

Chapter 27

Development of Foundation Suitability Maps for South Chennai Using GIS



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Introduction

The recent growth of the construction activities has been accompanied by a need for better construction techniques, land use planning, and management, sustainable development, environmental planning which in turn will ensure efficient and economic outcomes. The successful planning and execution of any construction activity, as well as environmental hazards study and management, depends majorly on the subsoil investigation of the site and the subsequent determination of underlying soil and rock layers and their respective properties. The properties of the underlying soil, being a heterogeneous material, alter from one point to another in a site. In many cases, the subsurface data collection proves to be difficult and expensive due to issues such as inaccessibility, cost of equipment required, proximity to nearby structures. The different types of soil and rock test data already available are abundant and widely scattered. A spatial database management system can be used to map these surficial conditions as well as to determine the missing spatial data. Over the last four decades, geographical information system (GIS) has emerged as one of the major spatial database tools playing a key role in the studies of land suitability, ground response, hydrology studies, various hazard risks, and so on [1]. Geotechnical zonation maps can help in the preliminary planning stages of construction as well as in assessing the safety and economy of various engineering projects. Rajesh et al. [2] conducted a synoptic analysis of the safe bearing capacities of the soil in the

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southern parts of Chennai, India, and subsequent digitization of varying depths using surfer-based Kriging interpolation methods. Sakunthala Devi and Stalin [3] explored various interpolation techniques to analyse the spatial continuity and variability of bearing capacity of pile of various diameters and embedded length as well as other important geotechnical parameters and developed ultimate bearing capacity maps for the study area of Chennai. Smith et al. [4] formed a digital borehole geotechnical database using Microsoft Access 2000 for the Mackenzie Valley/Delta region by compiling already available geological and geotechnical data of over 13,000 boreholes from the pipeline and field drilling programmes between 1970 and 1975. The complete database was also provided in GIS compatible format for both MapInfo and ArcView. Joshphar et al. [5] combined GIS with a relational database management system (RDBMS) to develop a web-based geotechnical information system that could perform online spatial queries, generation of professional bore logs, and various geotechnical analyses in Singapore. Divya and Dodagoudar [6] formed a digitally formatted and integrated spatial database using geotechnical data and GIS in the study area of Chennai, Tamil Nadu, India. The study also demonstrated the application of the developed subsurface model in evaluating the effectiveness of multichannel analysis of subsurface wave (MASW) tests to evaluate the depth to bedrock.

Objective of the Study

This study focuses on compiling already available geotechnical data obtained from boreholes using GIS to generate foundation suitability maps for South Chennai, Tamil Nadu, India. The objectives of the proposed study can be listed as follows:

1. To create a database management system using GIS and Microsoft Excel for collecting and utilizing geotechnical data from the wide range of borehole and laboratory data available in and around South Chennai.
2. To analyse spatial continuity and variation of geotechnical parameters using suitable interpolation techniques.
3. To calculate and generate safe bearing capacity and total settlement maps of soil for shallow foundations of lightly, moderately, and heavily loaded structures in the study area.

Methodology

The conceptual flowchart for the development of the geotechnical parameter maps is as shown in Fig. 27.1.

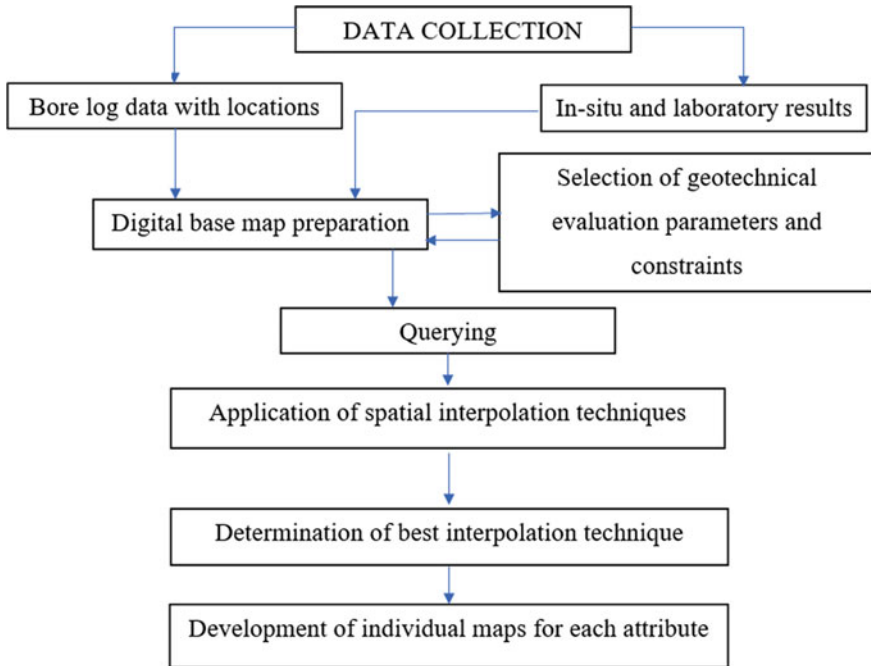


Fig. 27.1 Conceptual flowchart showing the proposed methodology

Details of the Study Area

The region along the Old Mahabalipuram Road (OMR) in Chennai has become the hub of various IT companies and industries accompanied by a huge rise in residential projects, educational institutions, national research laboratories, etc.

The study area of 88.932 km² considered in this project is along the OMR beginning from Perungudi to Kelambakkam and consists of mainly Pallikaranai, Oggiamduraipakkam, Karapakkam, Sholinganallur, Navalur, Egattur, Siruseri, and Padur as shown in Fig. 27.2.

Data Collection

The data collected consist of spatial and non-spatial information. The spatial data consist of the latitudes and longitudes of the borehole locations used in the study which were mapped through a GPS survey. The geotechnical attributes and site details of all the borehole locations were collected. The non-spatial data contained city boundaries, arterial roads, rivers, marshlands, water bodies, etc. (Fig. 27.3).

Fig. 27.2 Base map of the study area in OMR (Source Imagery in ARCMAP 10.8)



Fig. 27.3 Borehole locations in the study area in OMR

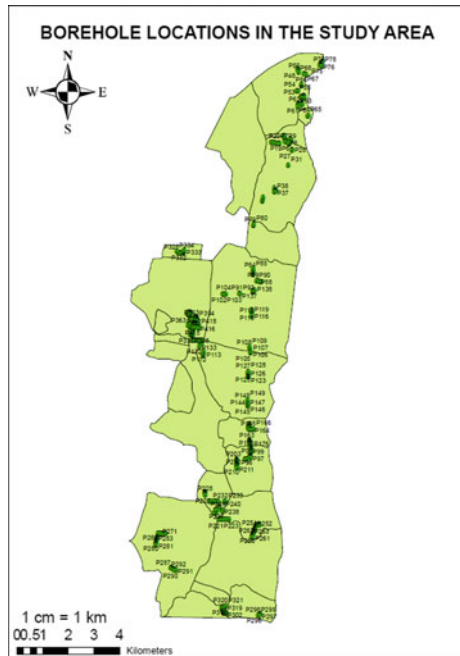


Fig. 27.4 Non-spatial data in the study area



Development of Base Map

A digitized base map with adequate control points and information is necessary for the development of a spatial database. The base map consisting of the study area boundaries starting from Perungudi to Kelambakkam was developed from Chennai city map and land use maps using ArcMap 10.8 software. The major non-spatial attributes in the study area such as city boundaries, main road, arterial roads, rivers, and waterbodies have been incorporated in the Chennai city map as shown in Fig. 27.4.

Formation of Geotechnical Database

The geotechnical data used in the study were collected from VRR Engineering Consultancy, Chennai. The geotechnical database was created using Microsoft Excel and consisted of borehole IDs, latitude, and longitude of each borehole, descriptions of the site, *N* values at various depths (0.75, 1.5, 2.25, 3, 3.75, 4.5, 5.5 m, etc.), soil classification, density details, cohesion, and angle of internal friction at varying depths.

The Excel sheet was then converted into a shapefile to integrate with the base map of the study area created. The borehole data were spatially plotted in the base map using the XY data, i.e. longitude and latitude of each borehole location. As a result,

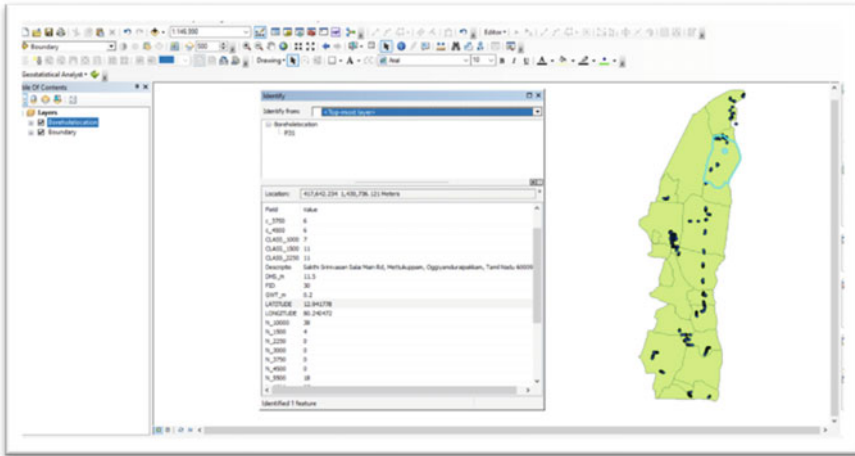


Fig. 27.5 Geotechnical data at the borehole location (Point ID: P31) in ArcMap

each point in the map could be accessed to get the borehole details of that particular location as shown in Fig. 27.5.

Mapping of Attribute Data Using Interpolation Technique

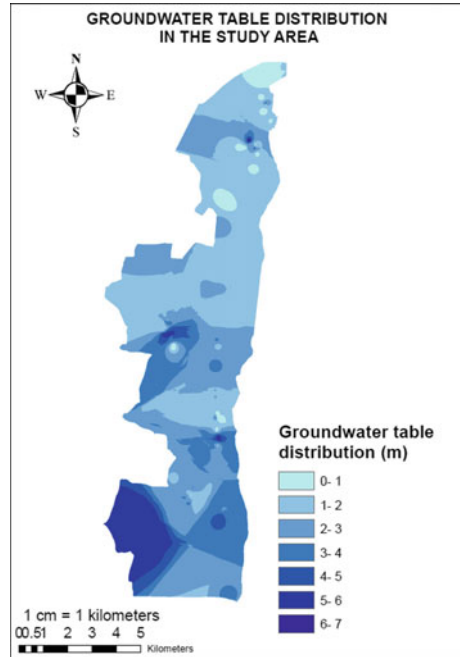
Interpolation methods in ArcMap 10.8 were used for predicting a continuous spatial surface from sampled point values in the study. The various spatial interpolation techniques used in this study are: Inverse Distance Weighted (IDW), Natural Neighbour, Spline, Kriging, and Topo to Raster interpolation. The determination of the best interpolation technique was done by using cross-validation. The spatial model has been developed using 374 borehole locations out of a total of 418 borehole locations in the study area. The geotechnical data of the remaining 44 borehole locations were compared with the observed values in the borelog and laboratory reports. The interpolation technique with the least RMSE error was adopted as the best method for generating the geotechnical parameter models.

Results and Discussions

Groundwater Table Map in the Study Area

The groundwater table distribution was developed from the borelog report of various borehole locations. The groundwater table depth map was developed using the Inverse

Fig. 27.6 Groundwater table distribution in the study area



Distance Weighting interpolation technique in the study area as shown in Fig. 27.6. Shallow groundwater table was found in some places towards the northern part of the study area due to the presence of nearby marshlands.

SPT N Value Map at Different Depths in the Study Area

The variation of SPT N value with respect to the depth in the study area was analysed and modelled using Topo to Raster interpolation. These N value maps can be used to find the N value at a particular location using the latitude, longitude, and the depth of the layer below ground level. The N value maps for depths 3, 4.5, and 6.5 m are shown in Figs. 27.7, 27.8 and 27.9. The SPT N values predominantly increased in value with increasing depth below ground level in the study area.

Soil Classification Map at Different Depths in the Study Area

The soil classification used in this study as per Unified Soil Classification System is poorly graded sand (SP), poorly graded sand with silt and gravel (SM-SP), clayey sand with gravel (SC), sand with low plasticity clay (SC-CL), sand with intermediate

Fig. 27.7 SPT N value at 3.0 m depth

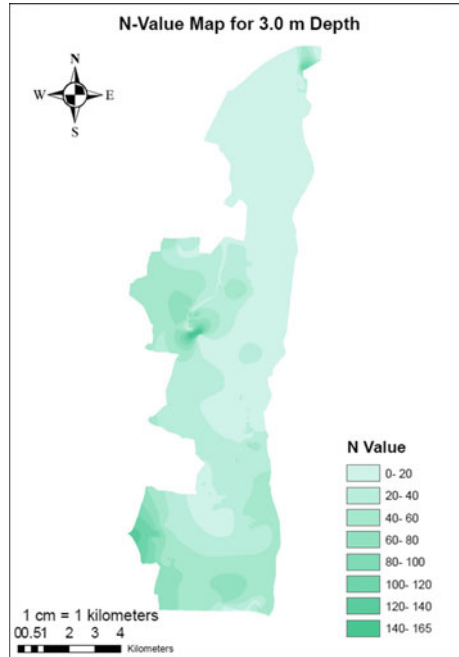


Fig. 27.8 SPT N value at 4.5 m depth

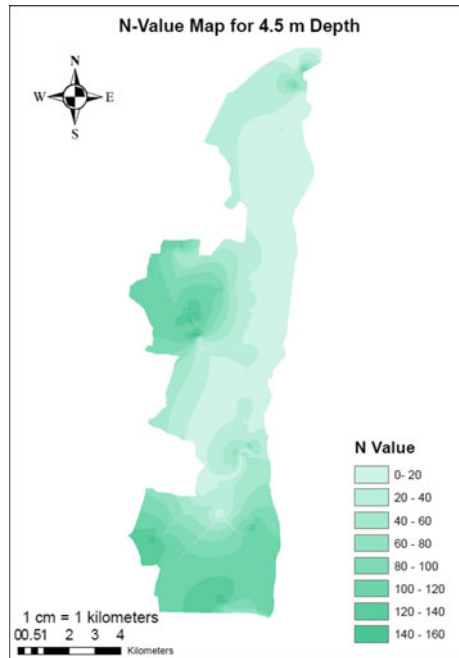
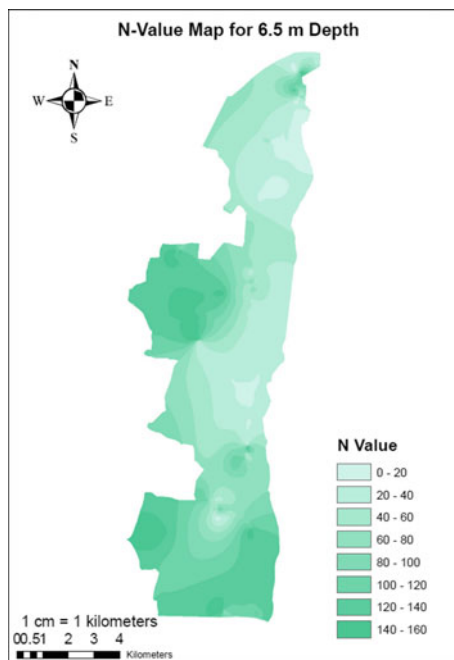


Fig. 27.9 SPT N value at 6.5 m depth



plasticity clay (SC-CI), and intermediate plasticity clay (CI). No problematic soils such as those containing peat, expansive clays, dispersive clays were found in the study area which can cause hindrances in construction activities. The variation of soil types with varying depth was analysed, and soil classification maps at depths varying between 0.75 and 10.0 m were generated using Inverse Distance Weighted interpolation. The soil classification maps at depths of 1.5, 2.25, and 3 m are as shown in Figs. 27.10, 27.11 and 27.12.

Safe Bearing Capacity Maps in the Study Area

The shallow foundation was assumed to be an isolated square footing. The safe bearing capacity (SBC) was calculated using IS equation as per IS 6403–1981 [7] at the sampled locations considering foundation width of 1.5 and 2 m. Bearing capacity calculations were done for depths of foundation 1.5, 2.25, and 3 m. The water table correction factor, shape factor, and depth factor were also taken into consideration. The cohesion, c , and angle of internal friction, ϕ , at the corresponding depths were adopted in the calculation. The maps were generated using Topo to Raster interpolation. The SBC maps with width of foundation of 1.5 m at various depths are as shown in Figs. 27.13, 27.14 and 27.15.

Fig. 27.10 Soil classification map at 1.5 m depth

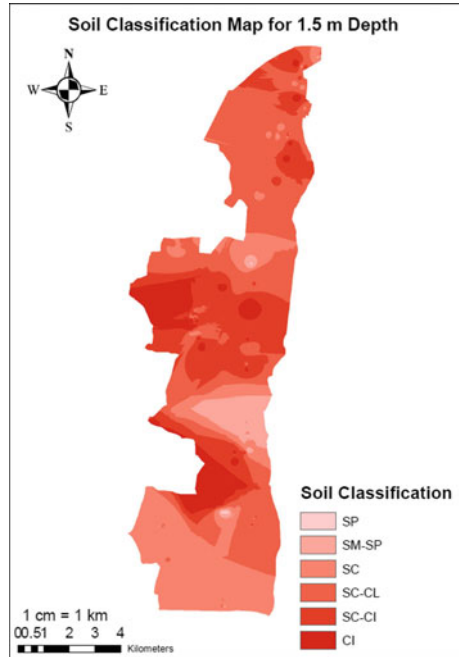


Fig. 27.11 Soil classification map at 2.25 m depth

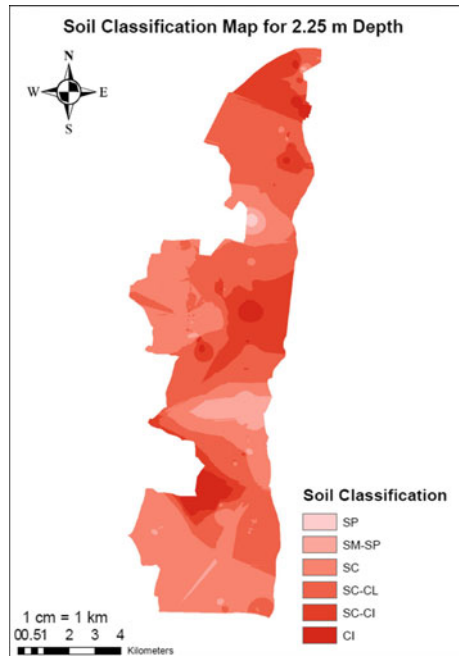


Fig. 27.12 Soil classification map at 3 m depth

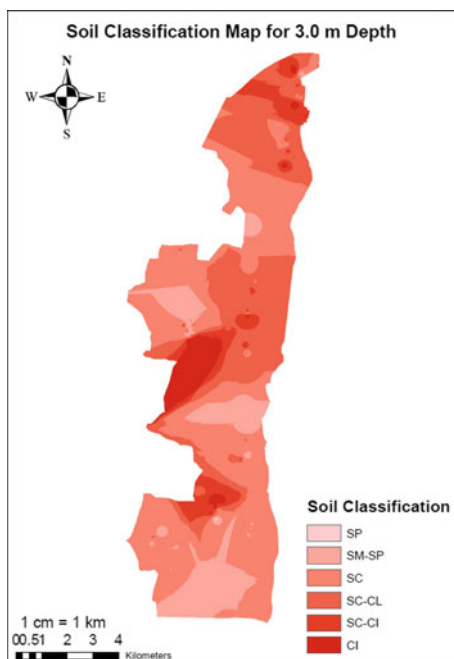


Fig. 27.13 SBC map at 1.5 m depth

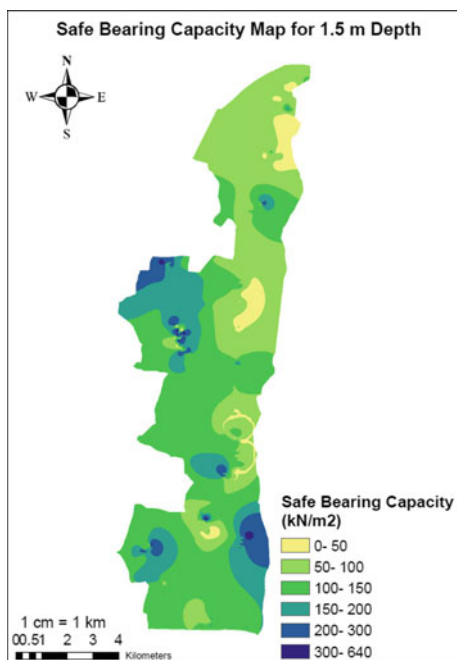


Fig. 27.14 SBC map at 2.25 m depth

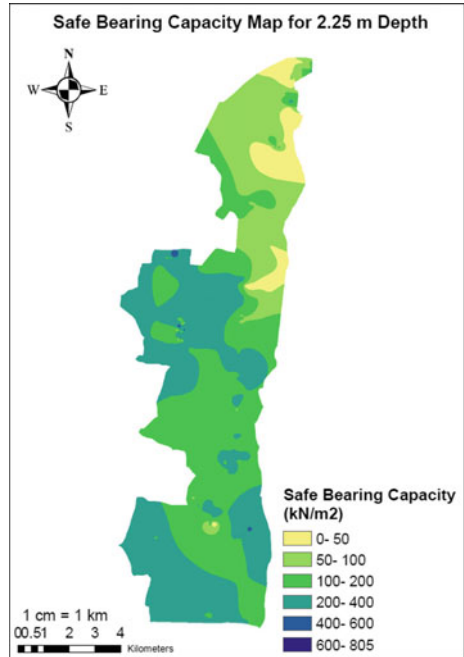
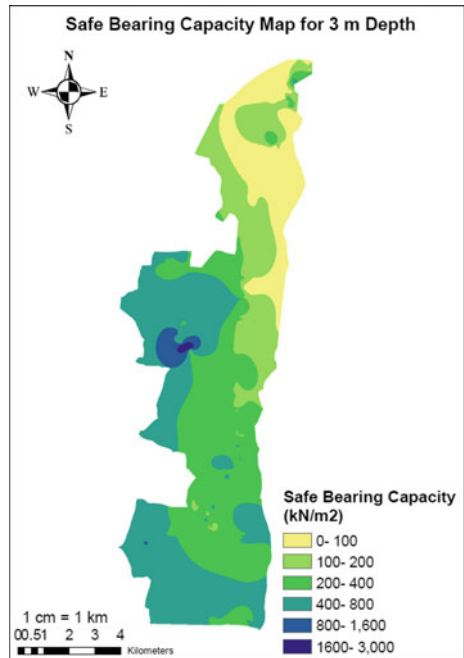


Fig. 27.15 SBC map at 3 m depth



SBC Map for 1.5 m Depth It is observed that 4.354% area has SBC between 0–50 kN/m², 32.839% between 50–100 kN/m², 44.555% between 100–150 kN/m², 14.089% between 150–200 kN/m², 3.957% between 200–300 kN/m², and 0.204% between 300–600 kN/m².

SBC Map for 2.25 m Depth It is observed that 5.966% has SBC between 0–50 kN/m², 17.862% between 50–100 kN/m², 38.385% between 100–200 kN/m², 37.673% between 200–400 kN/m², 0.114% between 400–600 kN/m², and 0.001% between 600–805 kN/m².

SBC Map for 3 m Depth It is observed that 14.637% has SBC between 0–100 kN/m², 17.201% between 100–200 kN/m², 32.344% between 200–400 kN/m², 33.932% between 400–800 kN/m², 1.698% between 800–1600 kN/m², and 0.189% between 1600–3000 kN/m².

Total Settlement Maps in the Study Area

The total settlement of the soil, S_T , in the study area due to foundation loading was calculated for 3 column loads: 250, 500, and 1000 kN considering lightly loaded, moderately loaded, and heavily loaded structures as per IS 875 (Part 1 and Part 2): 1987 [8, 9]. Total settlement of the soil layer was calculated as the summation of immediate (elastic) and consolidation settlement of soil layers up to an influence depth of 1.5B for width of foundation of 1.5 and 2 m and depth of foundation of 1.5, 2.25, and 3 m. Meyerhoff's correlation was used for calculating the elastic settlements of sandy soil based on standard penetration resistance, N , where average SPT N value between the bottom of the foundation to a depth of 2B and the bottom was considered. The elastic settlement of clayey soil was calculated using the equation based on theory of elasticity. The consolidation settlement of clayey soil was determined using the formula $S_c = \Delta\sigma m_v H$ where coefficient of volume compressibility (m_v) was calculated from the elasticity modulus (E_s) of the soil [10] which in turn depended on the SPT N value and the soil classification at various depths. The total settlement maps for the study area were developed using various interpolation techniques, and Inverse Distance Weighted interpolation was found to be the suitable method for developing the settlement maps using cross-validation process. These maps can be used to estimate the settlement of isolated foundations at different depths within the study area using the latitude, longitude, and depth of the foundation to be used.

Total Settlement Maps for a Moderately Loaded Structure in the Study Area.

The column load in the case of a moderately loaded structure was approximated as 500 kN as per IS 875 (Part 1 and Part 2): 1987. The total settlement of the soil was calculated considering widths of foundations as 1.5 and 2 m with varying depth of foundation of 1.5, 2.25, and 3 m. The total settlements maps thereby developed are as shown in Figs. 27.16, 27.17, 27.18, 27.19, 27.20 and 27.21.

Fig. 27.16 Total settlement map for 1.5 m depth and 1.5 m width

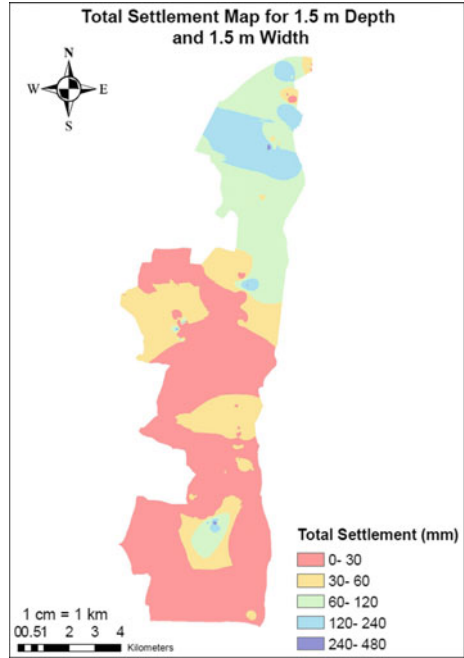


Fig. 27.17 Total settlement map for 2.25 m depth and 1.5 m width

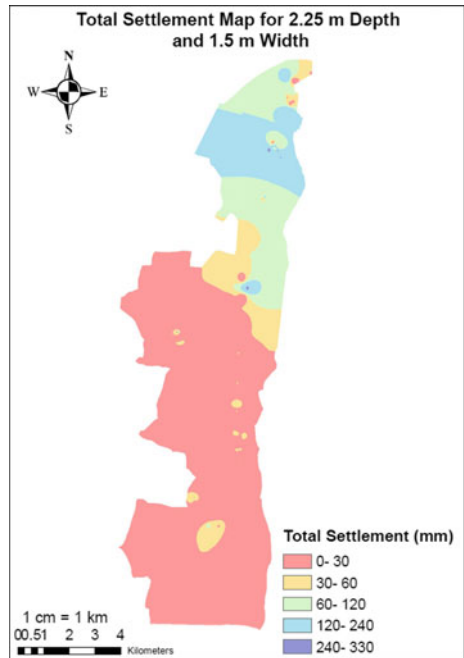


Fig. 27.18 Total settlement map for 3 m depth and 1.5 m width

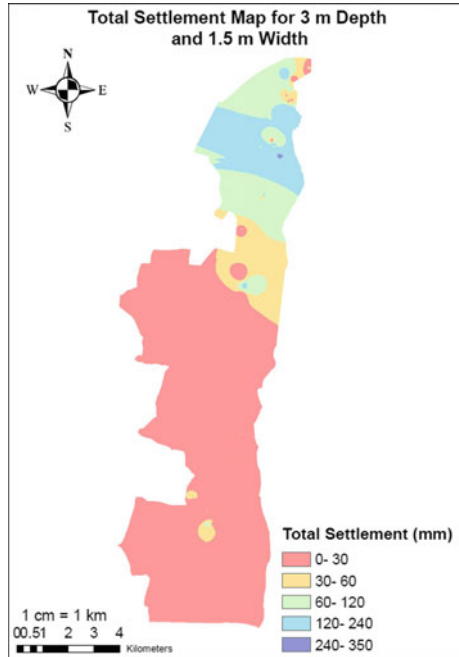


Fig. 27.19 Total settlement map for 1.5 m depth and 2 m width

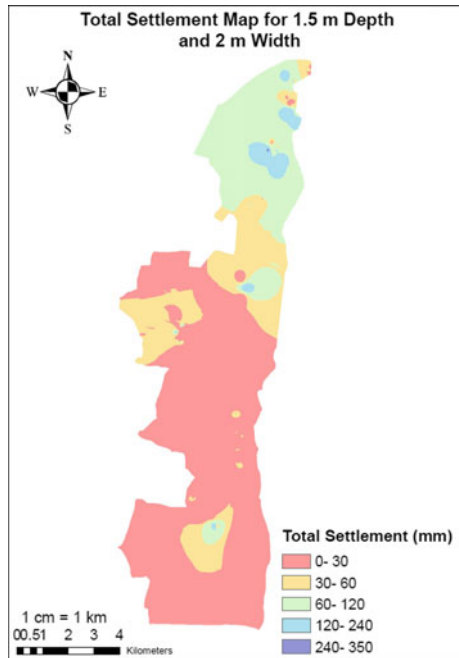


Fig. 27.20 Total settlement map for 2.25 m depth and 2 m width

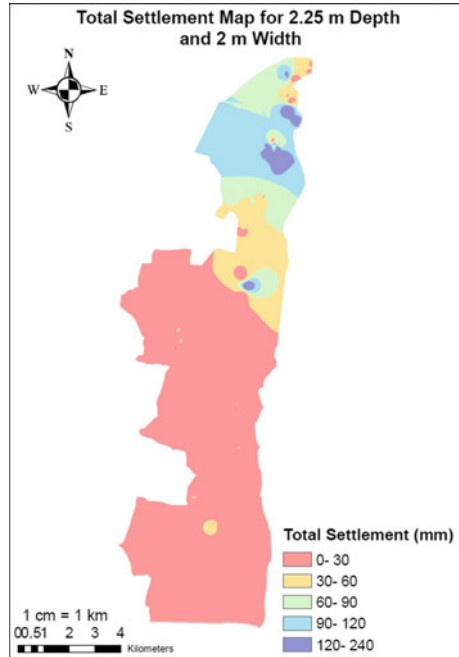
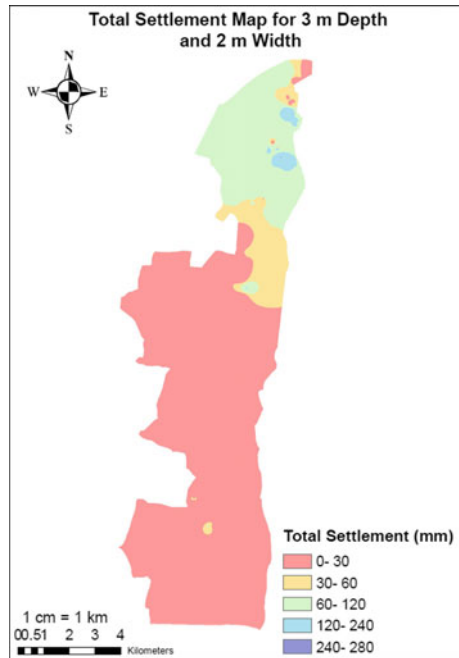


Fig. 27.21 Total settlement map for 3 m depth and 2 m width



Total Settlement Map for 1.5 m Depth and 1.5 m Width. It can be observed that the total settlement of 51.707% area is between 0–30 mm, 20.12% between 30–60 mm, 19.603% between 60–120 mm, 8.521% between 120–240 mm, and 0.049% between 240–480 mm.

Total Settlement Map for 2.25 m Depth and 1.5 m Width. It can be observed that the total settlement of 66.773% area is between 0–30 mm, 8.11% between 30–60 mm, 14.115% between 60–120 mm, 10.974% between 120–240 mm, and 0.028% between 240–330 mm.

Total Settlement Map for 3 m Depth and 1.5 m Width. It can be observed that the total settlement of 70.704% area is between 0–30 mm, 8.061% between 30–60 mm, 8.061% between 60–120 mm, 9.734% between 120–240 mm, and 0.032% between 240–350 mm.

Total Settlement Map for 1.5 m Depth and 2 m Width. It can be observed that the total settlement of 60.574% area is between 0–30 mm, 17.716% between 30–60 mm, 19.32% between 60–120 mm, 2.379% between 120–240 mm, and 0.011% between 240–360 mm.

Total Settlement Map for 2.25 m Depth and 2 m Width. It can be observed that the total settlement of 70.25% area is between 0–30 mm, 9.829% between 30–60 mm, 8.146% between 60–90 mm, 10.072% between 90–120 mm, and 1.703% between 120–240 mm.

Total Settlement Map for 3 m Depth and 2 m Width. It can be observed that the total settlement of 73.953% area is between 0–30 mm, 7.474% between 30–60 mm, 17.525% between 60–120 mm, 1.047% between 120–240 mm, and 0.002% between 240–280 mm.

Validation of Attribute Maps Developed

Cross-validation was done for groundwater table, depth of hard stratum, SPT N value, soil classification, safe bearing capacity, and total settlement maps. The values obtained from the field and laboratory tests and those observed in the developed maps were found to be in good agreement with each other. Mean error and root mean square error were also calculated to ensure minimum error in the interpolation techniques adopted. The comparison of actual safe bearing capacity with the corresponding values obtained from the maps is shown in Table 27.1.

Table 27.1 Comparison of actual safe bearing capacity and predicted safe bearing capacity for 1.5 m width and 1.5 m depth of foundation from the map

Borehole ID	Latitude	Longitude	Actual SBC (kN/m ²)	Predicted SBC (kN/m ²)
P5	12.9501389	80.2393889	56.783	50–100
P46	12.9703333	80.2451111	80.645	50–100
P56	12.9634444	80.2454444	16.168	0–50
P110	12.8743056	80.21	129.195	100–150
P117	12.8904444	80.2274722	48.791	0–50
P120	12.8668056	80.2263889	58.571	50–100
P152	12.8440833	80.2268611	161.159	150–200
P193	12.8227778	80.2153889	113.049	100–150
P215	12.8377778	80.2255833	64.608	50–100
P241	12.8143889	80.2306111	530.555	300–640
P273	12.8111667	80.1940278	116.463	100–150
P292	12.7981944	80.2006111	84.014	50–100
P343	12.8832222	80.2062778	225.746	200–300
P394	12.8870556	80.20775	214.052	200–300

Conclusions

A geotechnical database management system was developed using the data from already available borehole and laboratory tests for generating geotechnical attribute maps using various spatial interpolation techniques in South Chennai, Tamil Nadu, India, using Microsoft Excel and ArcMap 10.8. Geotechnical attribute maps can act as an aid in site investigation processes and provide an insight into the approximate value of safe bearing capacities and total settlement of soil in the study area which can be helpful in deciding the shallow foundation details. The following conclusions can be drawn from the proposed study:

1. The safe bearing capacity (SBC) of the soil (in kN/m²) was calculated using the IS equation as per IS 6403: 1981 considering widths of foundation 1.5 and 2 m at varying depths of foundation of 1.5, 2.25, and 3 m. Good bearing stratum with high bearing capacity was observed towards the southern parts of the study area, whereas the northern parts showed lower bearing capacity values due to the presence of waterlogged areas and shallow groundwater table.
2. The total settlement of soil was calculated considering loads from lightly, moderately, and heavily loaded structures for foundation widths of 1.5 and 2 m at different depths such as 1.5, 2.25, and 3 m. The soil present in the northern parts of the study area experienced more settlement when compared to that towards the southern areas.

3. Inverse Distance Weighted and Topo to Raster interpolation were identified as the best interpolation technique for developing the spatial attribute maps in the study.

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