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Development and Optimization of Geotechnical Soil Zonation Maps by Using the Inverse Distance Weighted Spatial Interpolation Technique

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Abstract

Due to the increasing expenses for on-site soil tests and investigations, which in turn led to an increase in the project's total cost, there is a need to use geotechnical soil maps to determine the necessary degree of investigations to be conducted, thus saving time, effort, and expense. This study explains the spatial interpolation of data obtained from soil investigation reports for various construction sites. It also presents the creation of soil classification maps using ArcGIS. An analysis of the research area was conducted to evaluate the soil type and the standard penetration resistance of subsurface soil. The inverse distance weighting method was used in Arcmap10 to create area classification maps at different depths within the boundaries of the research area, where soil classification maps were made according to safe construction zones according to (OSHA) and (SPT) by interpolating each depth as a surface. This study provided correlations based on linear regression between the predicted and actual values, contributing to the proposed project's planning and early design phase to estimate the soil's strength and hardness. Engineers can also use data from neighboring sites to evaluate the soil of the intended work site. This leads to building an excellent initial ground model that can be relied upon.

Keywords

Inverse distance weighting, Safety zoning, Soil investigation, Soil mapping, Spatial interpolation

HIGHLIGHTS

-Predicted soil parameter in untested location.
-Generated map of classification soil based on SPT data and strength of soil.
-Classification of safe excavation areas according to OSHA.

INTRODUCTION

Despite technological progress in the building and construction industry, the soil beneath the earth's surface remains an unknown space. Many geotechnical reports are collected in municipal databases, which result from investigations over many decades. However, in the project's early design and feasibility phase, the information mainly comes from the unorganized accumulation of soil investigation reports rather than an organized database. In this case, Geographic Information Systems (GIS) has proven to be a powerful tool that can be used to store and manage geotechnical data and retrieve and display data when needed [1]. Using these systems, soil data is encoded to analyze it to create geological, geophysical, and engineering geotechnical maps, as these maps can be considered accurate outputs. It can be adopted in the design, construction and implementation of the construction process, thus achieving significant savings in the cost and time spent on site exploration due to readily available information about subsurface conditions. The continuous development of data infrastructure provides a suitable context for project management and planning, and a map can also be created to display the diversity of soil types at any required level determined in advance by specialists. These maps are considered highly valuable in solving expected problems before construction. However, conducting comprehensive site investigations is ultimately necessary to accurately assess ground conditions and provide guidance for geotechnical design. This research aims to create a classification map of the soil for a group of boreholes implemented in Basra Governorate in Iraq. After presenting the results of this research, this approach will be expanded to include the most significant possible amount of areas of the governorate, which will provide a comprehensive database for decision-makers, thus providing an initial understanding. Moreover, the ability to overcome problems before they occur on the work site about the safety of construction workers during drilling. The geotechnical modelling proposed in this study extends to depths of up to 30 meters below the earth's surface, depending on the availability of information at these depths. This paper aims to provide a sufficient and reliable database about the nature of the subsoil, the type of soil, and the extent of its strength at any point in the study. It will be updated in the future according to the availability of information.

The application of GIS in civil and geotechnical engineering has gained broad resonance in the literature. The authors (Hallowell, E.E., Lamont, B.J., Kemp, A.C., and Hughes, J. (2001) identified GIS as a tool in applying GIS in civil and geotechnical engineering and has gained broad resonance in the literature. The authors [2]Components of geographic information systems are databases, analysis of this data, and finally, graphical and pictorial interfaces. A method has been developed for drawing soil maps showing the possibility of swelling occurring in the soil using these systems [3]. The data for this region, as well as digital maps, were used using geographic information systems in order to suggest dividing the maps, as well as evaluating the various processes that caused the soil to swell, and indicating the areas according to the potential risk, where they are classified into areas with high or low risks. These maps help reduce the resulting cost. Of accidents while working on the project and avoiding many potential risks before they occur. Player2066 presented [4] By using geographic information systems applications to identify potential geological risks. The chemical properties were also evaluated in the ghazvin plains of Iran by using geographic information systems and remote sensing [5]. An excellent experimental study was conducted by Williams 2002 in order to verify the possibility of developing geographic information systems in a way that works to improve the management and dissemination of soil information. This method was developed using the results of borehole, which makes obtaining soil data easy [6]. Geographic information systems were applied to create geotechnical and geological maps in Athens, Greece [7] It has also been used in Brazil [8] to manage geotechnical and environmental risks related to oil pipelines

STUDY AREA

The study area is located in Tanomah, an Iraqi town in Basra Governorate, southern Iraq, to the east of the city of Basra on the banks of the Shatt al-Arab near the Iraqi-Iranian border. Tanomah and its areas are considered the densest in the world regarding palm and fruit cultivation. They are located at a longitude of 47.8° and a latitude of 30.5°. It is considered within the alluvial plain region with a climate of hot, dry summers and cool, moderate, rainy winters. Figure (1) shows the location of study area.

Fig. 1 Location of the study area

In recent years, due to the construction of dams, the amount of water reaching the rivers has decreased. Consequently, there has been a lot of fluctuation in river levels, as well as a rise in the salts in the soil and the impact on the cohesion and texture of the soil. Given the development taking place in construction industry processes and the interest in infrastructure, the competent authorities have realized the importance of easy availability of information. From the ground, as it is an important step in construction, it also reduces cost and wastage of time and takes the construction process a step forward.

DATABASE DESCRIPTION

Various categories of data that can be obtained from geotechnical investigation reports, such as Borehole ID, comprise an identification number and essential details about the investigation recorded in the borehole log, such as the project name, location, depth of the borehole, contractor information, and other relevant information. The groundwater table refers to the variation of the water level during drilling or the water depth during the monitoring period. Lithology refers to studying and describing rocks and their composition, structure, and origin. The comprehensive depiction of each stratum, including its thickness, color, consistency, and other relevant characteristics. Further information required for rock formations includes the measurement of spacing, roughness, degree of weathering, aperture, and the composition of infill material within discontinuities.

Fig. 2 (a) Study area with locations of data points and sample path 3D profile by Arcsene
(b) Study area with locations of data points 2D profile

Moreover, testing soil can be defined in two categories. The first one is in-situ tests, which are data acquired from examinations conducted within boreholes. Overall, in situ tests are highly dependable, and numerous empirical correlations have been established globally between their outcomes and the mechanical properties of soils. Moreover, the second one, lab tests, consists of data obtained from laboratory tests conducted on soil and rock samples. In addition to the depth, sampling technique, and soil sample quality, the physical and mechanical characteristics of the specimens are also documented. These data can be expressed as both numerical and alphanumerical values.

Table 1 Statistical descriptors of SPT-N Data

Depth:	D0.5	D9.5	D12	D17	D27	D32
Count:	19	19	19	19	19	19
Minimum:	3	4	4	5	13	18
Maximum:	13	16	31	30	62	83
Sum:	142	180	273	351	694	946
Mean:	7.473684	9.47368	14.3684	18.4737	36.5263	49.7895
St. Deviation:	2.414178	3.45449	6.9222	7.42945	12.963	17.3799

This study presented the results of test drillings taken in Basra Governorate. The distribution of the drilling holes is shown in the figure (2), which shows that the points were distributed regularly within the area of investigation. The information obtained from these test drilling holes was the depth and thickness of each layer and the SPT value. N at different depths, up to 45 meters below the earth's surface, with 19 wells. The depths (0.5-9.5-12-17-27-32) m were chosen for the test holes (1-5-10-11-14-17) to verify the method's validity. Figure (3) shows histogram of SPT data for selected depth and Table.1 shown the statistical descriptors of selected borehole

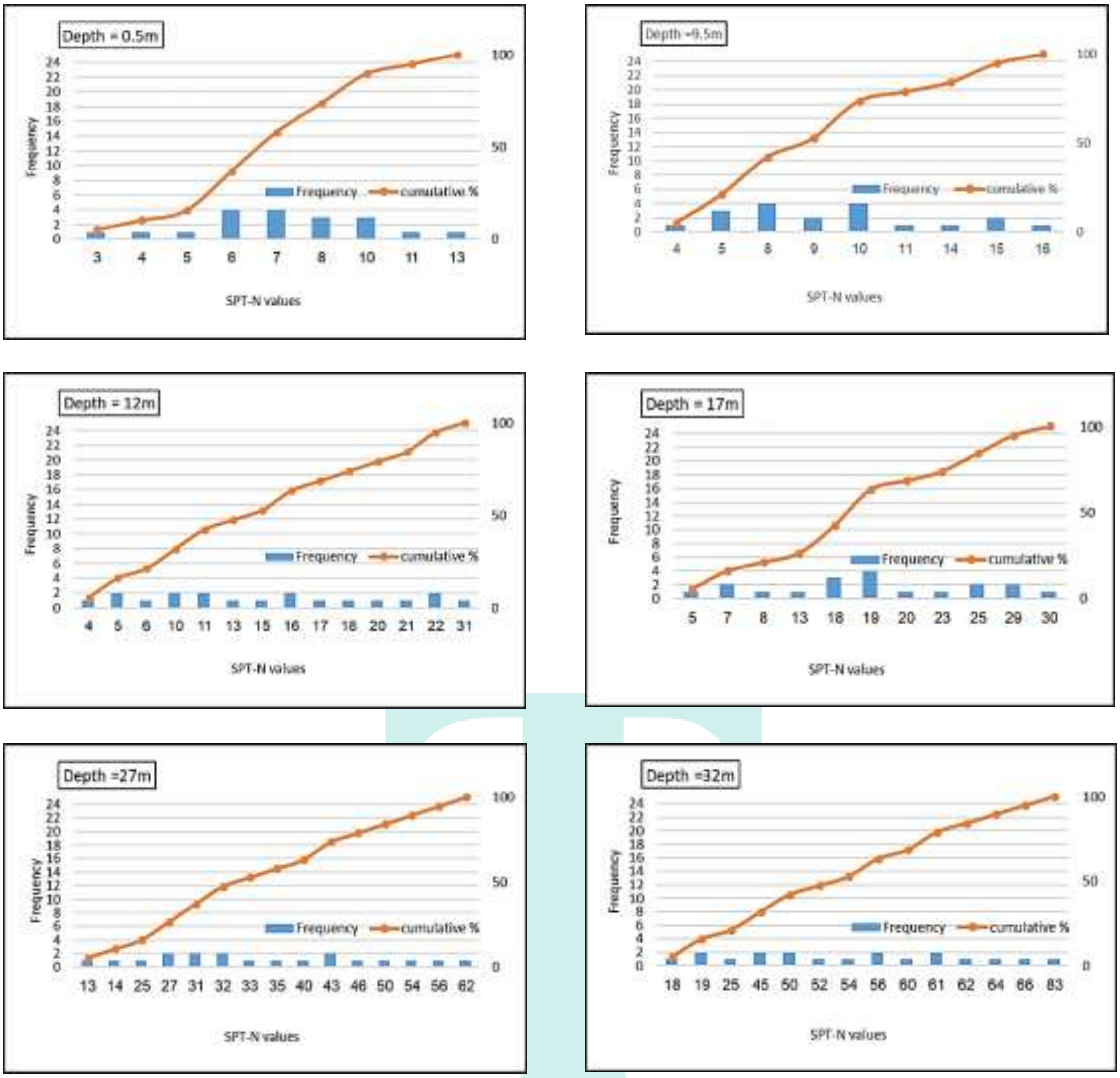


Fig. 3 SPT-N histograms at various depths

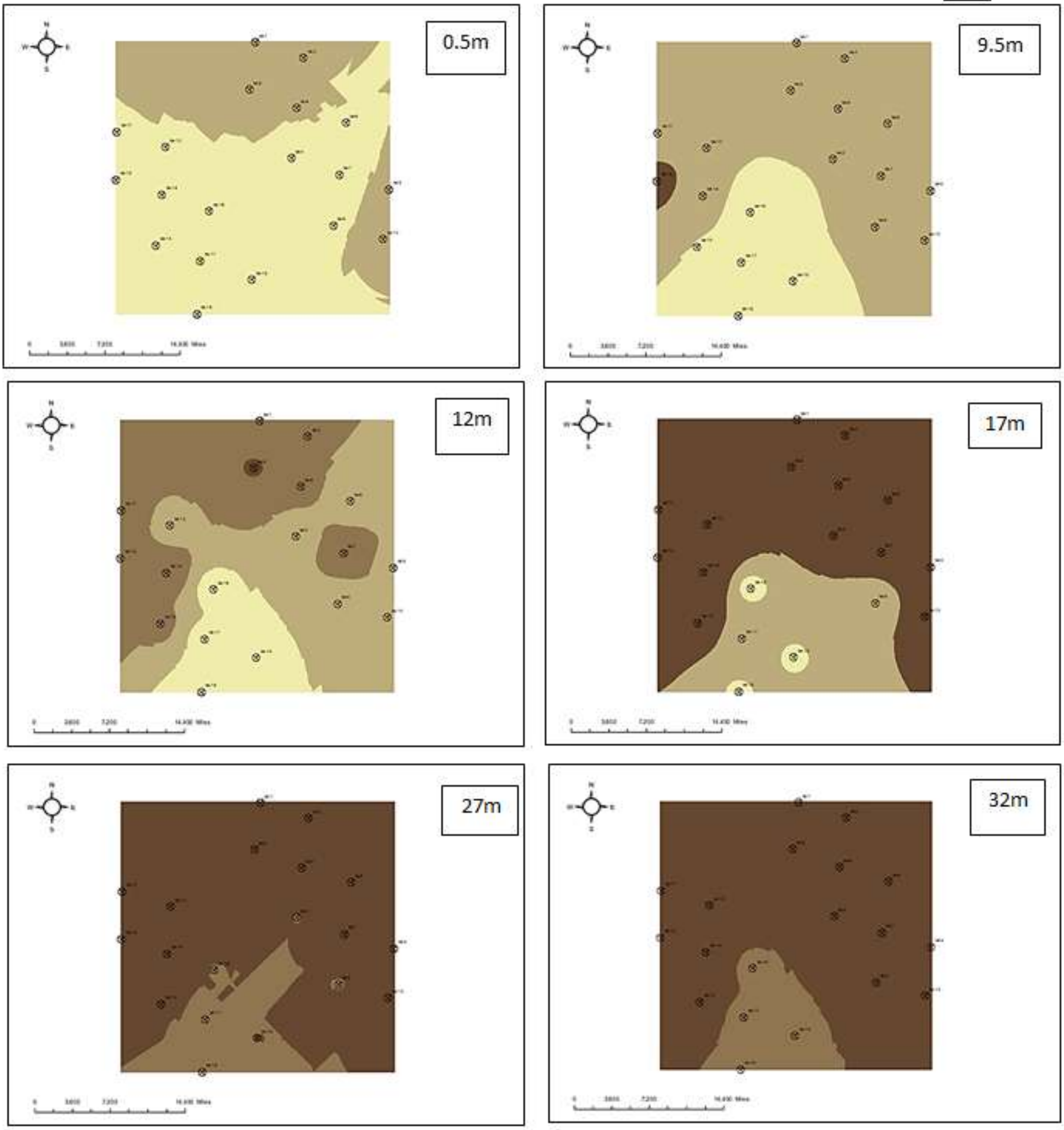
DEVELOPMENT OF ZONATION MAPS

Data was collected from 19 different wells using geotechnical verification reports. The collected data included 332 SPT tests and 360 soil descriptions. The depths, coordinates, SPT values, and soil classification at different depths were clarified and used as input data into ArcMap, which is one of the components of the ArcGIS suite. To prepare soil zonation maps and complete the spatial processing and spatial interpolation process in the table to predict values in unexamined areas. It also allows users to modify geospatial data and search for data within a data set and its representation. Spatial interpolation methods are divided into Geostatistical analysis and spatial analysis. Where the first method includes (Inverse Distance Weighting (IDW)- Diffusion, Global polynomial, and Kernel), while the second method includes (Ordinary kriging, Universal kriging, Spline, and Inverse Distance Weighting) The difference in IDW in the two categories is that within the first category, it is (Output cell size, power, search neighborhood, major semi-axis, minor semi-axis, max. neighbor, min. neighbor, angle), while in the second category, it is (Output cell size, power, search radius (fixed, variable), number of points, max distance)

ZONATION MAPS BASED ON SPT VALUE

The test drilling coordinates were determined using ArcMap, and area classification maps for depths (0.5,9.5,12,17,27,32) m below ground level were created by using spatial interpolation techniques for SPT , test method of SPT test [9] data using the inverse distance weight method, as this technique is considered one of the easiest and simplest methods based on " estimated value of a point is influenced more by nearby known points than by those farther away" [10]. After a comparison presented by (Al-Ani et al. (2014)), it was found that relying on the IDW technique to perform spatial interpolation provides better results and representation of zoning maps according to SPT [11]. The figure (4) shows the zonation of the area according to SPT-N at different depths. These maps generally show that at depths less than 9.5 meters, the SPT value is less than 15, after which the values increase until they reach their maximum value of 90 at a depth of 44.5 meters.

a



	N ≤ 2		4 < N ≤ 8		15 < N ≤ 30
	2 < N ≤ 4		8 < N ≤ 15		N > 30

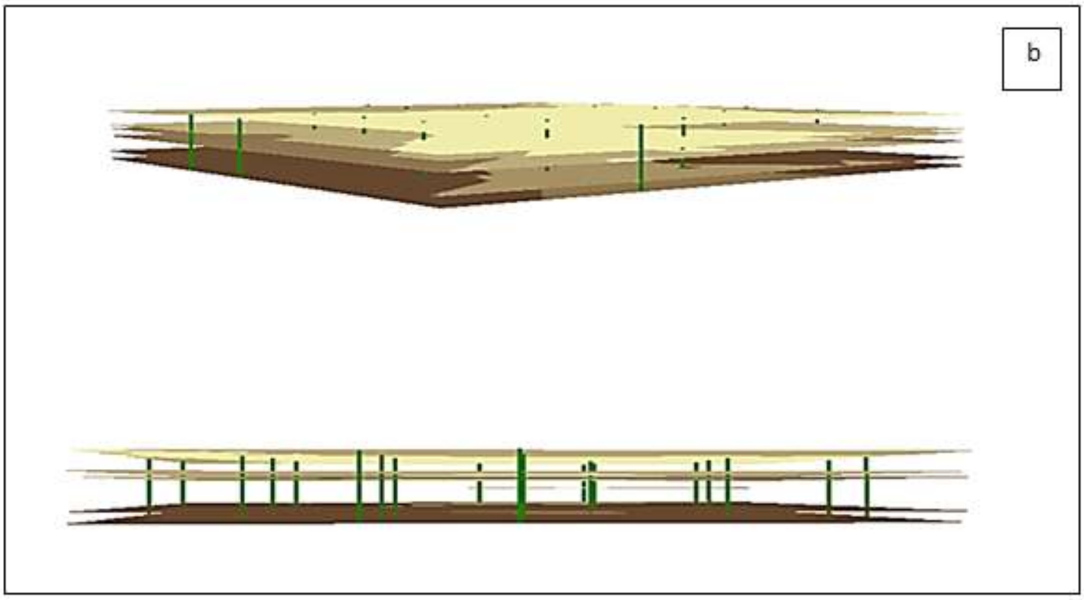
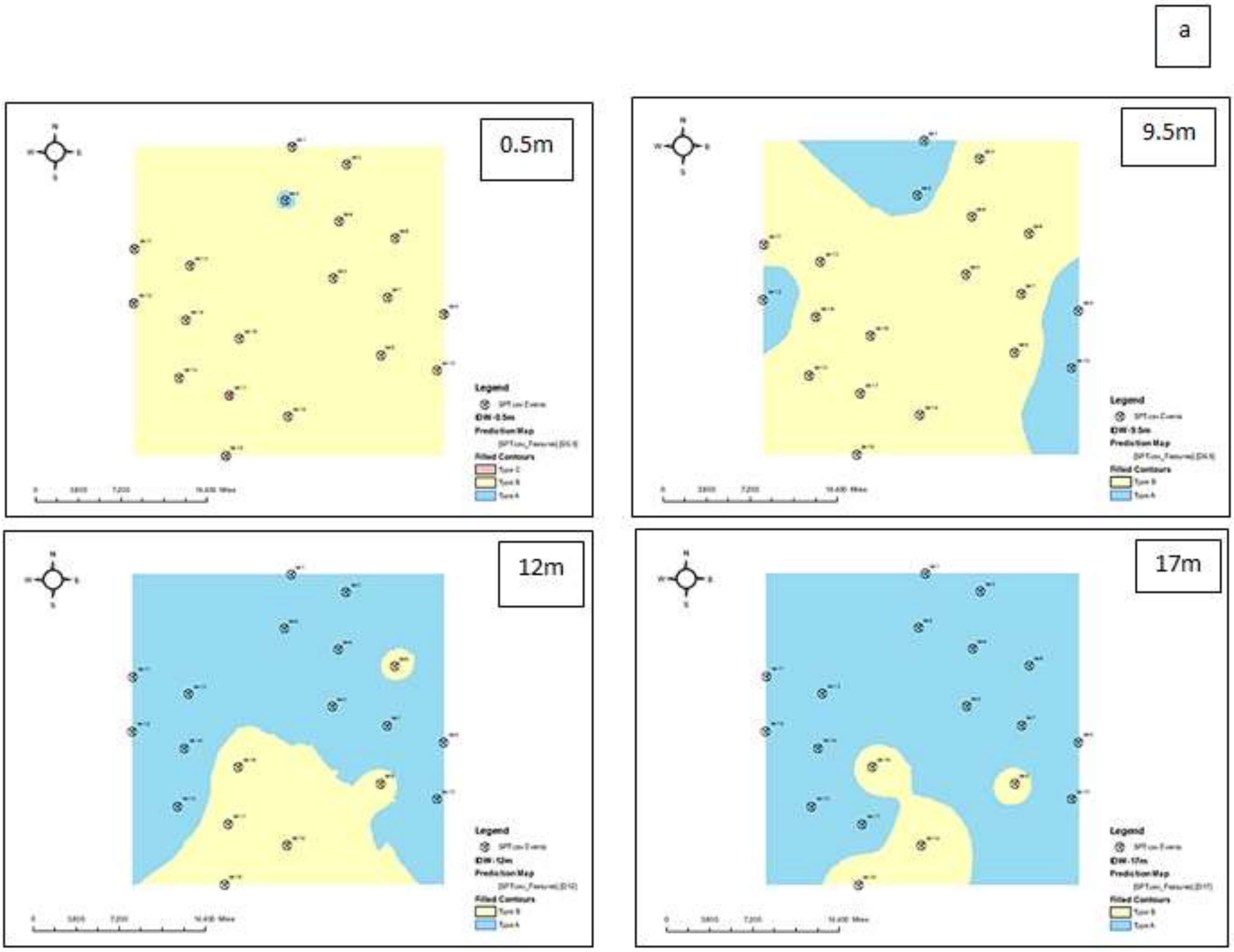


Fig. 4 (a) Zonation maps of study area based on SPT-N values 2D
(b) Zonation maps of study area based on SPT-N values 3D by Arcsene

ZONATION MAPS BASED ON THE OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA-1926 SUBPART P)

Based on The Occupational Safety and Health Administration [12], zoning maps were developed at depths (0.5-9.5-12-17-27) m below the surface of the earth. which were classified into soil type A when (unconfined compressive strength of 1.5 ton per square foot (tsf) (144 kPa) or greater), type B (unconfined compressive strength greater than 0.5 tsf (48 kPa) but less than 1.5 tsf (144 kPa);), and type C (unconfined compressive strength of 0.5 tsf (48 kPa) or less), and the figure (5) displays zoning maps of the study area according to soil type at depths. It was noted that the upper layers consist mainly of type B soil, extending from a depth of (9.5m) and less. And then, at greater depths, it consists of type A.



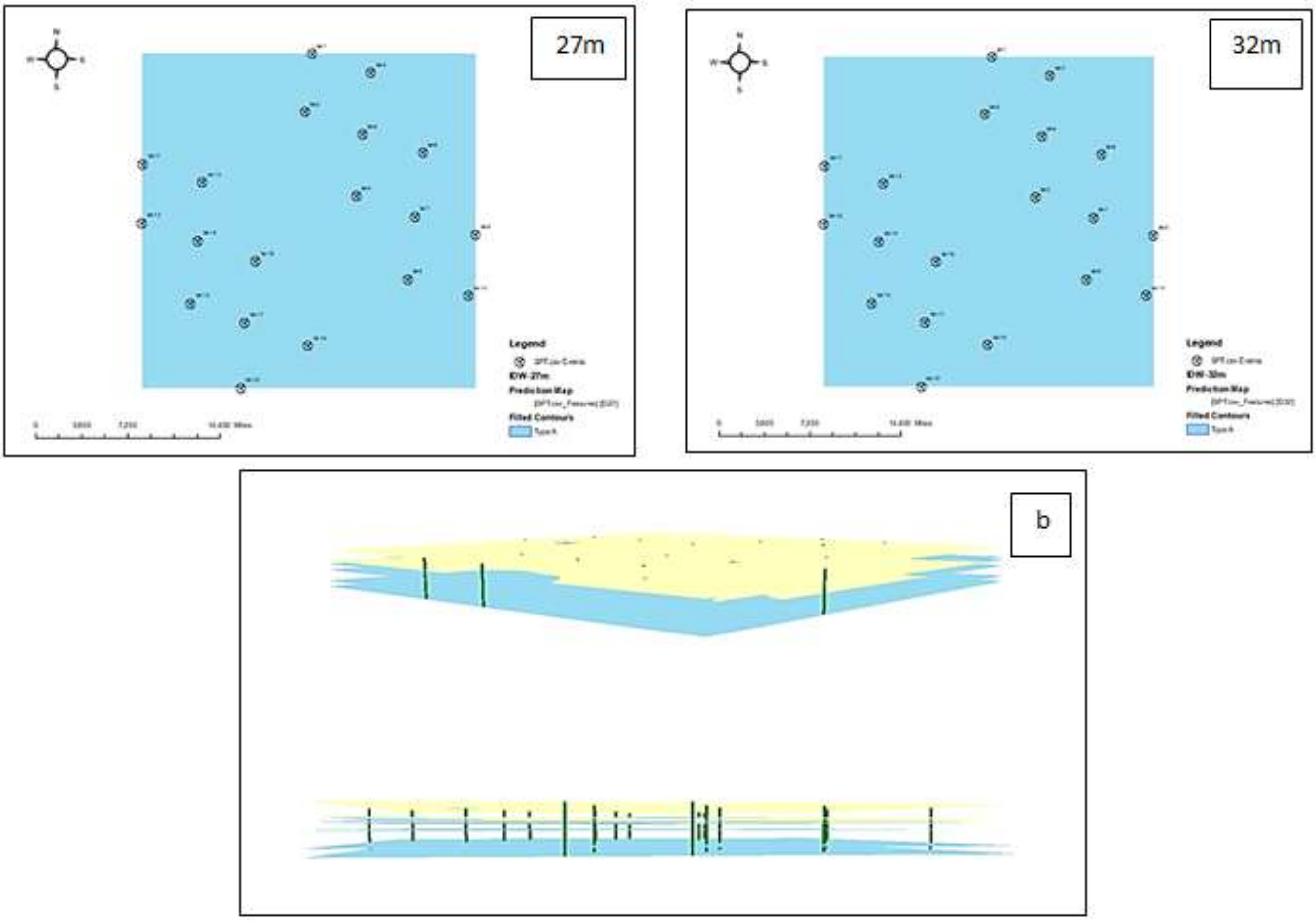


Fig. 5 (a) Zonation maps of study area based on (OSHA) 2D
(b) Zonation maps of study area based on (OSHA) 3D by Arcsene

VALIDATION OF ZONATION MAPS

Of the total of 19 test wells, 13 were used to prepare zoning maps, and the remaining were used to verify the spatial and residual interpolation process for specific locations and depths. The figure (6) shows the comparison between the expected and actual values taken from drilling logs, and the table (2) represents the comparison between the expected and actual soil types. The clarified one does not make any difference or differences in the proposed geotechnical design regarding the foundation selection process. Likewise, these maps are intended to study the project's feasibility during the initial design phase. Detailed project verification regarding geotechnical investigations for the final design will always be conducted.

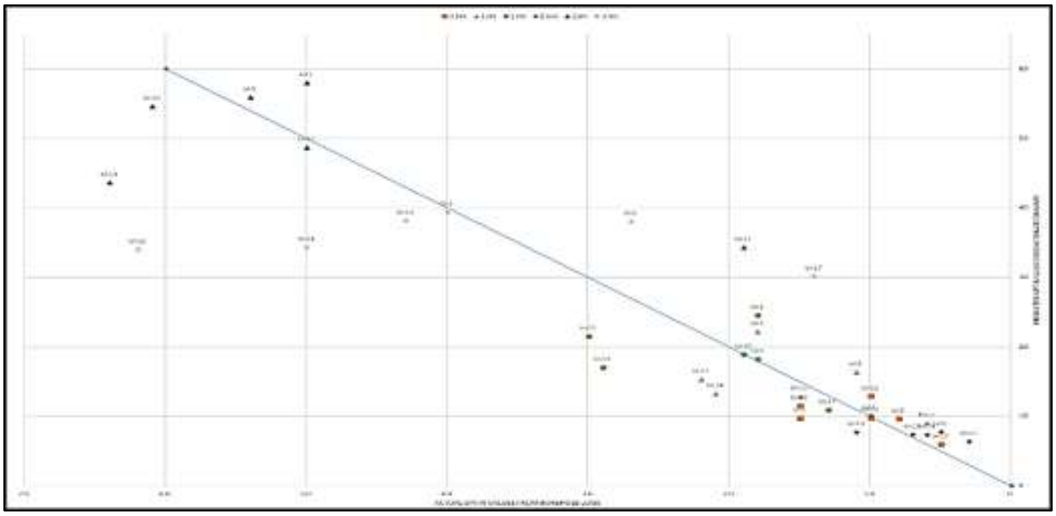


Fig. 6 Comparison of predicted and actual SPT-N values

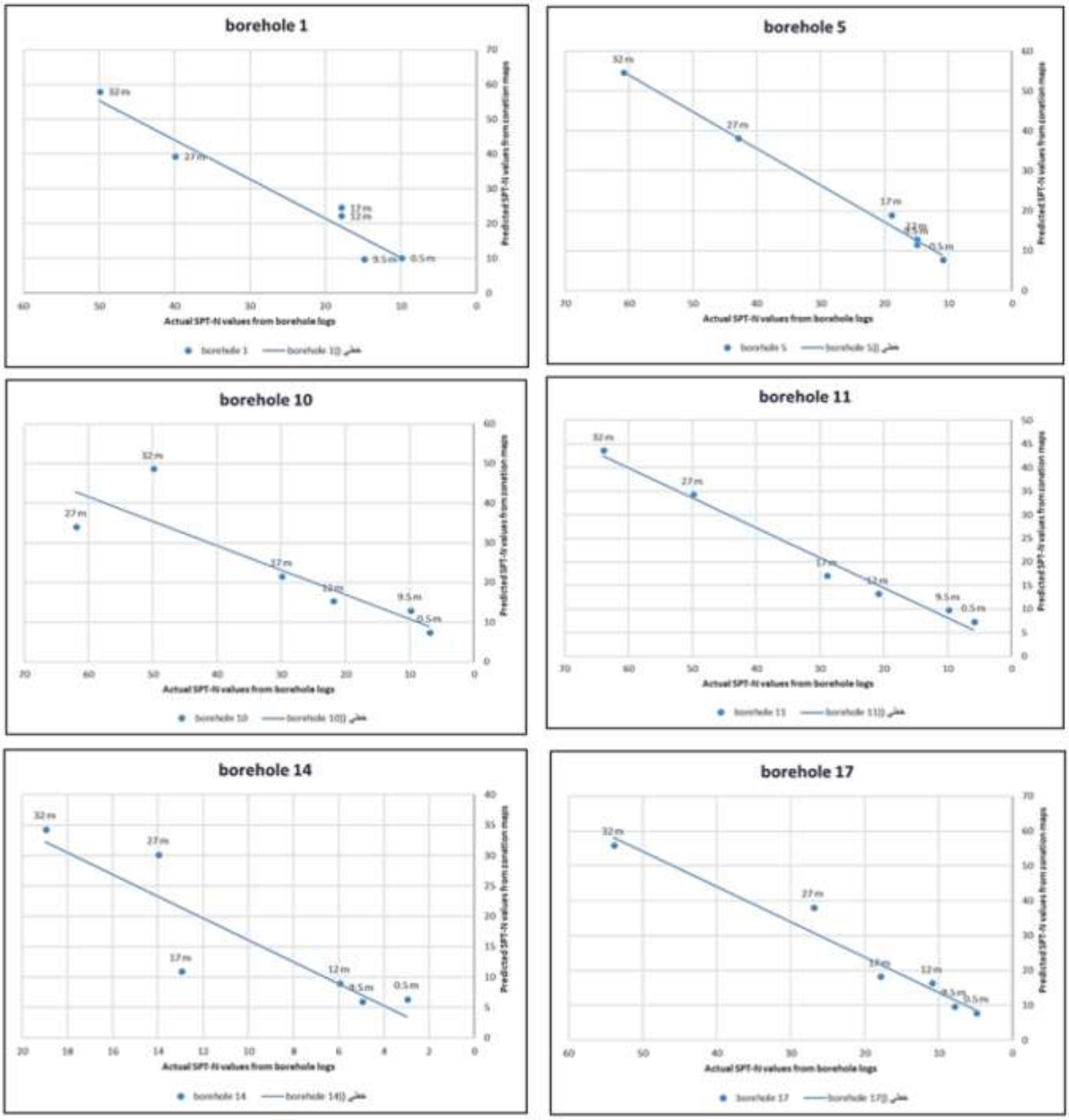


Fig. 7 Linear regression analysis for different borehole

Table 2 Comparison of predicted and actual soil types according to OSHA

Depth (m)	BH-1		BH-5		BH-10	
	A	P	A	P	A	P
0.5	Type B	Type B	Type B	Type B	Type A	Type B
9.5	Type A	Type B	Type B	Type B	Type A	Type A
12	Type A	Type A	Type A	Type A	Type A	Type A
17	Type A	Type A	Type A	Type A	Type A	Type A
27	Type A	Type A	Type A	Type A	Type A	Type A
32	Type A	Type A	Type A	Type A	Type A	Type A
Depth (m)	**BH-11**		**BH-14**		**BH-17**	
	A	P	A	P	A	P
0.5	Type B	Type B	Type B	Type B	Type C	Type B
9.5	Type B	Type A	Type B	Type B	Type B	Type B
12	Type A	Type A	Type A	Type A	Type B	Type B
17	Type A	Type A	Type A	Type A	Type A	Type B
27	Type A	Type A	Type A	Type A	Type A	Type A
32	Type A	Type A	Type A	Type A	Type A	Type A

P: Predicted soil type from zonation maps; A: Actual soil type from borehole log
Highlighted text shows the actual and predicted soil type doesn't match

CONCLUSIONS

The goal of this research paper is to clarify the appropriate and safe areas for construction, as well as to take the necessary measures during the drilling process through the use of geotechnical maps that are produced from geographic information systems, as well as to benefit from these maps in order to provide a wide database that includes geotechnical information that can be used. Including when planning to conduct geotechnical investigations for the proposed project for the study area. The results of this study were as follows:

1- From the area classification maps, it is clear that the areas occupying depths of less than 9.5 meters consist mainly of soil with an LL of less than 50 and a PI of greater than 7 with an average SPT value of 13, meaning that the soil ranges from medium stiff to stiff, which It represents approximately Type B

2- It appears from the maps that the areas at depths of more than 9.5 meters begin to be gradually represented by type A soil, with average SPT values ranging between 35 up to a depth of 22 meters, and begin to increase gradually to reach high values of up to 80, where the soil is mainly composed of type A soil. That is, between Very stiff and Hard soil, which is very suitable for most engineering structures

3- It is planned to improve the process of verifying the spatial interpolation processes presented in the research paper by increasing the number of points taken in the area and adding more geotechnical tests conducted in the study area.

4- The maps presented in this study will likely be useful in the preliminary investigation stage to provide some important information about the soil layers required for the design stage of engineering foundations and in planning earthworks. However, the need remains to conduct a comprehensive investigation to reach a comprehensive interior vision of the earth

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REFERENCES

1. Mohamed and A. El-Rahman Shehata, "GIS Application in Documenting and Analyzing Architecutal Heritage."
2. E. E. Hellawell, J. Lamont-Black, A. C. Kemp, and S. J. Hughes, "GIS as a tool in geotechnical engineering," *Proceedings of the Institution of Civil Engineers - Geotechnical Engineering*, vol. 149, no. 2, pp. 85–93, Apr. 2001, doi: 10.1680/geng.2001.149.2.85.
3. Orhan and H. Tosun, "Visualization of geotechnical data by means of geographic information system: A case study in Eskisehir city (NW Turkey)," *Environ Earth Sci*, vol. 61, no. 3, pp. 455–465, 2010, doi: 10.1007/s12665-009-0357-1.
4. R. S. V Player, "Geographic Information System (GIS) Use in Geotechnical Engineering," in *GeoCongress 2006*, pp. 1–6. doi: 10.1061/40803(187)123.
5. Bostani, M. Salahedin, M. M. Rahman, and D. N. Khojasteh, "Spatial Mapping of Soil Properties Using Geostatistical Methods in the Ghazvin Plains of Iran," *Mod Appl Sci*, vol. 11, no. 10, p. 23, Sep. 2017, doi: 10.5539/mas.v11n10p23.
6. T. Williams, M. Patrick Szary, M. T. Thomann, M. C. Konnerth, and M. E. Nemeth, "GIS APPLICATIONS IN GEOTECHNICAL ENGINEERING," 2002.
7. A. Antoniou, A. G. Papadimitriou, and G. Tsiambaos, "A geographical information system managing geotechnical data for Athens (Greece) and its use for automated seismic microzonation," *Natural Hazards*, vol. 47, no. 3, pp. 369–395, 2008, doi: 10.1007/s11069-008-9226-6.
8. O. Augusto Filho, J. Hirai, A. Oliveira, and E. Liotti, "GIS applied to geotechnical and environmental risk management in a Brazilian oil pipeline," *Bulletin of Engineering Geology and the Environment*, vol. 69, pp. 631–641, Nov. 2010, doi: 10.1007/s10064-010-0310-2.
9. "Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils 1", doi: 10.1520/D1586_D1586M-18E01.
10. K.-T. Chang, *Introduction to geographic information systems*.
11. H. Al-Ani, E. Oh, L. E. Andargoli, and G. Chai, "Subsurface Visualization of Peat and Soil by using GIS in Surfers Paradise," 2014. [Online]. Available: https://www.researchgate.net/publication/259179085
12. "Title: Safety and Health Regulations for Construction Title: Soil Classification GPO Source: e-CFR Appendix A to Subpart P of Part 1926-Soil Classification."