Geospatial approach to determine Soil bearing capacity of Nagpur city, Maharashtra India

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Abstract

Geological Information System (GIS) is a technique which can make geotechnical investigation easy for engineering purpose. It helps the engineer to analyze the ground data before physical inspection of the site. The area of research is the Nagpur district of Maharashtra, India. The topographic sheet for Nagpur is 55K/16 and 55O/4 of 2010. The Major purpose of this research was to determine the bearing capacity map, Contour map, and total land cover/land use map for a different purpose. From the above map, it will be easier for engineers to decide the type of Foundation and the trend of development across the city. Earlier, there was no method to store bore log and soil data to the exact location of the borehole, but today with the help of the Geospatial technique, researchers can assign soil data with every borehole. Nowadays, urbanization is speedily taking place due to which proper utilization is necessary for land according to its strength and properties. In this research, the author wants to collect different satellite imageries of Nagpur city and bore logs comprising of geotechnical data. The predicted outcome should show the contour map, elevation map, changes in land use pattern, and bearing capacity across the city. These help the researcher and engineers who are working in the same area for future site selection.

Keywords: Interpolation; Contour; Geospatial technique; Geotechnical investigation; Bearing Capacity

1. Introduction

Geographic information system it is defined as “the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information”(Raju, 2003). GIS is a versatile program that is commonly used to monitor all the data that is important for human life, i.e. air, temperature, water, soil, land, agriculture. GIS collects the data from satellite imageries, and after applying the correction to these images, we can quickly identify the surface of specific land location which can be of the forest, water, agriculture, barren land region. This Geographic information system is also described as “the art, science or technology dealing with the acquisition, storage, processing production, presentation and dissemination of geo information”(Ehlers, 2008).

GIS requires satellite images which are available with proper latitude and longitude coordinates, this latitude and longitude make it easy to pinpoint any location within these coordinates.

The study of soil is essential for all kind of construction work (Dungca et al., 2017) as we all know that Geotechnical engineering deals with a different aspect of soil. The foundation durability depends on the type of soil. If the soil is soft, the bearing capacity will be less, and if the soil is hard, we will get adequate bearing capacity. The Foundation's ability to sustain load depends on the soil allowable load carrying capacity.

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In geotechnical engineering or civil engineering, the works carried out on the soil, i.e. construction of reservoirs, buildings, bridges and many more. The work of Geotechnical engineer is tedious and time-consuming. It consists of from soil survey till test result analysis for different properties. These all require paperwork. Nevertheless, if the same data of soil is available on the GIS database, then the efforts of engineers will minimize. They will get more time for analysis and designing. Hence this GIS database will help the engineers to understand the properties of soil nearby the developing area.

To fill this dire need author has collected bore log of different location of Nagpur city from Nagpur metro rail corporation limited (NMRCL). Using the data from bore log available, which consist of different soil parameters and bearing capacity, reference is made of the covered areas using GIS techniques.

GIS data base will save the cost and increase the quality of small contractor works because due to tight budget issues they don’t perform soil test and starts the construction based on the engineering drawing. From the Spatial data base, the test result will be available for all and they contractors can take the reference of test result for their area without getting affect to the budget and will results in quality work with better strength. The main aim of the research is to develop a spatial data base that can provide allowable bearing capacity, water table, Elevation, soil type at different depth for Nagpur city.

1.1. Location of Site

This research is conducted in Nagpur city, Maharashtra. It lies between 21°14'0″ N to 21°3'0″ N latitudes and 78°59′E to 79°10′E longitudes approximate area is 228 sq.km as shown in Figure.1. It is also located in the center of India peninsula. The average Elevation of Nagpur is 310m. Nagpur has a tropical savannah climate with dry conditions prevailing for most of the year. It receives about 163 mm of rainfall in June. In July, the amount of rainfall increased to 294 mm. A gradual decrease of rainfall has been observed from July to August (278 mm) and September (160 mm). The temperature of Nagpur varies from 35˚C to 45˚C (Nandankar et al., 2011). Nagpur has a total population of 2,405,665, making it India’s 13thlargest city (District Census Handbook, 2011).

1.2. Purpose and Scope

As we know, GIS can be used for incorporation of geotechnical data. The primary purpose of the research is

1. To save time.
2. To organize the data.  
3. To make it available for all personnel.  
4. To minimize the cost of geotechnical exploration work.  
5. To study soil profile with visualization  
6. To have a better understanding and visualization of the actual situation with the help of 3D models  
7. To develop bearing capacity, contour, aspect, elevation maps.  

By this research, the author wants to show how we can compile soil data to the borehole, and it can be easily accessible. These can be a good initiative for organizing the geotechnical investigation data concerning the latitude and longitude of boreholes. In future expansion, we can add new soil data to the file, which will keep the database updated.

2. Methodology

The research begins with the reconnaissance survey where the author has studied the map, location, climate the soil condition present from previous data. Then the satellite imagery, i.e. Landsat 7 having the resolution of 30m for band 1 to band 7 and spatial resolution of 15m for band 8 (USGS). These images of the satellite are not clear, so different satellite images are stacked together to form a composite image which makes it easier for others to understand the map. These images will help in the determination of land use and land change pattern.

For the bearing capacity map preparation sixty number of bore logs are collected across the city. These bore logs contain details about the location, depth, type of soil at different locations. After this, the borehole logs are plotted on the map with its location coordinates to get proper visualization of borehole distribution. The bearing capacity is calculated using two different criteria (a) for Pile Foundation IS 2911 part 2 (2010) & IRC: 78 (2014) is used (b) For open Foundation IS 6403-1981 is used.

A factor of safety of 3 was divided by the ultimate bearing capacity to calculate allowable bearing capacity at a different location. A contour map is created to visualize the Elevation in Nagpur city.

An outline of the Methodology can be understood from a flowchart in Figure 2.

![Flow chart of Methodology](image-url)
3. Results

3.1. Soil Characteristic

Nagpur sits on the Indian Peninsula's Deccan plateau and has an average elevation of 310.5 m above mean sea level. Alluvial deposits occurring from the flood plain of the Kanhan River are covered with the underlying rock strata. These give rise to granular sandy soil in some areas. The soil is alluvial clay with poor permeability characteristics in low lying areas which are poorly drained. Crystal metamorphic rocks such as gneiss, schist and granites are found in the eastern part of the city, while yellowish sandstones and clays of the lower Gondwana formations are found in the northern part. The landscape varies from east to northeast due to the rock lying under the surface. The rocks of the Gondwana group show a low rolling topography with limited soil cover and vegetation. The upland ranges in the north are the continuation of Sapura’s, which eventually narrows down to the west. South of this upland range stretches the hills of Ambegad, the western extremity of which is the Nagpur district. The temple of Ramtek is at the base of this range. The Girad hill spreads along the southeast and divides the Kar valley from the Jamb valley to the Kondhali.

In Nagpur there are six types of soils present they are (a) Khardi soil (b) kali soil (c) Morand soil (d)Bardi soil (e)Wardi soil (f)kachchar soil. The freshwater layers of sedimentary soil, generally known as intertrappeans, it is interspersed with the igneous lava-flows of the Deccan Pit, abounding to the west of Nagpur. They range in thickness from a few inches to around five feet. Blanford finds multiple occurrences of these rocks, namely in Dhapewara, between Bokhara and Ma- hurjhari, in Takli, in Sitabaldi, and near Telinkheri. The character of these rocks is very variable; they can be calcareous, argillaceous, cherty, or made up of trap detritus. There is a significant number of fossils from some of the exposures in the Nagpur District were collected. Takli is the most popular location.

3.2. Elevation and Topography

Figure 3 shows the surface topography and the elevation map of Nagpur city about the mean sea level. The data of Elevation is retrieved from the bore log data of Nagpur city at a different location. It is found that the average Elevation of the Nagpur city ranges from 285m to 375m.

![Figure 3 Elevation and Contour Map of Nagpur City](image)

3.3. Borehole Locations

Figure 4 shows the location of the borehole at a different location along with the data of Nagpur city. Each borehole consists of different soil test data which is shown in Table 1. Here in this study, sixty borehole location is taken, and all the sixty bore logs have been connected to the respective map for analysis. From bore logs, we got the location, Elevation, Bearing capacity, Strata at a different depth, Water table, and total depth of bore.
Figure 4 Map Of borehole location

| Name  | Total depth | Soil  | Soft Rock | Hard Rock | Water Table | Bearing capacity | Elevation (meters) |
|-------|-------------|-------|-----------|-----------|-------------|------------------|-------------------|
| BH-1  | 25          | 15    | 10        | 17.2      | 25          | 293              |
| BH-2  | 16.5        | 6.5   | 10        | 7.1       | 25          | 296              |
| BH-3  | 15.5        | 5.5   | 10        | 6         | 25          | 303              |
| BH-4  | 16          | 6     | 10        | 7.1       | 25          | 305              |
| BH-5  | 14.5        | 4.5   | 10        | 5.4       | 25          | 305              |
| BH-6  | 14.5        | 4.5   | 10        | 5.15      | 25          | 311              |
| BH-7  | 20          | 10    | 10        | 5         | 25          | 312              |
| BH-8  | 12          | 2     | 10        | 4.25      | 25          | 315              |
| BH-9  | 11.5        | 1.5   | 10        | 4.4       | 25          | 318              |
| BH-10 | 12          | 2     | 10        | 4         | 20          | 318              |
| BH-11 | 11          | 1     | 10        | 3.85      | 20          | 318              |
| BH-12 | 14.5        | 4.5   | 10        | 5         | 20          | 307              |
| BH-13 | 17          | 7     | 10        | 4.6       | 20          | 304              |
| BH-14 | 17.5        | 7.5   | 10        | 5.1       | 25          | 303              |
| BH-15 | 15          | 5     | 10        | 3.6       | 25          | 315              |
| BH-16 | 11.5        | 1.5   | 10        | 3.25      | 20          | 311              |
| BH-17 | 12.5        | 2.5   | 10        | 4         | 20          | 313              |
| BH-18 | 12.5  | 2.5  | 10   | 2.9  | 20   | 308  |
| BH-19 | 12.5  | 2.5  | 10   | 3.6  | 20   | 314  |
| BH-20 | 13    | 3    | 10   | 3    | 20   | 312  |
| BH-21 | 13    | 3    | 10   | 4.1  | 20   | 311  |
| BH-22 | 14.5  | 4.5  | 10   | 2.1  | 20   | 302  |
| BH-23 | 14.5  | 4.5  | 10   | 3.7  | 20   | 307  |
| BH-24 | 10.5  | 0.5  | 10   | 2.65 | 20   | 300  |
| BH-25 | 11.5  | 1.5  | 10   | 2.5  | 25   | 306  |
| BH-26 | 17.5  | 7.5  | 6    | 4    | 4.3  | 25   | 325  |
| BH-27 | 17    | 7    | 6    | 4    | 4.2  | 25   | 345  |
| BH-28 | 12.5  | 2.5  | 10   | 3.4  | 25   | 315  |
| BH-29 | 21.5  | 2.5  | 9    | 10   | 4.2  | 25   | 322  |
| BH-30 | 13    | 3    | 10   | 4.4  | 25   | 316  |
| BH-31 | 13    | 3    | 10   | 5.1  | 20   | 312  |
| BH-32 | 13    | 3    | 10   | 5.15 | 20   | 311  |
| BH-33 | 14    | 4    | 10   | 4.9  | 20   | 309  |
| BH-34 | 14    | 4    | 10   | 5.5  | 20   | 309  |
| BH-35 | 14.5  | 4.5  | 10   | 4.9  | 20   | 307  |
| BH-36 | 14    | 4    | 10   | 5.1  | 20   | 305  |
| BH-37 | 14    | 4    | 10   | 5.7  | 20   | 304  |
| BH-38 | 14.5  | 4.5  | 10   | 4.6  | 20   | 307  |
| BH-39 | 13    | 3    | 10   | 4.5  | 20   | 315  |
| BH-40 | 12    | 2    | 10   | 3.9  | 20   | 317  |
| BH-41 | 12.5  | 2.5  | 10   | 4.35 | 20   | 309  |
| BH-42 | 13.2  | 3.2  | 10   | 4.7  | 21   | 307  |
| BH-43 | 13.15 | 3.15 | 10   | 4.6  | 21   | 304  |
| BH-44 | 13    | 3    | 10   | 4    | 21   | 293  |
| BH-45 | 13    | 3    | 10   | 2.9  | 20   | 291  |
| BH-46 | 14.5  | 4.5  | 10   | 3.6  | 21   | 293  |
| BH-47 | 14.5  | 4.5  | 10   | 3    | 21   | 287  |
| BH-48 | 10.5  | 0.5  | 10   | 4.1  | 21   | 322  |
| BH-49 | 11.5  | 1.5  | 10   | 2.1  | 25   | 320  |
| BH-50 | 17.5  | 5.5  | 8    | 4    | 3.7  | 25   | 341  |
| BH-51 | 17    | 7    | 10   | 2.65 | 25   | 303  |
| BH-52 | 12.5  | 2.5  | 10   | 2.5  | 25   | 300  |
| BH-53 | 21.5  | 10   | 11.5 | 4.3  | 20   | 292  |
| BH-54 | 13    | 3    | 10   | 4.2  | 20   | 292  |
| BH-55 | 14.5  | 4.5  | 10   | 3.4  | 20   | 302  |
| BH-56 | 13    | 3    | 10   | 4.2  | 20   | 300  |
| BH-57 | 12    | 2    | 10   | 4.4  | 20   | 329  |
| BH-58 | 12.5  | 2.5  | 10   | 5.1  | 25   | 300  |
| BH-59 | 13.2  | 3.2  | 10   | 5.15 | 25   | 299  |
| BH-60 | 13.15 | 3.15 | 10   | 4.9  | 25   | 324  |
3.4. Landuse/Landcover

For land use map generation Landsat images of 2019 have been selected. Then supervised classification of the image is done. This classification gives more accurate results as compared to unsupervised classification technique. The classification was done based on four classes Water, Forest, Urban, and Barren. Different colours give the legends for these four classes; blue colour shows water, green shows Forest, red shows urban and dark brown shows barren land. The LULC classification given in Table 2 below.

Table 2 Coverage of Area under different classification heads.

| Classification | Type                      |
|----------------|---------------------------|
| 1. Water       | Lakes, Pond, Rivers, Reservoirs |
| 2. Forest      | Trees, Vegetation, Gardens |
| 3. Urban       | Residential, Industrial, Commercial |
| 4. Barren      | Waste Lands, Areas with no vegetation’s |

After the supervised classification, the map is generated, as shown in Figure 5. This image also gives the detail of the area covered by different classes based on which classification was done. The statistics of the above Landuse/Landcover map is given in Table 3.

Table 3 Statistics of Landuse/Landcover

| Class   | The area in the Year 2019 (211.57 Sq. Km) | Percentage area covered (100 %) |
|---------|------------------------------------------|---------------------------------|
| Water   | 2.80                                     | 1.3                             |
| Forest  | 18.61                                    | 8.80                            |
| Urban   | 113.47                                   | 53.6                            |
| Barren  | 76.69                                    | 36.3                            |
This classification is important from the engineering point of view as after knowing the trend of development, one can easily decide the area of interest for new construction work viz. roads, bridges, flyovers.

3.5. Bearing Capacity

The construction of the foundations requires engineers to consider how the soil works with the structures (Dungca et al., 2017). Many low-rise constructions slack this Data due to economic constraints as results in early failure. The bearing capacity is calculated using the Standard Penetration Test at every 1.50 m interval and every stratum change as per the specifications (limited, 2013). In the study, we only combined 60 bore log data to generate a map of bearing capacity of Nagpur city it is required to get bore log from every location. The interpolation technique of ArcGIS geostatistical analyst software is used to determine the bearing capacity for each location.

Kriging geospatial technique is used for interpolation of data has this technique is suitable with large input datasets. In Figure 6, we can observe that the bearing capacity varies between 20 ton/m² to 25 ton/m². For these values, the square footing of size 5m by 6m and RCC piles are used at a different location depending upon conditions.
3.6. Prediction, Error, Standardized Error, Normal Value

Methods of Kriging depend on quantitative and computational models. It is used to predict the unknown values for any area concerning known value using statistics by the mathematical expression given below

Equation 1 Mathematical Expression for Kriging (Esri, 2016):

\[
Z(S_0) = \sum_{i=1}^{N} \lambda_i (S_i) Z
\]

Where \(Z(si)\) = the measured value at the ith location

\(\lambda_i\) = an unknown weight for the measured value at the ith location

\(S_0\) = the prediction location

\(N\) = the number of measured values

An Inverse Distance Weighted, the value of weight \(\lambda_i\) depends solely on the distance from the predicted location. However, in Kriging the weights depend on the distance and overall spatial arrangement of points. Spatial autocorrelation is to be quantified, to use the spatial arrangement in weights. Thus, in ordinary kriging process, the weight, \(\lambda_i\), depends on the installed model at the measured points, the distance to the position of the prediction, and the spatial relationship between the measured values around the position of the prediction.

This prediction is considered as decent for making prediction models. Hence using Kriging, the bearing capacity map is generated along with it the graphs for prediction, Error, Standardized error, and normal value is obtained in Figure 7.
4. Discussion

From the above research, the author has determined the soil characteristic’s, Elevation and topography, borehole location, Landuse land cover, Bearing capacity and prediction of data. In Geotechnical engineering, the strength and topography of an area affect the design and construction work, so before this, the area where construction is to be done should be analyzed precisely. (Aghamelu et al., 2011). There is an array of bearing capacity analytical techniques for foundation stability; however, most current procedures involve the execution of a sequence of field and laboratory experiments to produce most components of the bearing capacity equation(s) adopted. One of the common topics of geotechnical engineering for researchers and engineers has already been the bearing capacity for both strip and circular footings on un-drained clay. From this research, the better idea of the area will be known using the topography map of Nagpur city.

The borehole location map is essential to locate the boring site and to identify the strata of the soil layer. The elevation variation is shown in the research to select the site location according to the desired Elevation for construction. In this study, the Elevation ranges from 285m to 375m, from the elevation map the site selection will be easy. Landuse/Landcover analysis is the demand of time as we are as a global moving towards the urbanization the land use pattern is changing, depending on the areas. The research shows the total area of Nagpur city viz. 211.57 Sq. Km. and total occupied area under different feature classes, i.e., water, forest, urban, Barren. This research suggests the trend which affects the landuse in present time, which will be helpful for decision making for future expansion of the Nagpur city. From the land cover map, Nagpur city has water 1.3%, Forest 8.80%, urban 53.6% and Barren 36.3% of the total area.

Bearing capacity of the soil is the vital property which enables any structure to withstand on the soil. Hence above research has shown that Nagpur city has different strata and the allowable bearing capacity of the soil ranges from 20 ton/m² to 26 ton/m² which is suitable for construction as per Indian standard code. The bearing capacity of Sixty specific location is available with the author, but for whole Nagpur city, the soil testing was not done so to overcome this issue author has generated a prediction map which is based on kriging method to predict the bearing capacity of the neighbour area. This prediction map shows the area having a similar bearing capacity of soil with different colour
patterns. The kriging model is not 100% accurate, but it is generally used for making the prediction. The different graph above shows that the error percentage is negligible, and the prediction map can take into consideration for designing purposes.

5. Conclusion

1. The bearing capacity data from different location of Nagpur city is linked to the Geodatabase using an Excel sheet.
2. The bore log which is attached to the Geodatabase consists of different data of research location, i.e. Elevation, allowable bearing capacity, water table, total depth of bore and strata soil classification.
3. The bearing capacity for all the location of Nagpur city was not available, so interpolation is done using Geospatial tool.
4. Ordinary kriging technique is used for prediction of bearing capacity of Nagpur city.
5. The allowable bearing capacity value lies between 20 to 25 ton/m².
6. The elevation map is generated for the Nagpur City, which shows the highest and lowest Elevation of the research area.
7. The value for Elevation lies between 285m to 375m.
8. The Land use classification was done to determine the land use pattern of Nagpur and to get the total area covered under the different classes of Nagpur city
9. With the help of Land use map, the area of interest for different works like construction, agriculture, bridges can easily be determined.

By creating similar data for a large area, city, the country will be very beneficial for all. The availability of Borehole data with complete details will be easily accessible and be useful for better construction work. Decision making for construction will also become easy; hence this ArcGIS can show the trend towards the development. The future scope can be using the same method for developing soil maps with different soil properties for Nagpur district and analyzing it using GIS.

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