



COMPARATIVE ANALYSIS OF BEARING CAPACITY METHODS FOR BATMAN SOILS: A GIS-BASED APPROACH

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Abstract: In this study, the spatial distribution of Standard Penetration Test (SPT) data and allowable bearing capacity calculations were evaluated for the central district of Batman, covering an area of approximately 54 km². Geotechnical data obtained from 253 boreholes were analyzed within a Geographic Information Systems (GIS) environment, and spatial prediction maps were generated for various depths (1.5, 3.0, 4.5, 7.5, 9.0, and 15.0 m) using the Inverse Distance Weighting (IDW) interpolation method. The allowable bearing capacities of the soils were calculated based on the empirical approaches proposed by Terzaghi and Peck (1967) and Meyerhof (1974), assuming a foundation width of 3 m. The analyses revealed that SPT-N values generally exhibit a linear increase with depth. At shallow depths, the northern and western parts of the study area—particularly near the Batman River (Girberesiik and Yeniköy)—are characterized by 'loose' to 'medium dense' soil formations, indicating low bearing capacity and potential settlement risks. The spatial distribution of bearing capacity showed that approximately 19% of the area has a low bearing capacity (< 163 kN/m²), 32% has a moderate capacity (163–325 kN/m²), and 49% presents a high bearing capacity (326–488 kN/m²). A comparison of the two analytical methods demonstrated a high degree of spatial compatibility; however, as depth and SPT-N values increased, the Meyerhof (1974) method yielded higher (more optimistic) bearing capacity values compared to the Terzaghi and Peck (1967) approach due to the influence of the depth factor. The GIS-based microzonation maps produced in this study provide a crucial spatial database for safe foundation design, urban planning, and earthquake risk mitigation in the region.


Keywords: Geographic information systems, Standard penetration test, Bearing capacity, Inverse distance weighting

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1. Introduction

In geotechnical engineering design, the safe and economical transfer of structural loads to the foundation soil constitutes the cornerstone of structural sustainability. The direct interaction between engineering structures and the ground necessitates the determination of soil parameters with high precision. While data obtained from laboratory tests provide a fundamental baseline, in-situ tests—which reflect the natural stress conditions and stratification characteristics of the soil—remain an indispensable part of modern geotechnical investigations. Particularly, the Standard Penetration Test (SPT) is recognized as one of the most reliable empirical tools for predicting soil bearing capacity and settlement potential, owing to its operational simplicity, cost-effectiveness, and globally standardized extensive database.

Determining soil bearing capacity is a complex analytical process that involves not only ultimate limit states of strength but also acceptable settlement criteria. Numerous approaches have been developed in the

literature for bearing capacity calculations based on SPT blow counts (N). However, the methods proposed by Terzaghi and Peck (1967) and Meyerhof (1974) have been accepted as benchmarks in both academic and applied engineering projects for decades, due to their reliability coefficients and performance across diverse soil types.

Conversely, borehole logs obtained through traditional geotechnical investigation methods—which generally provide 'point-specific' data—remain limited in reflecting the lateral and vertical heterogeneity exhibited by the soil across large geographical areas such as urban centers. To overcome this limitation, recent academic studies (Karabaş, 2019; Cabalar et al., 2021; Şengül and Karabaş, 2021; Demirtaş, 2022; Yıldız, 2022; Acar and Özdemir, 2023; Yıldız, 2024; Karabaş et al., 2026) have turned toward Geographic Information Systems (GIS)-based spatial modeling techniques. Advanced interpolation algorithms within GIS, such as Inverse Distance Weighting (IDW), transform irregularly distributed borehole data into continuous surface



models, providing engineers and urban planners with the opportunity for regional 'microzonation.' In the specific context of Türkiye, GIS-based studies conducted in seismically active regions such as Elazığ, Batman, and Erzincan have proven the effectiveness of these methods in geotechnical risk management.

This study is designed to meet the increasing need for safe construction alongside rapid urban development and industrialization in the Batman central district. The geological structure of Batman consists of complex alluvial deposits formed under the influence of the Batman Stream and the Tigris River. The variability that bearing capacity exhibits depending on depth in such formations is often overlooked in local projects. To address this gap, this study analyzes an extensive data pool derived from 253 boreholes spread across an area of approximately 54 km². The original value of this research lies not only in mapping the bearing capacity but also in comparatively evaluating the performance of Terzaghi-Peck and Meyerhof methodologies across six different

depth levels from 1.5 m to 15.0 m within the Batman soil profile. The findings provide a high-resolution engineering baseline for urban planning and seismic risk mitigation strategies.

1.1. General properties of the study area

Located in the Tigris Section of the Southeastern Anatolia Region, Batman was granted provincial status by Law No. 3647 published on May 16, 1990, becoming Türkiye's 72nd province (Law No. 3647, 1990). Covering a total surface area of 4,694 km², the province constitutes approximately 0.6% of Türkiye's total land area. Geographically, it is situated between 38° 40' - 37° 50' North latitudes and 41° 10' - 41° 40' East longitudes. Administratively, the province consists of six districts: the central district (Batman city center), Kozluk, Sason, Hasankeyf, Gercüş, and Beşiri (Directorate of EIA and Permitting, 2017). The location map illustrating the general boundaries and geographical setting of the study area is presented in Figure 1.

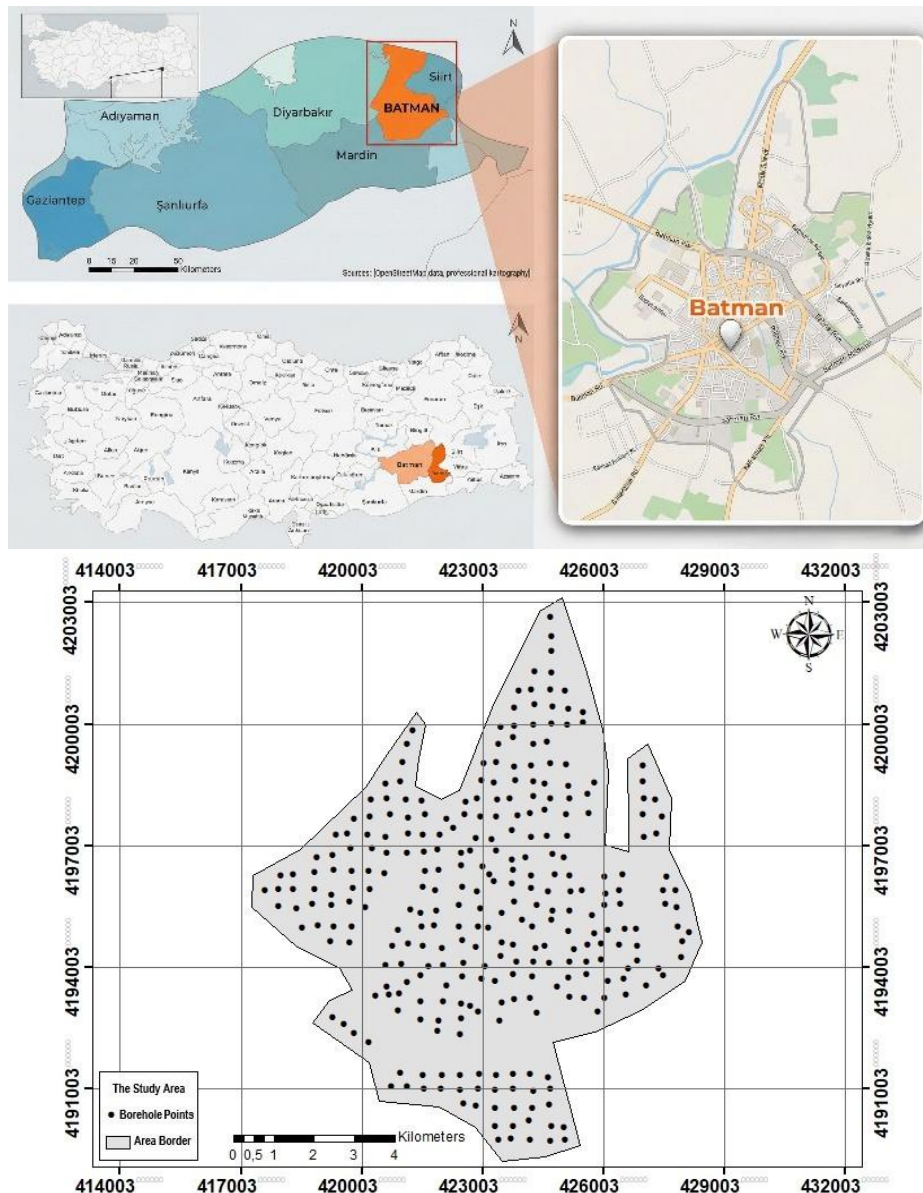


Figure 1. The map of the study area.

Regarding the geopolitical and transportation network relationships of the region, Batman is a bordering province to Muş (218 km) to the north, Diyarbakır (100 km) to the west, Bitlis (135 km) to the east, and Mardin (149 km) to the south (General Directorate of Highways [KGM], 2023). This strategic location establishes the region as one of the most significant transit corridors in Southeastern Anatolia.

From geomorphological and topographical perspectives, Batman is situated within a narrow synclinal area in the eastern part of the Diyarbakır Basin. Historically referred to as the "Tilmis Plain" and currently known as the "Batman Plain," this basin floor is surrounded by the Kırâ and Raman Mountains, with a mean elevation ranging between 650 and 800 meters above sea level (Tonbul and Sunkar, 2008). Morphological analysis indicates that the northern and northeastern parts of the province exhibit a rugged, high, and mountainous topography, whereas the southern regions are characterized by a relatively undulating and hilly terrain (Directorate of EIA and Permitting, 2017).

The primary element shaping the hydrological and drainage network of the region is the Tigris River, which flows through the provincial borders on a west-east axis. Additionally, the Batman Stream, along with the Sason, Kayser, Garzan, and Pisiyar streams, constitutes the most significant surface water systems in the study area, directly influencing the regional water potential and alluvial soil structure (Directorate of EIA and Permitting, 2017). The extensive fluvial network in the region suggests a potential for long-term groundwater level fluctuations, particularly in the low-lying areas surrounding the Batman Stream. The low SPT-N values recorded in certain sectors necessitate a careful evaluation of geotechnical risks. In this context, the study focuses on quantifying the spatial distribution of static bearing capacity to establish a scientific baseline.

1.2. General geological properties of the area

The spatial distribution and engineering behavior of geotechnical parameters—specifically soil stiffness, SPT blow counts, and bearing capacity—are directly related to the fundamental geological structure and tectonic evolution of the region. In this context, the geological history of the Southeastern Anatolia Region, including the study area, reflects a highly dynamic tectonic regime. The fundamental geological framework began to take shape toward the end of the Mesozoic era with the north-south convergence of the Eurasian and Arabian plates, leading to the closure of the Tethys Ocean. This massive crustal movement resulted in the suturing of the colliding plates along the "Bitlis-Zagros Suture Zone" (Southeastern Anatolian Thrust), creating the primary geomorphological and geological units of the region (Şengör, 1980).

The tectonic forces prevailing in the region have undergone characteristic changes across the geological timescale. Prior to the Pliocene epoch, the intense compressive forces generated by plate movements were

generally dissipated through northward-verging thrust faults and dense fold systems. By the Late Pliocene, these compressions could no longer be fully accommodated by thrust mechanisms alone, and strike-slip fault systems began to dominate the regional tectonics (İmamoğlu and Çetin, 2007).

Currently, the active geological character of the Southeastern Anatolia Region, and particularly the vicinity of the Batman Plain, is controlled by strike-slip and thrust systems, primarily the East Anatolian Fault and its counterparts, such as the Lice Fault Zone and the Bozova Fault. Historical seismic records prove that these fault zones have generated numerous large-scale earthquakes that altered the crustal equilibrium in Southeastern Anatolia and its surroundings. Furthermore, the mass movements (active landslides and surface deformations) frequently observed along these fault lines even today demonstrate the ongoing seismic activity of these geological systems (İmamoğlu and Çetin, 2007). A tectonic map detailing the boundaries of tectonic plates, regional fault zones, and movement directions across Türkiye is presented in Figure 2 (Barka, 1992; Rockwell et al., 2001).

1.3. Seismicity of the Region

In the design of engineering structures, and particularly in evaluating the bearing capacity performance of foundation soils under dynamic loads, an accurate definition of the seismic activity potential of the region is of critical importance. Türkiye is situated on the Alpine-Himalayan Orogenic Belt, which hosts some of the world's most active and destructive fault systems. Within this massive tectonic framework, the continuous interaction between the Eurasian Plate to the north and the Arabian and African plates pushing from the south facilitates the deformation of the Anatolian block and the occurrence of large-scale earthquakes. The "Bitlis-Zagros Suture Zone (Bitlis Thrust Zone)," which serves as the most prominent eastern boundary of this compressional regime and separates the Arabian Plate from Eastern Anatolia, is the fundamental tectonic element defining the seismic characteristics of the study area, Batman (Batman Provincial Directorate of Disaster and Emergency Management, 2022). To predict sudden decreases in bearing capacity and deformations during potential seismic tremors, it is mandatory to evaluate SPT data in conjunction with the city's seismicity parameters.

Analysis of historical and instrumental earthquake catalogs reveals no major earthquake records with an epicenter directly within the Batman city center that caused large-scale destruction. However, the fact that the city lies within the direct influence zone of the Bitlis Thrust Zone and its relative proximity to the East Anatolian Fault Zone (EAFZ) keeps the seismic hazard in the region constantly active. Historical records include the 1670 Muş, 1866 Kulp, 1884 Pervari, and particularly the 1975 Lice (M=6.7) earthquakes as destructive seismic events generated by this thrust belt, affecting a wide

geography including Batman (Batman Provincial Directorate of Disaster and Emergency Management, 2022).

According to the Türkiye Earthquake Hazard Map, which entered into force on January 1, 2019, although the local seismic hazard of the Batman city center appears to be at medium-to-low levels, the accelerations that could be generated by surrounding fault systems harbor significant risks for both structures and soils. The national map showing the distribution of earthquake hazards across Türkiye is presented in Figure 3 (AFAD, 2025). The most striking recent example of this peripheral seismic risk is the M=6.8 Elazığ-Sivrice earthquake that occurred on January 24, 2020, along the EAFZ. This tremor was felt quite severely in Batman and once again highlighted the importance of soil-structure

interaction and SPT-based microzonation studies in alluvial soils with low bearing capacity and high groundwater levels.

In analyses conducted through the AFAD database based on instrumental period data, numerous micro and light seismic events with magnitudes ranging between 3.0 and 4.0 were recorded in and around the province of Batman between 1900 and 2025. This situation indicates that the fault systems in the region are actively releasing energy. The distribution map showing the locations of seismic activities that occurred in Batman between the specified dates is presented in Figure 4, while the instrumental period parameters of some seismic activities with magnitudes greater than 3.0 are provided in Table 1 (AFAD, 2025).

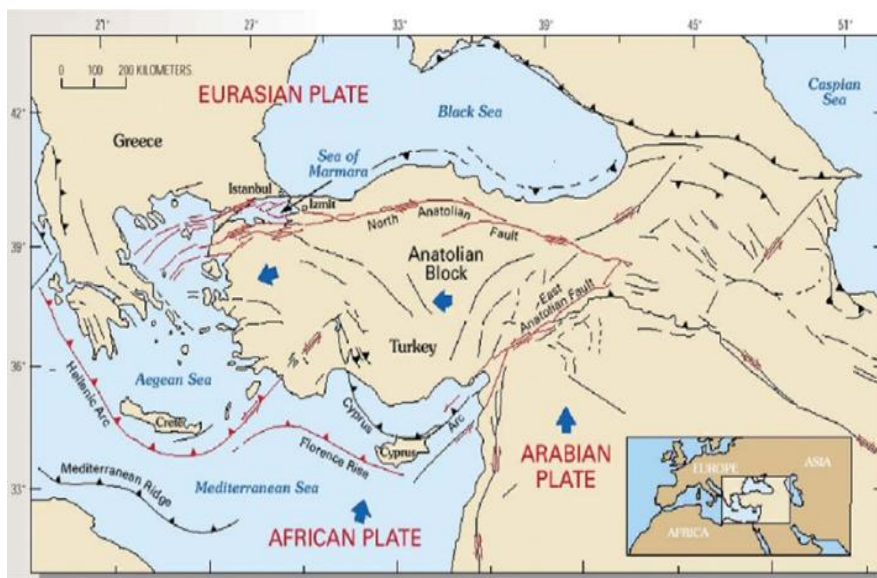


Figure 2. Tectonic map of Türkiye showing the plates and their direction of movement (Barka, 1992; Rockwell et.al., 2001).

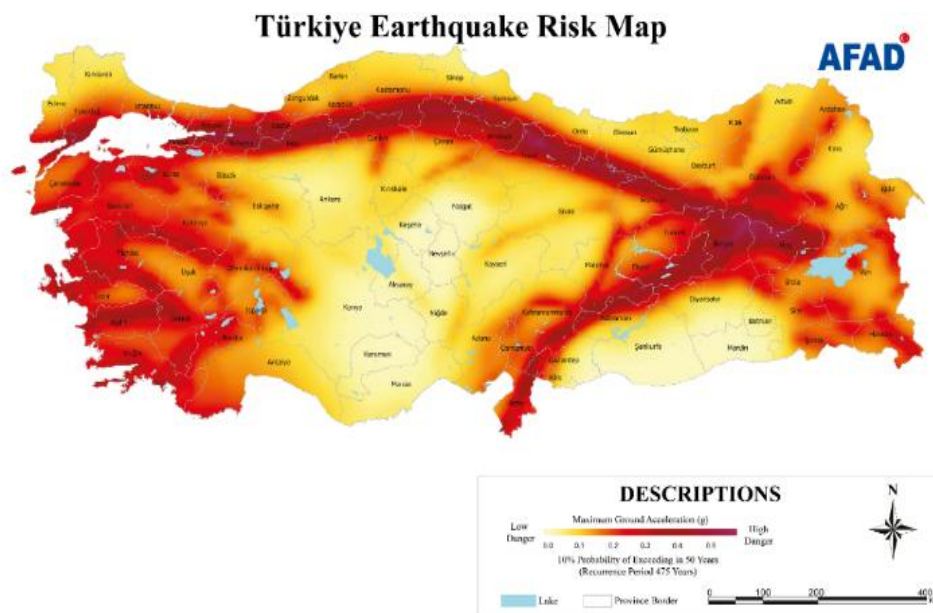


Figure 3. Map of earthquake zones of Türkiye (AFAD, 2025).

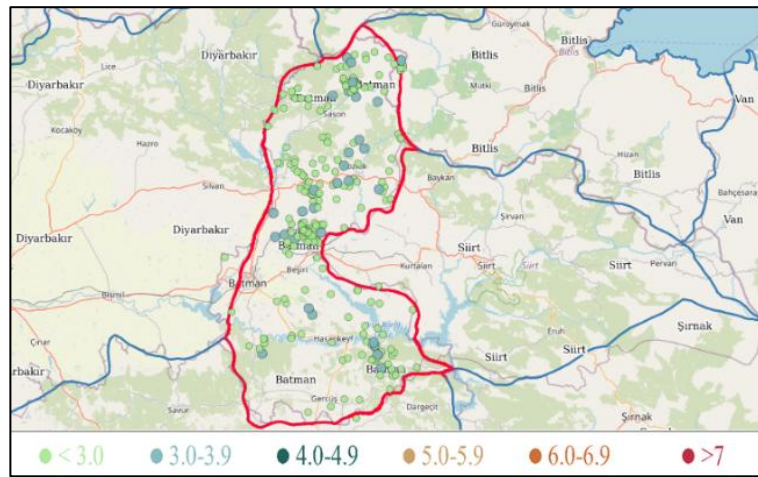


Figure 4. Distribution of earthquakes that occurred in Batman between 1900 and 2023 (AFAD, 2025).

Table 1. Earthquakes greater than $M_w=3$ occurred in Batman Province between 1900 and 2025 (AFAD, 2025)

Date	Location	Depth	Type	Magnitude
17.10.2022	Beşiri (Batman)	7.00	ML	3.1
28.10.2021	Kozluk (Batman)	5.99	ML	3.1
06.02.2021	Gercüş (Batman)	8.26	ML	3.1
04.09.2014	Hasankeyf (Batman)	10.24	Mw	3.8
02.09.2014	Beşiri (Batman)	17.40	ML	3.3
17.01.2006	Sason (Batman)	19.04	Md	3.7
04.12.2006	Kozluk (Batman)	9.42	Md	3.5
08.07.2005	Sason (Batman)	16.69	Md	3.7
17.04.2004	Merkez (Batman)	10.09	Md	3.5
25.09.2001	Beşiri (Batman)	12.70	Md	3.8

2. Materials and Methods

2.1. Geographic Information Systems

In contemporary geosciences and engineering applications, Geographical Information Systems (GIS) have become an indispensable technological infrastructure for processing, storing, and visualizing multidimensional data. GIS is a high-performance, computer-based information system used to collect, store, query, and map data regarding terrestrial objects and spatial events at desired formats and scales, as well as to perform multi-layered analyses on these datasets (Karabaş, 2019; Şengül and Karabaş, 2021). Beyond providing storage for georeferenced data, this system functions as a comprehensive management tool for decision-makers by enabling the rapid updating, synthesis, and generation of new spatial outputs. Conceptually and operationally, GIS is an integrated structure consisting of hardware, software, geographic data, methods, and qualified personnel to process the data (Küpçü et al., 2015; Çabalar et al., 2021). The successful operation of the system and its ability to produce accurate spatial analyses depend on the harmonious integration of these five fundamental components (Karabaş et al., 2026). A schematic diagram illustrating the operating principles and the core components of the system is presented in Figure 5.

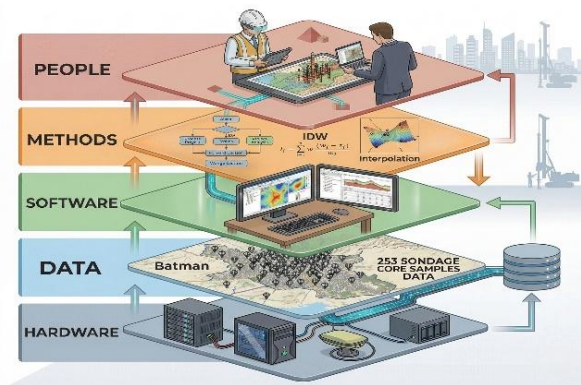


Figure 5. A view of CBS components (Küpçü et al., 2015).

In geotechnical engineering and seismic microzonation studies, data obtained from boreholes and in-situ tests (e.g., SPT blow counts, soil profiles, etc.) traditionally reflect only the specific location characteristics where the data were collected. However, transferring this point-source data into a GIS environment and distributing it over extensive areas using advanced interpolation algorithms provides engineers with a much more holistic perspective of the site’s overall subsurface structure. As a decision support mechanism, GIS enables complex overlay analyses and the production of geotechnical parameter maps—which could otherwise take days—to be completed in a much shorter time, economically, and

with high accuracy (Civelekler and Pekkan, 2022).

In this study, GIS was utilized not merely as a visualization tool, but as a robust analytical framework for spatial modeling and predictive analysis of geotechnical parameters. The integration of 253 borehole datasets into a GIS environment facilitated the transition from discrete point-source data to a continuous spatial surface, enabling the identification of geotechnical trends that remain indiscernible through traditional tabular analyses.

To evaluate the validity of GIS-based spatial predictions, the Inverse Distance Weighting (IDW) interpolation method was employed. IDW is a deterministic interpolation technique used within GIS to generate continuous surfaces from point-based measurement data. The fundamental assumption of this method is that spatially proximal points exhibit higher similarity than distant ones. Consequently, the value of an unmeasured location is calculated as a distance-dependent weighted average of the surrounding sample points. In this approach, closer points exert a greater influence (weight) on the prediction, while the influence of distant points diminishes rapidly, adhering to the principle that 'similarity decreases with distance.' Thus, the method provides a spatial proximity-based estimation rather than a physical process modeling. Beyond simple map production, this feature allowed for the generation of predicted values at coordinates where borehole logs were unavailable, providing public authorities with a preliminary control mechanism for future field data.

As a decision-support mechanism, GIS enables complex overlay analyses and the generation of geotechnical parameter maps—processes that might take days using traditional methods—to be completed in a significantly shorter time, economically, and with high accuracy (Civelekler and Pekkan, 2022). Within the scope of this research, the geotechnical characteristics of the soils in the central district of Batman were evaluated by leveraging these GIS capabilities. Standard Penetration Test (SPT-N) data from 253 different borehole locations, along with foundation bearing capacity values calculated via the empirical methods of Terzaghi and Peck (1967) and Meyerhof (1974), were digitized using ArcGIS software. While specific statistical error metrics (such as RMSE or R^2) were not explicitly calculated for the GIS-based predictions in this study, the bearing capacity values obtained from the Terzaghi and Meyerhof methods were comparatively evaluated against the GIS-based spatial distributions. It was observed that the results were highly consistent in terms of general engineering trends.

Through this comprehensive database, spatial prediction maps illustrating the engineering behavior and lateral variations of bearing capacity at shallow and deep levels (from 1.5 m to 15.0 m) were generated, thereby establishing a significant framework for safe and economical structural design.

2.2. Spatial Interpolation and Inverse Distance Weighting Method

In GIS-based geotechnical assessments, transforming discrete point data from boreholes into a continuous spatial surface is a critical process. Various deterministic and geostatistical interpolation techniques, such as Kriging, Spline, and Inverse Distance Weighting (IDW), are available for this purpose. While Kriging is a geostatistical method that requires a predefined semi-variogram model to account for spatial bias, and Spline is often preferred for generating smooth surfaces with minimum curvature, IDW was selected as the most suitable approach for this study due to the nature of the geotechnical dataset (Çabalar et al., 2019; Yıldız, 2022).

The IDW method is a deterministic technique that estimates values in unsampled areas based on the positional relationship and proximity of known sample points. The fundamental principle of this method is rooted in spatial autocorrelation, which assumes that points in close geographical proximity are more likely to share similar soil characteristics than those further apart. IDW calculates the predicted value of a specific cell by taking a weighted average of the surrounding sample points. In this calculation, points closer to the estimation site are assigned higher mathematical weights, whereas the influence of distant points diminishes in inverse proportion to their distance (Demirtaş, 2022).

The decision to prioritize IDW over other methods like Kriging or Spline in this research is based on its ability to handle the inherent heterogeneity of soil layers without the need for complex statistical assumptions required by geostatistical models. Especially in geotechnical applications—where parameters such as borehole logs and seismic velocities are irregularly distributed and site-specific—IDW provides a robust and computationally efficient framework for predicting engineering values between data points while producing highly interpretable and consistent results (Çabalar et al., 2021). Furthermore, IDW effectively preserves the local extrema of the borehole data, which is crucial for identifying critical zones of low bearing capacity.

In line with this framework, ArcGIS software was utilized to model the spatial distribution of geotechnical parameters (Standard Penetration Test blow counts, bearing capacity, groundwater level, consistency limits, and wave velocities) obtained from 253 different borehole locations in the central district of Batman. To holistically capture both lateral and vertical variations of these soil properties, all prediction maps were generated at a 10x10 meter grid resolution (cell size) using the IDW method, following the methodological precedents established in (Karabaş, 2019; Çabalar et al., 2019; Çabalar et al., 2021, Demirtaş, 2022; Yıldız, 2022).

2.3. Standard Penetration Test

The Standard Penetration Test (SPT) serves as the primary in-situ data source for this research, providing the necessary mechanical parameters to evaluate the bearing capacity across the Batman central district. While

the test is a globally recognized standard for determining soil resistance and density (Clayton, 1995; Orhan, 2022), its application in this study focuses on correlating blow counts (N) with the relative density and shear strength of the regional alluvial deposits.

Despite its operational simplicity and cost-effectiveness, the inherent variability of SPT results—often influenced by equipment energy losses and operator sensitivity (Aydın, 2010)—was considered during the data compilation phase. For the analyzed cohesionless soil layers in the study area, the empirical relationship between SPT-N values and relative density (Table 2) provides the fundamental framework for characterizing soil compactness. The field data from 253 boreholes were processed in accordance with international standards to ensure consistency in the spatial interpolation of soil resistance.

Table 2. Empirical relationship between SPT-N values and relative density of cohesionless soils (Demir, 2013).

Soil Compactness State	SPT-N (Blows/30 cm)	Relative Density (Dr) (%)
Very loose	< 4	< 15
Loose	4 - 10	15 - 35
Medium dense	10 - 30	35 - 65
Dense	30 - 50	65 - 85
Very dense	> 50	85 - 100

The geotechnical dataset for Batman city center was derived from Standard Penetration Tests (SPT) conducted systematically at 1.5-meter intervals across 253 boreholes. The field procedures followed international standards (Mayne et al., 2002), where the N-values were recorded based on the resistance encountered during the final 30 cm of a 45 cm penetration. To ensure data quality, the initial 15 cm 'seating drive' was excluded to eliminate the influence of disturbed soil at the borehole base (Orhan, 2022).

For horizons exhibiting high penetration resistance, standard refusal criteria (e.g., >50 blows per 15 cm) were strictly applied to maintain equipment safety and log accuracy (Aydın, 2010). The retrieved disturbed samples were utilized for soil identification and index testing, providing a lithological context for the bearing capacity estimations. This extensive field campaign resulted in a high-density primary dataset, which serves as the foundation for the subsequent GIS-based spatial mapping and comparative bearing capacity analyses.

As is widely recognized in geotechnical practice, the raw blow counts (N) obtained from the SPT must be subjected to a series of correction factors to determine the standardized and corrected SPT blow count, $(N_1)_{60}$. In this study, the corrections applied include the overburden pressure correction (C_N), energy ratio correction (C_E), borehole diameter correction (C_B), rod length correction (C_R), and the sampler/liner correction

(C_S). The corrected values were calculated using the following relationship (equation 1):

$$(N_1)_{60} = N \cdot C_N \cdot C_E \cdot C_B \cdot C_R \cdot C_S \quad (1)$$

These standardized values were subsequently utilized in all bearing capacity formulations and spatial interpolation analyses to ensure engineering accuracy.

2.4. Bearing capacity Calculations

The accurate determination of soil bearing capacity forms the foundation of geotechnical design, ensuring that loads transferred from engineering structures are supported safely. Bearing capacity is defined as the maximum base pressure that the foundation soil can support without exceeding its shear strength limits or causing unacceptable differential settlements in the structure (Genç, 2008). In addition to laboratory tests, empirical and graphical field methods based on SPT-N blow counts are widely used to calculate the bearing capacity of soils, particularly cohesionless ones. In this study, the widely accepted Terzaghi and Peck (1967) and Meyerhof (1974) approaches were used to obtain bearing capacity values, and the results were modeled comparatively in a GIS environment. However, it should be noted that groundwater levels were not integrated into the spatial models due to the lack of synchronized seasonal data across the 253 borehole locations. While this is a limitation, the results provide a conservative baseline for identifying regional trends in bearing capacity under 'as-recorded' field conditions.

The selection of Terzaghi and Peck (1967) and Meyerhof (1974) methods was intentionally based on their widespread adoption in routine geotechnical practice. The authors acknowledge the inherent methodological differences, particularly regarding how foundation depth influence is integrated into their respective formulations. However, rather than creating an inconsistency, the comparative analysis of these two distinct approaches across Batman's unique soil profile is a primary objective of this study. By mapping both methods, the research evaluates the sensitivity of bearing capacity estimations to depth-related factors in a spatial context. This comparison highlights the discrepancy between conservative empirical estimations and more comprehensive analytical formulations, providing engineers with a critical range of values for regional site assessments.

The soil profile in the central district of Batman predominantly consists of alluvial deposits characterized by dense gravels, sands, and stiff clay layers. Given that the available dataset consists of Standard Penetration Test (SPT-N) results from boreholes, the bearing capacity was calculated using empirical methods specifically developed for SPT data. While Terzaghi and Meyerhof methods are widely recognized for their applicability in cohesionless soils, they are also frequently employed in regional geotechnical assessments involving stiff alluvial deposits where SPT values provide a reliable index of soil resistance. In this study, the evaluation is focused on the

comparative spatial distribution of these calculated values rather than a site-specific laboratory-based analysis of cohesion.

In this research, certain foundation parameters, such as a uniform footing width of 3 m, were kept constant to provide a standardized basis for comparing the Terzaghi-Peck and Meyerhof methods. The study does not aim to provide a site-specific foundation design but rather to evaluate the spatial variability of soil resistance across the region. A constant width was selected as a controlled variable to ensure that the observed changes in bearing capacity maps reflect soil properties and depth influences rather than varying foundation geometries. Furthermore, evaluating depths between 9.0 and 15.0 m is intended to characterize the deeper subsoil profile and its engineering behavior, which serves as a valuable data source for potential deep-seated stress distributions or

future assessments of different foundation types.

2.4.1. Terzaghi and Peck (1967) bearing capacity method

The Terzaghi and Peck (1967) approach was utilized to estimate bearing capacity based on a 25 mm allowable settlement threshold. In accordance with the study's methodological framework, a uniform foundation width (B) of 3 meters was adopted (Bowles, 1996), and corresponding SPT-N values were processed to reflect regional bearing trends. Unlike generalized theoretical descriptions, this study focuses on the spatial distribution of these calculated pressures to provide a comparative geotechnical baseline for the Batman central district. By standardizing the foundation geometry, the analysis isolates the influence of soil variability across the 253 borehole locations.

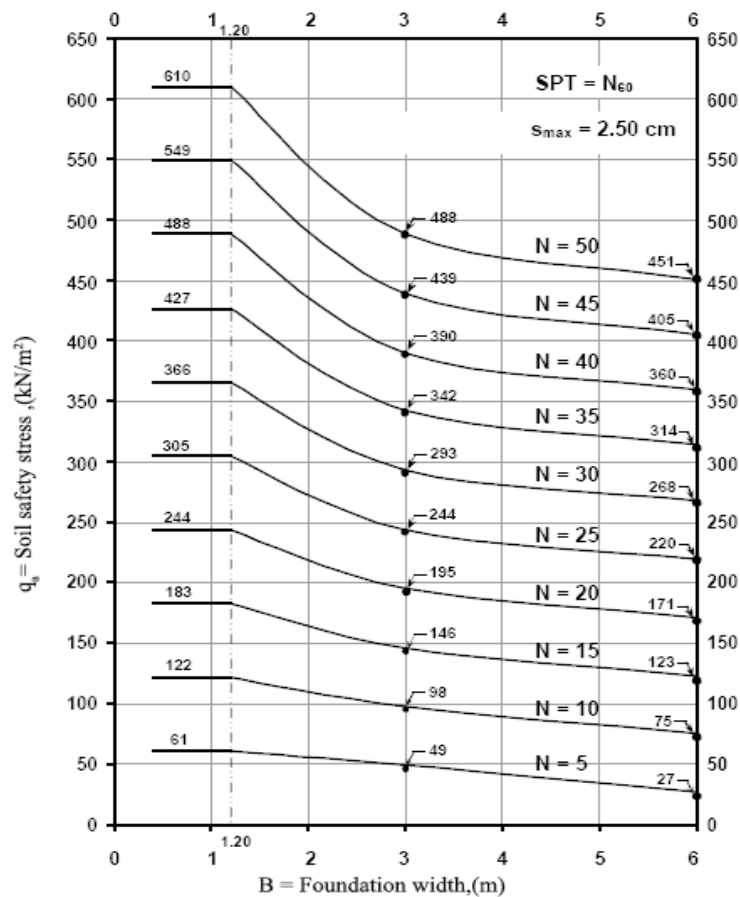


Figure 6. Change in allowable bearing capacity based on foundation width and SPT-N (Bowles, 1996).

2.4.2. Meyerhof (1974) method

The empirical formulations proposed by Meyerhof (1974) were utilized as an alternative approach to estimate the allowable bearing capacity (qa), assuming a maximum settlement limit of 25 mm (Çinicioglu, 2005). Unlike the Terzaghi-Peck method, Meyerhof's equations explicitly incorporate a depth factor (kd), allowing for a more nuanced evaluation of how embedment depth influences soil resistance. For the purpose of this study, qa values were calculated by standardizing the

foundation width (B) at 3 meters to maintain consistency across the 253 investigation points in Batman city center. The integration of the depth factor ($k_d = 1 + 0.33 D/B \leq 1.33$) serves to highlight the vertical variability of the subsoil profile from 1.5 m down to 15.0 m. By applying these distinct empirical standards to the same regional dataset, the research aims to quantify the spatial discrepancy between conservative graphical approaches and depth-influenced analytical equations.

3. Results and Discussion

Within the scope of this study, GIS-based spatial prediction maps were generated using Standard Penetration Test (SPT) data obtained from 253 borehole locations within the central district of Batman and the allowable bearing capacity values calculated through empirical methods. The maps were prepared in ArcGIS software using the Inverse Distance Weighting (IDW) interpolation method with a grid resolution of 10x10 meters for various depth intervals starting from the surface (1.5, 3.0, 4.5, 7.5, 9.0, and 15.0 m).

3.1. SPT Test Analysis Maps

The Standard Penetration Test (SPT) is one of the most widely accepted field tests worldwide for identifying critical engineering parameters such as soil bearing capacity and settlement potential (Orhan, 2022). In this study, SPT-N blow counts obtained from 253 different borehole locations were utilized to model the spatial variability of subsurface conditions in the Batman city center. To derive continuous and holistic surface maps from point-source borehole data, the IDW technique was preferred, and prediction maps with a 10x10 meter grid resolution were generated for depths of 1.5, 3.0, 4.5, 7.5, 9.0, and 15.0 m in the study area.

The empirical relationship between SPT blow counts and the relative density of soils has been standardized in geotechnical engineering literature by Terzaghi and Peck (1967), and the classification criteria presented in Table

2 were taken as the basis for interpreting the spatial analyses in this study (Demir, 2013).

When the generated spatial prediction maps are examined by depth, it was found that at shallow foundation levels (1.5 m), SPT-N values remained within the range of 1–20 in 78% of the 241 evaluated borehole locations. In the Yediyol Village, Tilmerc, and Gültepe neighborhoods located along the northern axis of the study area, blow counts generally fluctuate between 4 and 10; according to the criteria in Table 2, the soils in these regions are characteristically defined as a "loose" formation. Conversely, in the southern and southwestern parts of the site (Petrolkent, Seyitler, and Güneykent), the soil shows a tendency to stiffen starting from shallower levels, presenting a "medium dense" structure with blow counts of 10–30.

As the investigation depth increases, a clear and linear upward trend in the density levels of the soil profiles was observed. When the investigation depth reaches 15.0 meters, it was determined that only 2% of the data in the field remains within the 1–20 blow count band, while a vast majority of 95% rises to the 31–50 blow count range. At this depth level, a definitive "dense" soil dominance prevails across almost the entire study area. A comparison graph summarizing the percentage distributions of SPT-N blow counts across all depth intervals (from 1.5 m to 15.0 m) and the stiffening trend with depth is presented in Figure 7.

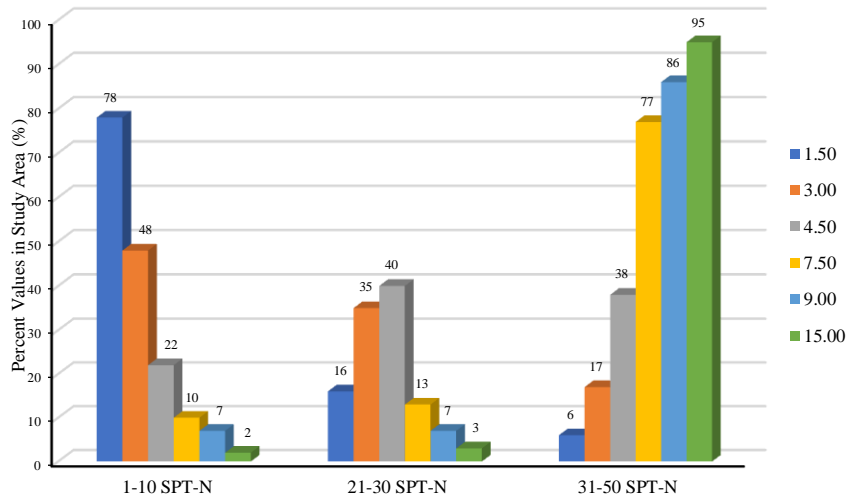


Figure 7. Distribution of SPT-N values for different depths.

One of the most critical findings obtained from the regional analyses is the soil behavior in the Girbereşik and Yeniköy neighborhoods, located in the western sector of the study site. Due to the physical proximity of these regions to the Batman Stream—resulting in groundwater levels fluctuating between depths of 3 to 7 meters—it was determined that SPT-N blow counts at shallow depths (ranging from 7 to 29) remain significantly lower than the overall city average. This phenomenon can be attributed to the high energy depositional environment of the fluvial system, which

often results in poorly graded, loose alluvial sediments with limited internal friction. These 'loose to medium dense' alluvial soil profiles, where bearing capacity directly decreases, radically increase the settlement risk and potential for soil instability in the region during a potential strong ground motion (Youd, 1984). The layered SPT-N spatial distribution maps (Figures 8-13) present a holistic perspective of these lateral and vertical variations.

Furthermore, the comparative analysis indicates that the Terzaghi and Peck (1967) approach provides a more

conservative and safer 'lower bound' for foundation design in these sensitive western zones. Unlike the Meyerhof method, which may overestimate capacity by incorporating depth-dependent increases, the Terzaghi-Peck limits offer a vital safety margin against differential settlements in Batman's heterogeneous alluvial plain. In conclusion, the generated microzonation maps demonstrate that soil properties in Batman city center are governed by a complex interplay of lithological depth and hydrological factors.

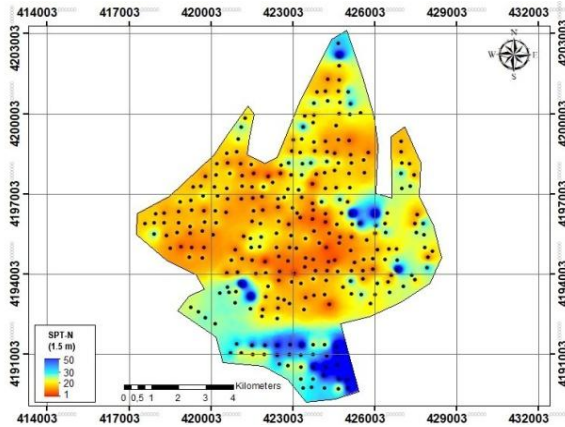


Figure 8. Spatial distribution maps of SPT-N values in the study area at a depth of 1.5 m.

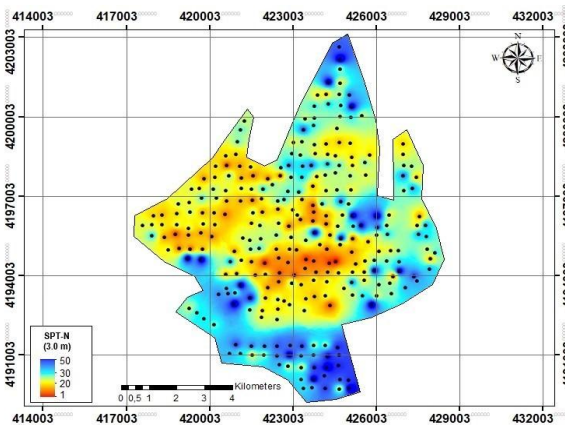


Figure 9. Spatial distribution maps of SPT-N values in the study area at a depth of 3 m.

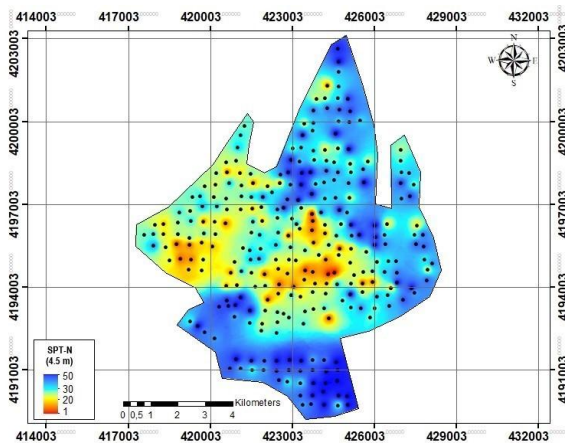


Figure 10. Spatial distribution maps of SPT-N values in the study area at a depth of 4.5 m

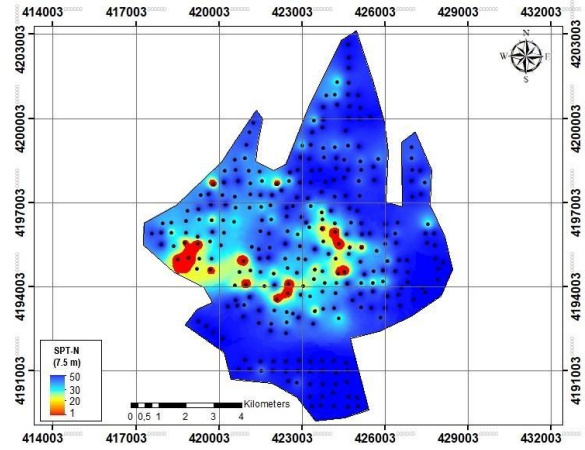


Figure 11. Spatial distribution maps of SPT-N values in the study area at a depth of 7.5 m.

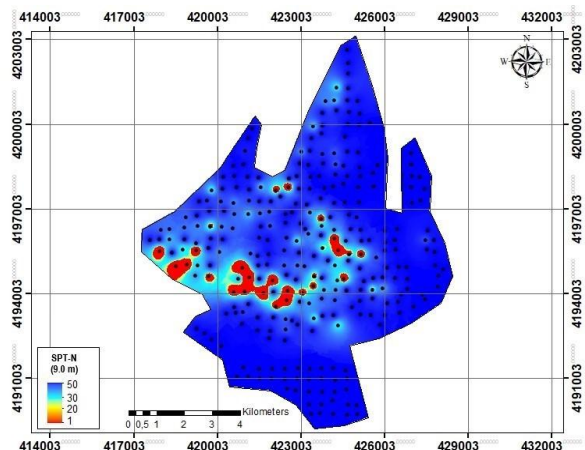


Figure 12. Spatial distribution maps of SPT-N values in the study area at a depth of 9 m.

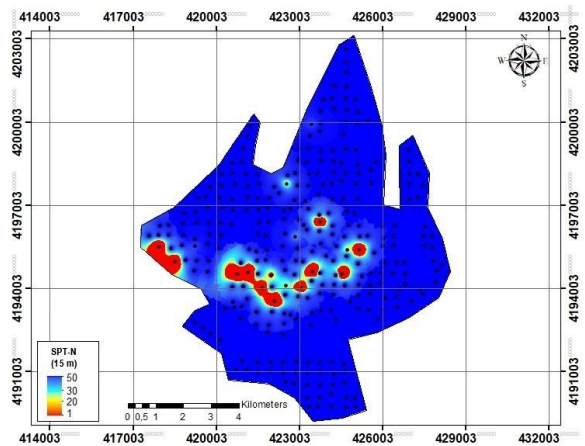


Figure 13. Spatial distribution maps of SPT-N values in the study area at a depth of 15 m.

3.2. Comparison of Bearing Capacity Findings Using the Terzaghi and Peck (1967) and Meyerhof (1974) Methods

Upon examining the bearing capacity values calculated using SPT-N data obtained from 253 different borehole locations across the study area, it was determined that both methods exhibit a high degree of correlation in terms of spatial distribution. When comparing the IDW

interpolation maps generated in the GIS environment, it was observed that low and high bearing capacity zones are concentrated in similar locations in both methods. However, structural differences arising from the formulations of the methods lead to specific deviations among the obtained quantitative (numerical) values.

When the findings are evaluated in detail, it is observed that as borehole depth and SPT-N blow counts increase, the allowable bearing capacity values calculated according to the Meyerhof (1974) method are significantly higher than those calculated by the Terzaghi and Peck (1967) method. For instance, at the shallow foundation level of 1.5 m depth, while the Terzaghi and Peck method yielded results between 39 and 488 kN/m², the Meyerhof method reached levels between 45 and 566 kN/m². As the investigation depth reached 15.0 meters, this gap widened further; Terzaghi and Peck results remained within the 88 to 488 kN/m² band, whereas the Meyerhof approach produced bearing capacity values between 116 and 646 kN/m².

The primary reason for this numerical discrepancy is that the mathematical equation of the Meyerhof (1974) method includes a specific depth factor (Kd) that accounts for the ratio of foundation depth to foundation width (D/B) (Bowles, 1996). Due to the influence of the depth factor, an additional increase in bearing capacity is calculated as the embedment depth of the foundation increases. In contrast, the Terzaghi and Peck (1967) method offers a graphical approach based on foundation width (B) and SPT-N values, which remains on the relatively conservative side (Uzuner, 2016).

Comparative graphs showing the correlation and variation trends of bearing capacity values obtained by the Terzaghi and Peck (1967) and Meyerhof (1974) methods against increasing SPT-N blow counts at different depth stages are presented in Figure 14-25.

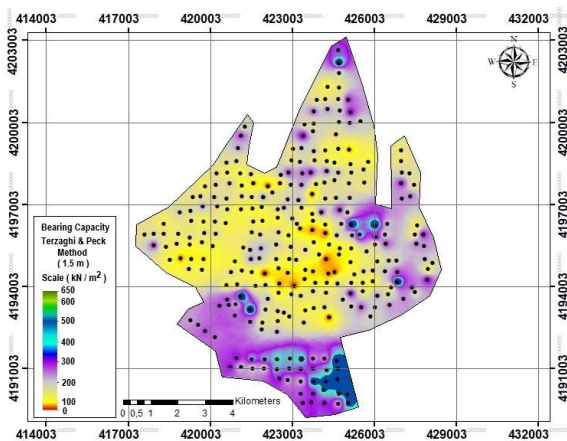


Figure 14. Terzaghi & Peck bearing capacity map D:1.5 m.

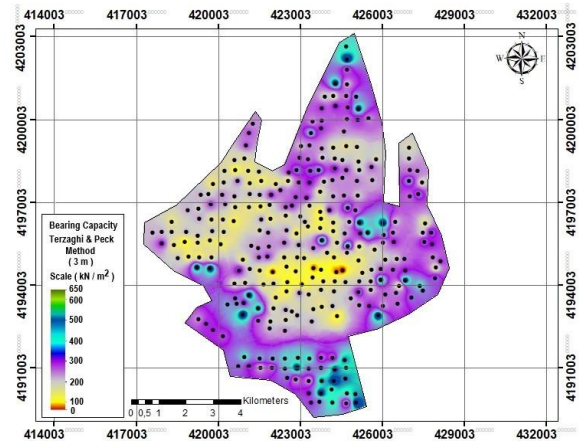


Figure 15. Terzaghi & Peck bearing capacity map D:3 m.

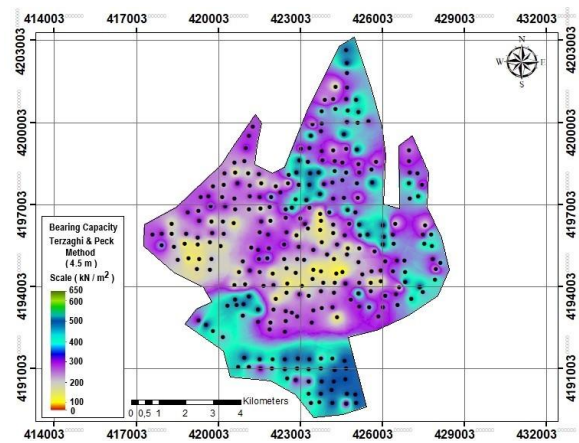


Figure 16. Terzaghi & Peck bearing capacity map D:4.5 m.

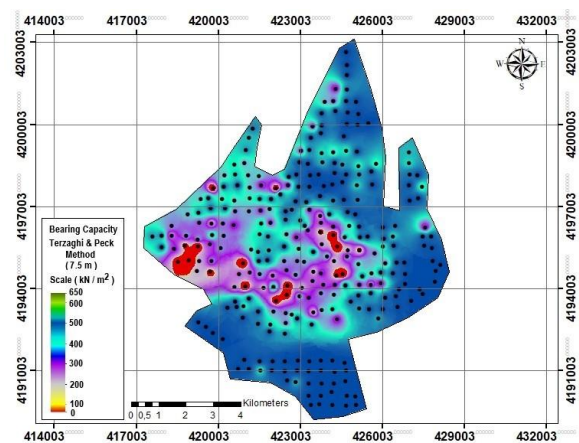


Figure 17. Terzaghi & Peck bearing capacity map D:7.5 m.

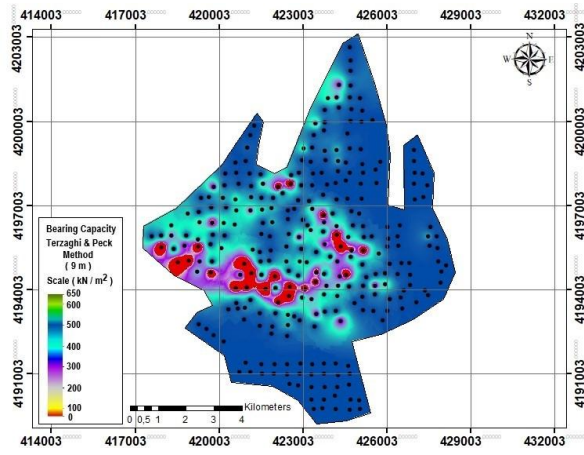


Figure 18. Terzaghi & Peck bearing capacity map D:9 m.

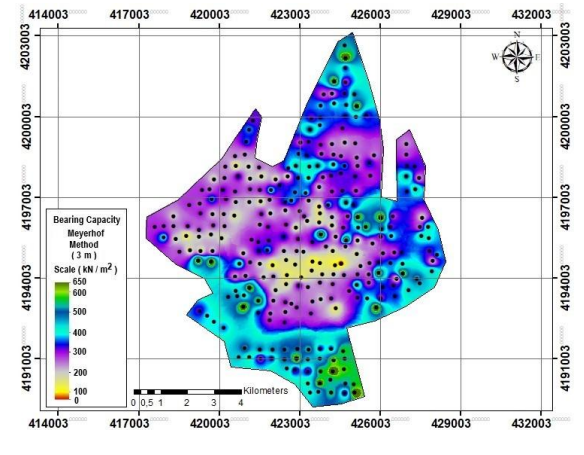


Figure 21. Meyerhof bearing capacity map D:3 m.

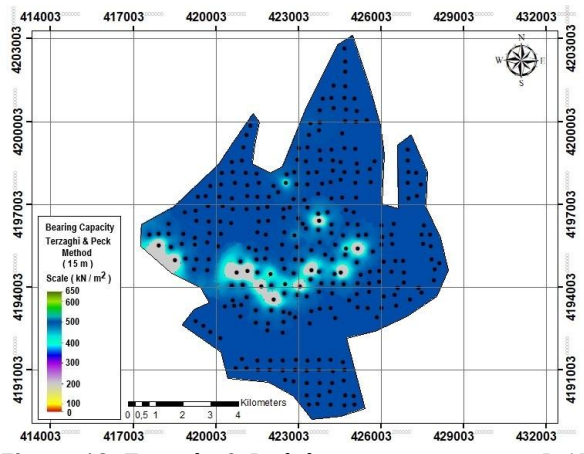


Figure 19. Terzaghi & Peck bearing capacity map D:15 m.

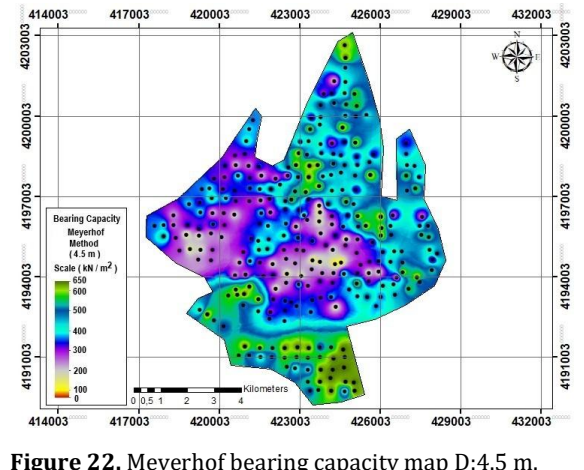


Figure 22. Meyerhof bearing capacity map D:4.5 m.

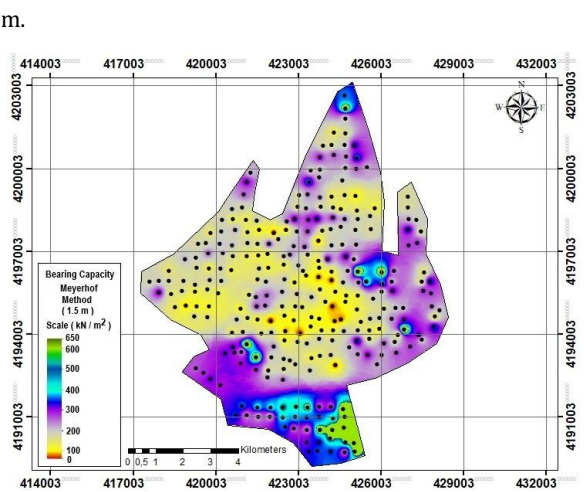


Figure 20. Meyerhof bearing capacity map D:1.5 m.

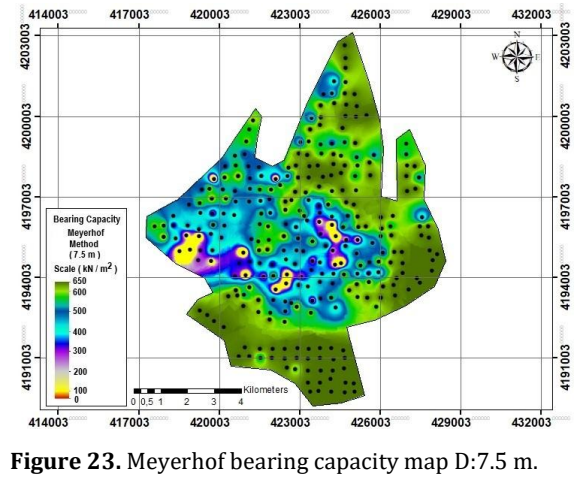


Figure 23. Meyerhof bearing capacity map D:7.5 m.

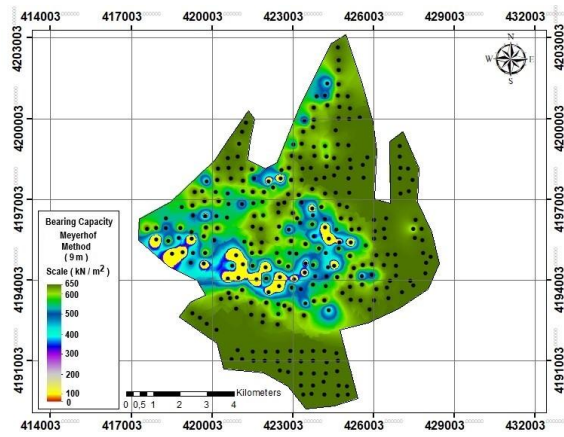


Figure 24. Meyerhof bearing capacity map D:9 m.

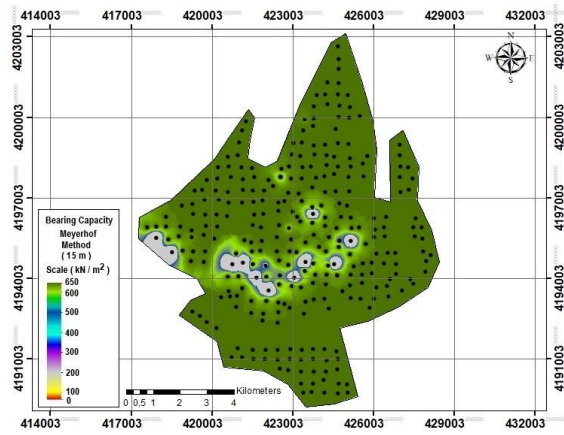


Figure 25. Meyerhof bearing capacity map D:15 m.

Analysis of the generated graphs and spatial distribution maps (Figures 14-25) confirms that the linear correlation gap between the two methods widens significantly in favor of Meyerhof as soil density increases. This discrepancy becomes more radical particularly in soil profiles categorized as 'dense' and 'very dense' (SPT-N > 30) and at deeper levels (9.0 m – 15.0 m). The analytical structure of the Meyerhof method, which incorporates the depth factor (k_d), leads to higher bearing capacity estimations in deeper strata where confining pressure increases. In contrast, the Terzaghi and Peck approach maintains a more conservative graphical trend across the same profiles.

Consequently, for geotechnical analysis and safe structural design—especially in the loose alluvial soils predominant in the western regions near the Batman Stream and for shallow foundations—adopting the conservative limits offered by the Terzaghi and Peck approach is evaluated as a more reliable engineering choice. In these alluvial zones, where seismic risk and differential settlement potential are elevated, the relatively high capacities provided by the Meyerhof method may lead to 'overly optimistic' design outcomes, potentially increasing structural vulnerability. Therefore, considering the heterogeneous nature of the local subsoil, it is recommended that design engineers in the Batman region perform comparative evaluations of both

methods and adopt the Terzaghi-Peck limits as a 'lower bound' safety threshold for weak soil conditions.

4. Conclusions

In this study, Standard Penetration Test (SPT-N) data obtained from 253 borehole locations across an area of approximately 54 km² within the central district of Batman were transferred to a Geographic Information System environment. Using ArcGIS software and the Inverse Distance Weighting interpolation method, spatial prediction maps for SPT-N and foundation bearing capacity were generated for depths of 1.5, 3.0, 4.5, 7.5, 9.0, and 15.0 m from the surface.

The study found that SPT-N blow counts generally exhibit a linear upward trend as depth increases. While soils in the northern parts of the field (Yediyol Village, Tilmerc, Gültepe) are generally in a "loose" state (SPT-N: 4–10) at shallow depths, "medium dense" and "dense" formations were observed in the southern and southwestern sectors (Petrolkent, Güneykent, etc.). Notably, in the Girberesiik and Yeniköy neighborhoods located to the west, soils were identified as having a "loose" formation at shallow depths due to their proximity to the Batman Stream.

The low SPT blow counts recorded in these areas serve as a preliminary indicator of potential geotechnical vulnerabilities, such as settlement and loss of bearing capacity. While these values suggest a susceptibility to liquefaction hazards during seismic activity, it is recommended that this issue be addressed in further site-specific studies.

Examination of the spatial distribution maps for bearing capacity—calculated assuming a foundation width of 3 meters—revealed that approximately 19% of the study area possesses low bearing capacity (below 163 kN/m²), 32% has medium bearing capacity (163–325 kN/m²), and a significant majority of 49% has high bearing capacity (326–488 kN/m²).

The bearing capacity distribution maps prepared using both empirical methods demonstrated a high degree of spatial correlation in identifying risky and safe zones. However, it was determined that as SPT-N blow counts and especially embedment depth increase, the Meyerhof (1974) method produces higher bearing capacity values compared to the Terzaghi and Peck (1967) approach, due to the influence of the depth factor in its formulation. In this context, to remain on the safer engineering side, especially in loose soil profiles, it is recommended to consider the limits provided by the Terzaghi and Peck approach.

However, explaining this phenomenon solely based on the present evaluation would not be sufficient. The soil density condition (loose or dense) and increasing depth variations may nonlinearly influence the magnitude of this difference. Therefore, it is suggested that a more comprehensive assessment of this issue should be conducted in future studies by incorporating a detailed multivariate regression or statistical sensitivity analysis.

Furthermore, while this study provides a robust spatial framework for regional bearing capacity trends, future research incorporating advanced geostatistical validation techniques such as Cross-validation, RMSE, and MAE is recommended to further quantify the predictive accuracy of the generated thematic maps as the dataset expands. In conclusion, the transformation of point-source SPT data into GIS-based maps has holistically revealed the lateral and vertical variability of soil properties and bearing capacities in the Batman city center. These geotechnical microzonation maps are evaluated as a critical framework for decision-makers in urban planning, disaster risk reduction, and the selection of safe residential areas in a region under the influence of the Bitlis Thrust Zone and the East Anatolian Fault Zone. Nevertheless, while these regional maps guide general zoning and settlement policies, they are not sufficient on their own; the necessity for detailed, parcel-based soil investigation (considering local heterogeneities) for each planned engineering structure remains mandatory.

Author Contributions

The percentages of the authors’ contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	N.A.B	B.K.	H.T.
C	40	30	30
D	40	30	30
S	40	30	30
DCP	40	30	30
DAI	40	30	30
L	40	30	30
W	40	30	30
CR	40	30	30
SR	40	30	30
PM	40	30	30
FA	40	30	30

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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References

Acar, M. C., & Özdemir, D. (2023). Geographical information system approach in evaluating geotechnical properties of soils: Kayseri Oymaağaç case study. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 38(2), 1079–1092.

AFAD. (2025). *AFAD earthquake catalog*. Disaster and Emergency Management Presidency. <https://deprem.afad.gov.tr/event-catalog>

Aydın, K. (2010). *A study on SPT-Vs correlation in Ankara metro routes* [Master's thesis]. Gazi University, Graduate School of Natural and Applied Sciences, Turkey.

Barka, A. A. (1992). The North Anatolian fault zone. *Annales Tectonicae*, 6, 164–195.

Batman Provincial Directorate of Disaster and Emergency Management. (2022). *Provincial disaster risk reduction plan (IRAP)*.

Bowles, J. E. (1996). *Foundation analysis and design* (5th ed.). McGraw-Hill Companies, Inc.

Çabalar, A. F., Canbolat, A., Akbulut, N., Tercan, S. H., & Işık, H. (2019). Soil liquefaction potential in Kahramanmaraş, Turkey. *Geomatics, Natural Hazards and Risk*, 10(1), 1822–1838.

Çabalar, A. F., Karabas, B., Mahmutluoglu, B., & Yildiz, O. (2021). An IDW-based GIS application for assessment of geotechnical characterization in Erzincan, Turkey. *Arabian Journal of Geosciences*, 14(20), 2129. <https://doi.org/10.1007/s12517-021-08535-6>

Civelekler, E., & Pekkan, E. (2022). The application of GIS in visualization of geotechnical data (SPT-soil properties): A case study in Eskisehir-Tepebaşı, Turkey. *International Journal of Engineering and Geosciences*, 7(3), 302–313. <https://doi.org/10.26833/ijeg.980611>

Clayton, C. R. (1995). *The standard penetration test (SPT): Methods and use*. Construction Industry Research and Information Association.

Çinicioğlu, S. F. (2005, May). *Understanding and calculation of bearing capacity under static and dynamic loads* [Seminar]. UCTEA Chamber of Civil Engineers, Istanbul Branch.

Demir, G. (2013). *Preparation of geo-engineering properties of the foundation soil in Gürsu (Bursa) residential area using Geographical Information Systems (GIS)* [Master's thesis]. Balıkesir University, Institute of Science and Technology.

Demirtaş, O. (2022). *Mapping geotechnical data by GIS: A case study of Elazığ city, Turkey* (Master's thesis, Hasan Kalyoncu University, Department of Civil Engineering).

Directorate of EIA and Permitting. (2017). *Batman province 2017 environmental status report*. Governorship of Batman.

Genç, D. (2008). *Soil mechanics and foundations*. UCTEA Chamber of Geological Engineers Publications.

Imamoğlu, M. Ş., & Çetin, E. (2007). Seismicity of Southeast Anatolia region and its vicinity. *Dicle University Ziya Gökalp Faculty of Education Journal*, (9), 93–103.

Karabaş, B. (2019). *Use of Geographic Information System for evaluating some geotechnical properties in Malatya, Turkey* [Master's thesis]. Hasan Kalyoncu University, Graduate Education Institute.

Karabaş, B., Akbulut, N., & Demirtaş, O. (2026). GIS-Based IDW Mapping of Soil Index Properties: A Case Study of Elazığ Center. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 17(1). <https://doi.org/10.24012/dumf.1850431>

KGM. (2023). *Intercity distance query*. General Directorate of Highways. <https://www.kgm.gov.tr/Sayfalar/KGM/SiteTr/Uzakliklar/illerArasiMesafe.aspx>

- Küpçü, S., Çabuk, A., & Uyguçgil, H. (2015). *Geographic information systems* (No. 2057; 1st ed.). Anadolu University Faculty of Open Education.
- Law on the Establishment of Two Provinces and Five Districts and Amending the Annexed Schedules of the Decree-Law No. 190, Law No. 3647 (1990). <https://www.mevzuat.gov.tr/mevzuatmetin/1.5.3647.pdf>
- Mayne, P. W., Christopher, B. R., & DeJong, J. (2002). *Subsurface investigations—Geotechnical site characterization: Reference manual*. Federal Highway Administration (FHWA).
- Orhan, M. (2022). *Geotechnical engineering and foundation construction* (Vol. 1). Gazi Publishing.
- Rockwell, T., Barka, A., Dawson, T., Akyuz, S., & Thorup, K. (2001). Paleoseismology of the Gazikoy-Saros segment of the North Anatolia fault, northwestern Turkey: Comparison of the historical and paleoseismic records, implications of regional seismic hazard, and models of earthquake recurrence. *Journal of Seismology*, 5, 433–448.
- Şengör, A. M. C. (1980). *Fundamentals of the neotectonics of Turkey*. Geological Society of Turkey.
- Şengül, T., & Karabaş, B. (2021). Kütahya Merkez ilçesinde sivilaşma potansiyelinin Coğrafi Bilgi Sistemi ile incelenmesi. *Bilecik Şeyh Edebali Üniversitesi Fen Bilimleri Dergisi*, 8(2), 817-825. <https://doi.org/10.35193/bseufbd.962190>
- Tonbul, S., & Sunkar, M. (2008, October). *Evaluation of site selection in Batman city in terms of geomorphological features and natural risks* [Paper presentation]. National Geomorphology Symposium, Çanakkale, Turkey.
- Uzuner, B. A. (2016). *Basic soil mechanics with solved problems* (10th ed.). Teknik Publishing.
- Yıldız, O. (2022). Seismic site characterization of Battalgazi in Malatya, Turkey. *Arabian Journal of Geosciences*, 15(9), 867. <https://doi.org/10.1007/s12517-022-10170-x>
- Yıldız, Ö. (2024). Integrated GIS-based mapping and ANFIS modelling for seismic and geotechnical characterization of soil properties. *KSCE Journal of Civil Engineering*, 28(9), 3708–3721.
- Youd, T. L. (1984). Geologic effects-liquefaction and associated ground failure. *Proceedings of the Geologic and Hydraulic Hazards Training Program*, 210–232.