Salud, Ciencia y Tecnología - Serie de Conferencias. 2024; 3:843
doi: 10.56294/sctconf2024843

Category: STEM (Science, Technology, Engineering and Mathematics)

ORIGINAL

Using GIS Tools for the Prediction of Bearing Capacity of shallow footing (qu) and Undrained Shear Strength (Su) values for Falluja City's Soils

Utilización de herramientas SIG para la predicción de la capacidad portante de las zapatas poco profundas (qu) y los valores de resistencia al corte no drenado (Su) de los suelos de la ciudad de Faluya

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Cite as: Abood MY, Aljanabi KR, Sayl K. Using GIS Tools for the Prediction of Bearing Capacity of shallow footing (qu)and Undrained Shear Strength (Su) values for Falluja City's Soils. Salud, Ciencia y Tecnología - Serie de Conferencias. 2024; 3:843. https://doi.org/10.56294/sctconf2024843

Submitted: 27-01-2024 **Revised:** 14-04-2024 **Accepted:** 06-07-2024 **Published:** 07-06-2024

Editor: Dr. William Castillo-González

Note: Paper presented at the 3rd Annual International Conference on Information & Sciences (AICIS'23).

ABSTRACT

Geotechnical engineering, similar to other branches of engineering, must adapt and progress in accordance with contemporary technological advancements. The present investigation endeavors to examine the spatial correlations between soil characteristics, such as Undrained Shear Strength (Su) and Bearing Capacity of shallow footing (qu), across various regions within the city of Falluja. This city experienced significant infrastructure devastation subsequent to the year 2017, necessitating the need to keep up with the rapid development occurring in this locality. Consequently, it is imperative to devise the most expeditious means of acquiring preliminary data at the most cost-effective rate and within the shortest timeframe. For this study, The NOVOSPT was used to test and evaluate the (SPT) standard penetration test readings to obtain the values of soil properties for the research area using the 149 test holes in the study area. These values were used to generate a digital geotechnical map of the urban area utilizing the Geographic Information System (GIS). This map accurately depicts the spatial distribution of geotechnical characteristics that can be promptly accessed whenever required, thereby resulting in time and cost savings for engineers.

Keywords: Soil Properties; Geographic Information System (GIS); Bearing Capacity(Qu); Undrained Shear Strength (Su).

RESUMEN

La ingeniería geotécnica, al igual que otras ramas de la ingeniería, debe adaptarse y progresar de acuerdo con los avances tecnológicos contemporáneos. La presente investigación pretende examinar las correlaciones espaciales entre las características del suelo, como la resistencia al corte no drenado (Su) y la capacidad portante de las zapatas superficiales (qu), en varias regiones de la ciudad de Faluya. Esta ciudad experimentó una importante devastación de infraestructuras después del año 2017, lo que hace necesario mantener el ritmo del rápido desarrollo que se está produciendo en esta localidad. En consecuencia, es imperativo idear los medios más expeditivos para adquirir datos preliminares al ritmo más rentable y en el plazo más breve. Para este estudio, se utilizó el NOVOSPT para probar y evaluar las lecturas de la prueba de penetración estándar (SPT) para obtener los valores de las propiedades del suelo para el área de investigación utilizando los 149 agujeros de prueba en el área de estudio. Estos valores se utilizaron para generar un mapa geotécnico digital de la zona urbana utilizando el Sistema de Información Geográfica (SIG). Este mapa representa con precisión la distribución espacial de las características geotécnicas, a las que se puede acceder rápidamente siempre que sea necesario, con el consiguiente ahorro de tiempo y costes para los ingenieros.

Palabras clave: Propiedades del Suelo; Sistema de Información Geográfica (SIG); Capacidad Portante (Qu); Resistencia al Corte no Drenado (Su).

INTRODUCTION

Soils play a crucial role in the preservation of ecosystems and human society. They not only serve as a limited and precious resource, but they also exhibit a wide range of characteristics and behaviors.(1,2) In almost every aspect of geotechnical design, the quality of soil holds significant importance. Numerous techniques, such as field investigations and laboratory tests, have been devised to assess soil quality. To determine the precise values of these properties, an intact sample is collected. However, due to the challenges associated with acquiring completely undisturbed samples caused by intense pressure and unfavorable testing conditions, field experiments like Standard Penetration Tests (SPT) are conducted to evaluate soil properties.(3) It's worth noting that the NOVASPT program employed the SPT test to obtain the values of soil parameters for the research region.

Soil, commonly referred to as "Earth," denotes the terrestrial realm in which we reside. Several constituents of the terrestrial expanse predate the third geological epoch, although the majority does not predate the Pleistocene epoch, a subsequent glacial era.(4) In order to effectively handle the design consequences of land utilization in expanding urban areas, it is imperative to conduct a comprehensive analysis and accurate evaluation of the spatial diversification of geological and geotechnical characteristics of soils and groundwater.(5,6,7)

The conventional method of acquiring data in the field of geotechnical practice can often be a time-consuming endeavor. There are preexisting sources of data available, encompassing maps, reports from site inspections, instructions, and even various forms of media, whether in electronic or physical form, that can be amalgamated. It is conceivable that by utilizing the GIS digital mapping platform, the organization's efficiency and performance could be enhanced, thereby potentially reducing the amount of time required.(8,9,10,11,12,13) To perform geotechnical assessments quickly and efficiently over vast areas, a geographic information system (GIS) is a must-have tool.(9,14,15) A GIS's ability to generate new information by combining heterogeneous data sets with a compatible GIS is a crucial advantage.(12,16,17,18,19)

Various publications have recently sought methods to enhance the management of geotechnical engineering data through the utilization of the spatial-location correlation of soil characteristics obtained via the SPT report. and organize it in a geotechnical database for use as a tool to aid in procedure planning and administration.(4,16,20)

Literature Review

Developing a digital geotechnical map for Falluja city using GIS is a topic that has garnered attention in the field of geotechnical engineering and urban planning. The integration of GIS technology with geotechnical data provides valuable insights into the geological and geotechnical characteristics of an area, aiding in infrastructure development, hazard assessment, and land-use planning. Several studies have explored the application of GIS in developing digital geotechnical maps for various regions. Al-Bazi et al. (2018) conducted a study on Al-Qadisiyah Governorate in Iraq, where they developed a geotechnical map using GIS techniques. The study demonstrated the effectiveness of GIS in analyzing slope stability and designing foundations, showcasing its potential for similar projects in Falluja city.(21)

Behnia et al. (2019) focused on the development of a digital geotechnical map for urban areas in Iran using GIS. The research highlighted the role of GIS in geotechnical hazard assessment and land-use planning, emphasizing its significance in understanding the subsurface conditions and making informed decisions regarding infrastructure development and urban growth.(22)

In addition to the studies, other researchers have also explored the integration of GIS and geotechnical data. For example, Huang et al. (2017) utilized GIS to develop a digital geotechnical map for a region in China(23), Alaa & dr. Khamees et al. (2023) utilized GIS to develop a digital geotechnical map for a region in Ramadi city(23). enabling the identification of potential geological hazards and the planning of appropriate mitigation strategies. Mamdooh, et al., (2018) utilized GIS to develop a digital geotechnical map for a region in Ramadi city(24). Mohammed et al (2021) used GIS to develop Geotechnical map of Thi Qar governorate(6). Similarly, Sharma et al. (2019) implemented GIS techniques to create a digital geotechnical map for an urban area in India(25), providing valuable insights for urban planners and engineers in managing geotechnical risks. These studies collectively highlight the significance of developing digital geotechnical maps using GIS for effective urban planning and infrastructure development. However, there is a research gap specifically pertaining to Falluja city. Given the unique geology and soil conditions in Falluja, it is essential to undertake a comprehensive study to develop a digital geotechnical map tailored to the city's specific needs. By addressing this research gap, the current study aims to contribute to the development of a digital geotechnical map for Falluja city using GIS. The map will integrate geological data, soil properties, and geotechnical information to provide valuable insights for urban planners, civil engineers, and decision-makers, enabling them to make informed decisions regarding infrastructure development, land-use planning, and hazard mitigation.

Study objectives

This work aims to develop a thematic map of the study area to estimate the (qu) Bearing Capacity of shallow footing and the (Su) Undrained Shear Strength at different depths.

The study area

AL- Fallujah is a city located in Anbar Governorate, about sixty kilometers northwest of the capital, Baghdad, east of Ramadi, at a distance of 45 kilometers. Its municipal boundaries encompass an area of 4205 km2 . The research area's elevation ranges from 20 to 35 meters above sea level, with coordinates Longitude (33^0 18′to 33^0 50′) N and longitude (43^0 45′to 43^0 50′) E. The soils of Falluja is a mixture of sand, clay,silt and gravel, but the percentage of sand is the highest, according to soil investigation reports . The Falluja city was chosen after being vandalized by the terrorist organization and is currently undergoing renovations. As a result, the region requires constructing a more significant number of structures. As a result, the possibility of significant subsidence of the Earth can be met, as well as the need to make quick initial decisions at a low cost.

METHODOLOGY

The study's methodology was divided into four distinct stages. The initial stage encompassed field research and the selection of laboratory tests. A feasibility survey was conducted to gather data on the study area, resulting in the collection of 149 experimental borehole from 22 September to 10 December 2022. The findings from the SPT test were compiled using Microsoft Excel. The pilot hole pits were strategically distributed across the study area to determine the most suitable cross-section for analysis. Excavation depths ranged from 1,5, 3, 4,5, 6, 7,5, and 9 meters. In the second stage, the data obtained from the SPT examination was analyzed using the NOVASPT program to extract relevant soil properties. The third stage involved digitizing and creating an ArcGIS study area map. A geodetic satellite and Google Earth were utilized to obtain a digital photograph of the area. GPS (GARMIN 64s) coordinates were gathered for borehole and used in the map. The research concluded by establishing a database and conducting an analysis of the results. The map database had already been established, and the results were entered accordingly(Allawiet al., 2023). The map has been updated to reflect the latest findings.[26]

Data collection

The initial phase of the approach is data collection. This data was collected from multiple sources, which encompassed consulting engineering offices(collected from the soil test laboratories at the University of Anbar), private contracting companies, and various offices. Data collection is an indispensable step in attaining optimal outcomes. Data were gathered from 149 wells dispersed throughout the eastern region of Falluja, at depths ranging from(0-1,5, 1,5-3, 3-4,5, 4,5-6, 6-7,5, and7,5-9) meters. Data collection and processing (next stage) can be combined into a single procedure. It is one of the most time-consuming procedures and requires preparation in advance. To produce a GIS database for the study region, hole sites were projected onto the rectified image; an attribute data of geotechnical parameters were recorded for each borehole in the study area by using the ArcMap9.2 as shown in figure 1.

Data analysis

Soil samples extracted from the designated study region were meticulously gathered for the purpose of analysis. The standard penetration test (SPT) was systematically executed on these specimens by the researchers [16,27,28] who employed this characteristic to delineate their respective areas of investigation the samples were obtained from engineering firms. This test is widely utilized globally for subsurface drilling. Subsequently, the data can be organized using Microsoft Excel. The analysis of SPT results in the SPT NOVA statistical program and the extraction of soil parameters (such as qu, Su, etc.) determine the usefulness of the results. The ability to perform procedures that relate the value of one site to those of multiple locations is the true advantage of employing spatial analysis of in-situ data, which requires knowledge of the properties of the soil being tested. For instance, the use of ArcMap 9.2 allows for the representation of differences in geotechnical features across a given depth using GIS capabilities. This representation is displayed as thematic maps that present value fluctuations through gradient hues, thereby enhancing users' understanding of the distribution.

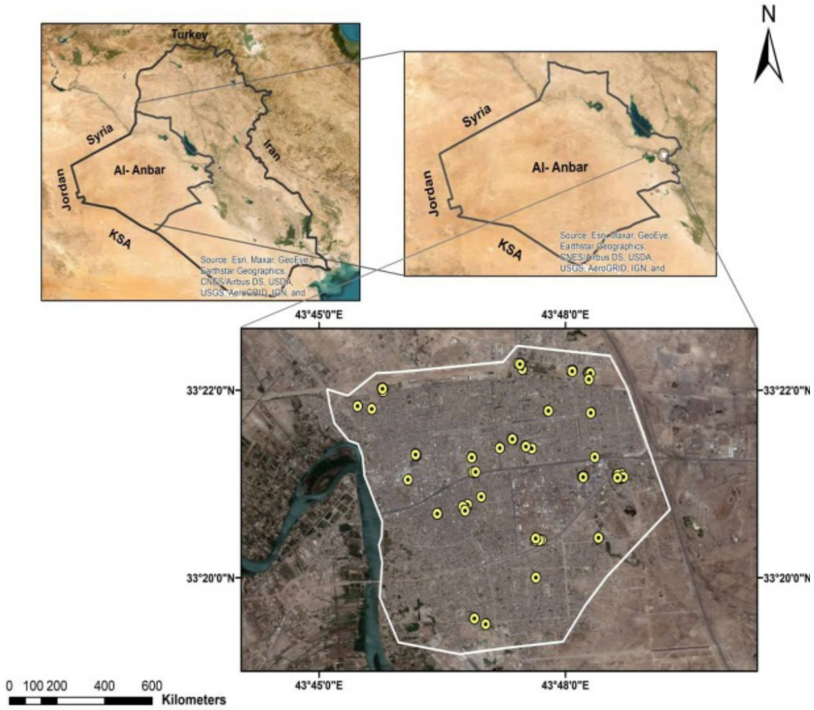


Figure 1. A digital photo map of the study area borehole locations

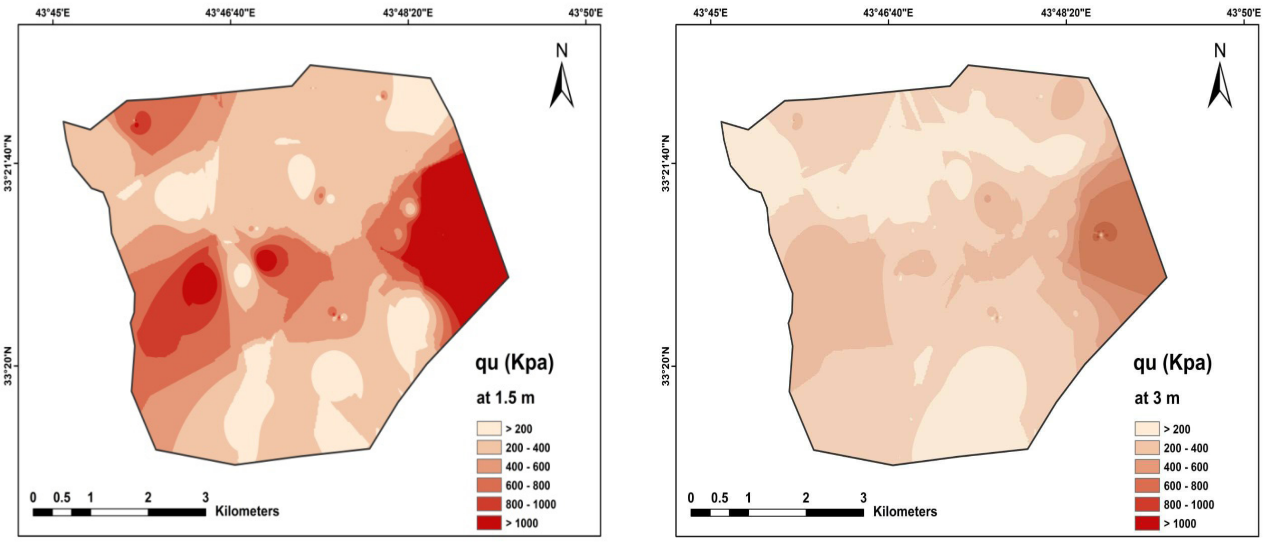
RESULTS AND DISCUSSION

The GIS's Bearing Capacity (qu)

Bearing capacity is a crucial parameter in geotechnical engineering as it determines the stability and safety of structures built on or in the ground.[29] The bearing capacity of soil or rock depends on factors such as strength, density, and deformation properties. Several studies have been conducted to investigate the bearing capacity of different materials and structures. Raskar et al.(2016) developed bearing capacity standards for forest roads constructed using various technologies[13], considering factors such as traffic intensity, operation time, soil conditions, and construction material. Figure 2 and table1show the spatially distributed of bearing capacity(qu) and their percentages with depths for study area.

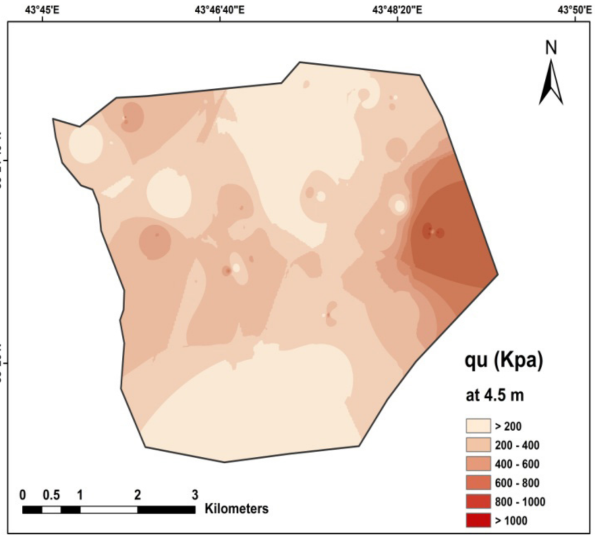
Zoning Maps on Shear Strength(su)

The load of the building generates shear stress, which can be assimilated by the earth. These strength parameters of the soil, known as shearing soil strength parameters, serve as descriptors for this strength. The application of shear stress induces a state of reduced stability in any type of soil. The imposition of weight may cause the soil to undergo stretching or contraction.[30] Figures 3 and 4 show the spatially distributed of undrained shear strength of clay and their percentages with depths for study area.

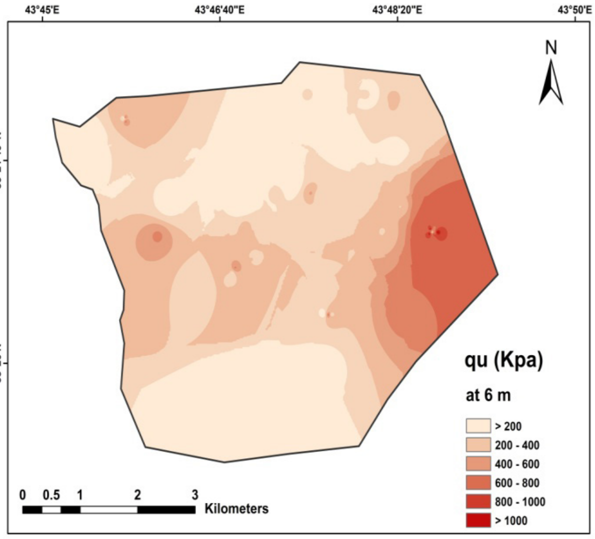


(a) 1,5m Bearing Capacity of shallow footing (b) 3m Bearing Capacity of shallow footing

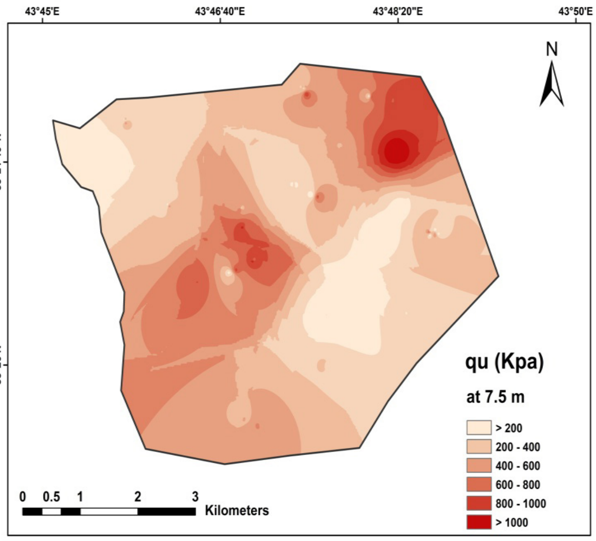
https://doi.org/10.56294/sctconf2024843



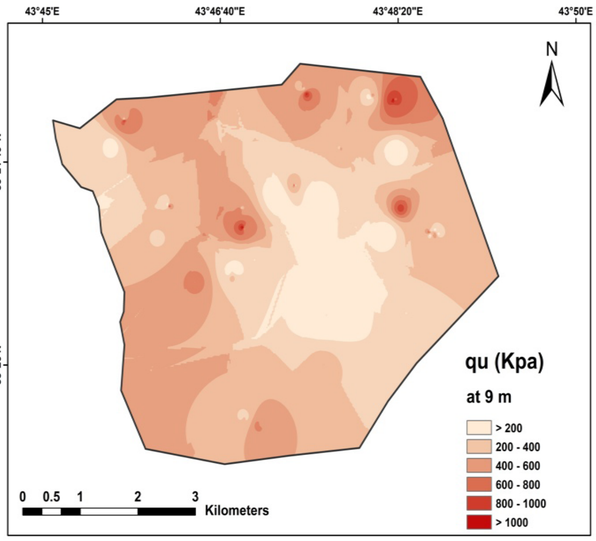
(c) 4,5 m Bearing Capacity



(d) 6m Bearing Capacity

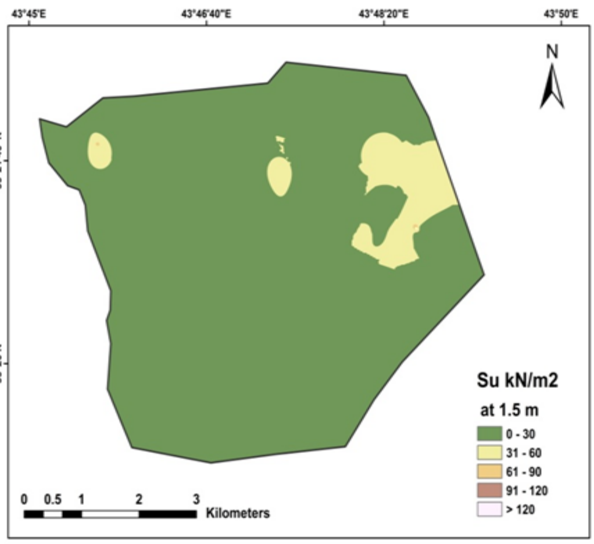


(e) 7,5m Bearing Capacity

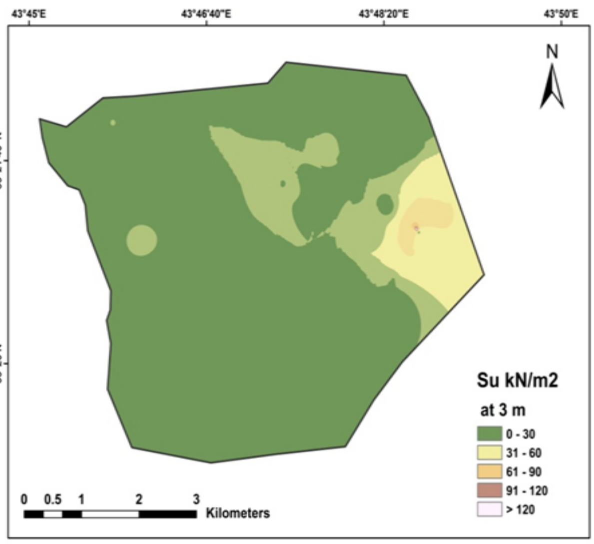


(f) 9m Bearing Capacity

Figure 2. The study area's Bearing Capacity map according to (a) 1,5 depth, (b) 3 depth, (c) 4,5 depth, (d) 6 depth, (e) 7,5 depth, (f) 9 depth



(a)1,5m Undrained Shear Strength



(b) 3 m Undrained Shear Strength

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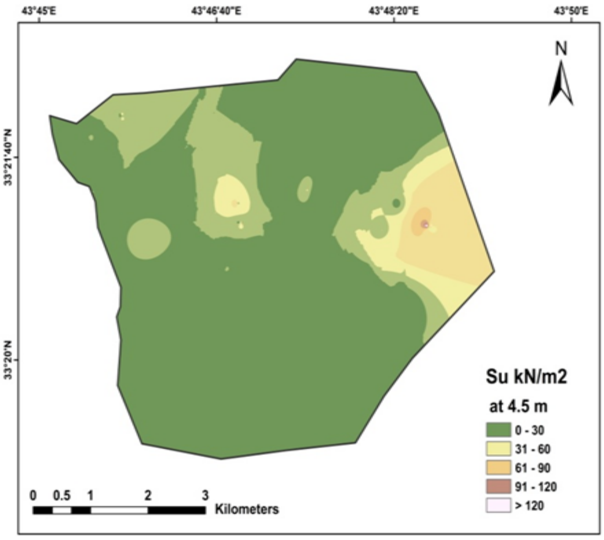
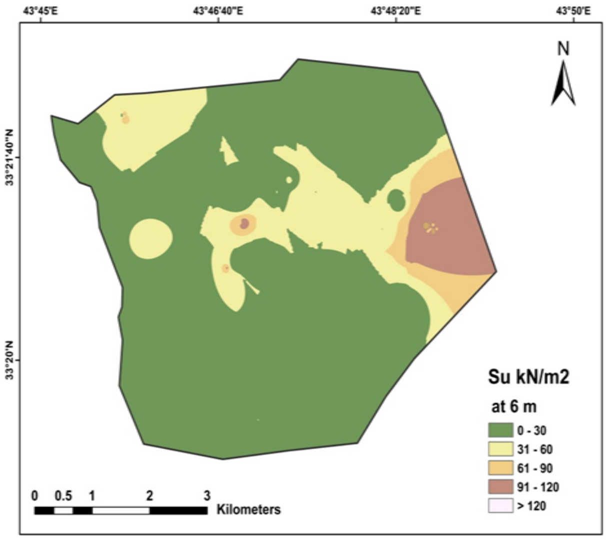
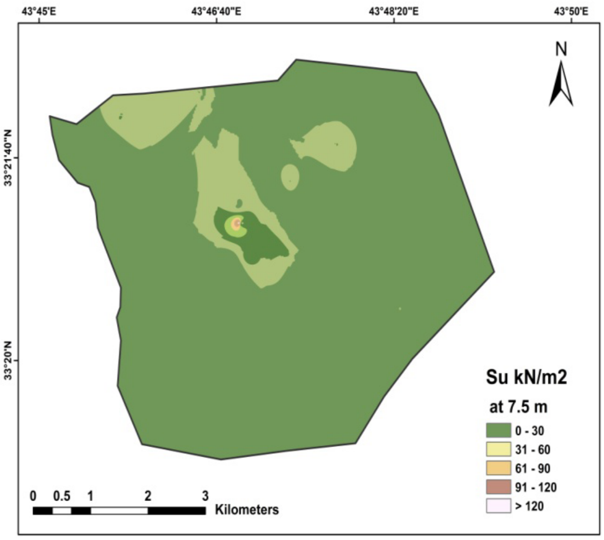


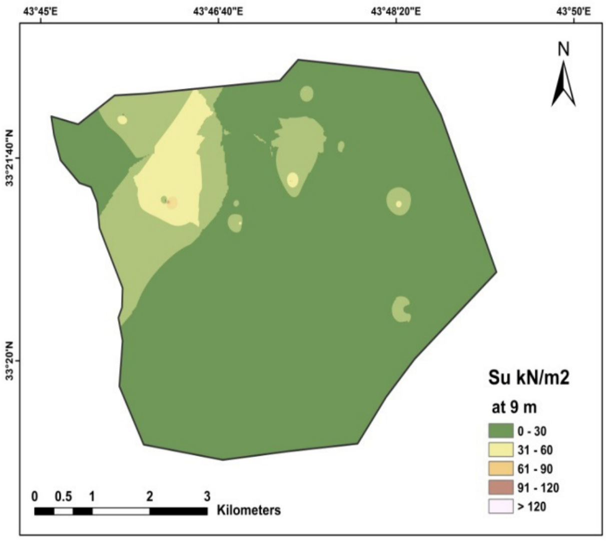
(c) 4,5m Undrained Shear Strength



(d) 6m Undrained Shear Strength



(e) 7,5 m Undrained Shear Strength



(f) 9m Unddrained Shear Strength

Figure 3. Undrained Shear Strength map according to (a) 1,5 depth,(b) 3 depth, (c) 4,5 depth, (d) 6 depth, (e) 7,5 depth, (f) 9 depth

Depth																	
1.5			3			4.5			6			7.5			9		
Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)
< 200	0.13027	3.583	< 200	0.17768	4.887	< 200	0.28701	7.894	< 200	0.36871	10.141	< 200	0.113	3.121	< 200	0.1362	3.746
200- 400	0.39816	10.951	200- 400	0.47568	13.083	200- 400	0.26763	7.361	200- 400	0.26556	7.304	200- 400	0.235	6.451	200- 400	0.1895	5.212
400 -600	0.19354	5.323	400 -600	0.15812	4.349	400 -600	0.17437	4.796	400 -600	0.15721	4.324	400 -600	0.191	5.247	400 -600	0.2304	6.337
600 - 800	0.09002	2.476	600 - 800	0.08464	2.328	600 - 800	0.05894	1.621	600 - 800	0.05316	1.462	600 - 800	0.182	5.013	600 - 800	0.28683	7.889
800 - 1000	0.05359	1.474	800 - 1000	0.10388	2.857	800 - 1000	0.07566	2.081	800 - 1000	0.14314	3.937	800 - 1000	0.165	4.543	800 - 1000	0.04857	1.336
> 1000	0.13442	3.697	> 1000	0	0	> 1000	0.13638	3.751	> 1000	0.01222	0.336	> 1000	0.114	3.129	> 1000	0.10849	2.984
	1	27.504		1	27.504		1	27.504		1	27.504		1.000	27.504		1	27.504

Figure 4. Variation of Bearing Capacity and their percentage with depth (1,5, 3, 4,5, 6, 7,5, and 9 m)

Depth																	
1.5			3			4.5			6			7.5			9		
Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)	Rage (Hits)	Percentage	Area (Km)
0 - 30	0.88576	24.362	0 - 30	0.73615	20.247	0 - 30	0.71302	19.611	0 - 30	0.71346	19.623	0 - 30	0.976	26.849	0 - 30	0.85918	23.631
31 - 60	0.11424	3.142	31 - 60	0.11315	3.112	31 - 60	0.11358	3.124	31 - 60	0.13631	3.749	31 - 60	0.015	0.403	31 - 60	0.12533	3.447
61 - 90	0	0	61 - 90	0.10515	2.892	61 - 90	0.1587	4.365	61 - 90	0.07072	1.945	61 - 90	0.008	0.211	61 - 90	0.01549	0.426
91 - 120	0	0	91 - 120	0.04556	1.253	91 - 120	0.01469	0.404	91 - 120	0.07952	2.187	91 - 120	0.001	0.041	91 - 120	0	0
> 120	0	0	> 120	0	0	> 120	0	0	> 120	0	0	> 120	0.000	0.000	> 120	0	0
	1	27.504		1	27.504		1	27.504		1	27.504		1	27.504		1	27.504

Figure 5. Variation of Undrained Shear Strength and their percentage with depth (1,5, 3, 4,5, 6, 7,5, and 9 m)

CONCLUSIONS

Using GIS in geotechnical engineering works makes it possible for spatial data area forecasting for geotechnical engineers. Geotechnical maps are shown effect of different geotechnical characteristics of the study area. A comprehensive and visual data base representation of data acquired from studies. As data is represented in the form of graphs, these maps save time, money and effort while being easy to use. Accurate data interpretation will aid in lowering the costs of new soil investigations. The study findings show that the bearing capacity values of less than 500(KPa) at the first layer (1,5 meters deep) represent roughly 0,53 % of the study area. The undrained shear strength increases with the depth.

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ACKNOWLEDGMENT

This research was carried out as part of a master's degree program in Geotechnical Engineering at the University of Anbar.

FINANCING

None.

CONFLICT OF INTEREST

None.

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