozari, H. 2019. Evaluation of geostatistical techniques and their hybrid in modelling groundwater quality index in the Marand Plain in Iran. *Environmental Science and Pollution Research*, Vol. 26(34), 34993–35009. https://doi.org/10.1007/s11356-019-06591-z

Vollgger, S. A., Cruden, A. R., Ailleres, L., & Cowan, E. J. 2015. Regional dome evolution and its control on ore-grade distribution: Insights from 3D implicit modelling of the Navachab gold deposit, Namibia. *Ore Geology Reviews*, Vol. 69, 268–284. https://doi.org/10.1016/j.oregeorev.2015.02.020

Wadi, D., Malik, I., Ahmed, H.A., Makki, A. 2021. Assessment of soil liquefaction potential based on standard penetration test for the upper Benue region in Nigeria. *Environmental Earth Sciences* Vol. 80(254), 1-11. https://doi.org/10.1007/s12665-021-09565-y

Wellmann, F., & Caumon, G. 2018. 3-D Structural geological models: Concepts, methods, and uncertainties. In *Advances in Geophysics* Vol. 59, 1–121. Academic Press Inc. https://doi.org/10.1016/bs.agph.2018.09.001