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Undrained Shear Strength Mapping of Al-Khalis Districts: A Geotechnical GIS Approach

Abdullah S. AbdulWahab [1*], Waad A. Zakaria [2], Nada Kadhim [3]
[1,2,3] Department of Civil Engineering, University of Diyala, Diyala, 32001, Iraq
[1]abdullahsameer838@gmail.com, [2] waadzakariya@yahoo.com , [3] nada.m.kadhim@uodiyala.edu.iq

Abstract

A geographic information system is an integrated collection of computer applications and materials that it is employed to assess geographic relationships, model spatial processes, and analyze and arrange geographic data. The gathering, organizing, and analysis of geographic data are made easier with the use of a geographic information system (GIS). Information systems about geography Thus, it is employed in the gathering, examination, assessment, updating, and presentation of geographic data. This study dealt with Al-Khalis District, one of the five districts of Diyala Governorate. Al-Khalis District is in the western part of Diyala Governorate and the northern part of the capital, Baghdad, about 55 km north of the capital, Baghdad. 227 boreholes were collected for the entire governorate. The soil was classified, its properties were taken, and they were collected in an Excel sheet. After that, this data was entered into geographic information systems to produce clay shear strength maps. A very helpful soil map that can be used in all aspects through structural and engineering simulation is produced when GIS is used in conjunction with physical and strong geotechnical qualities. Building engineering facilities, roadways, and industrial structures may be made easier with the use of a GIS map. Additionally, it offers a strong tool for extrapolating developed regions. GIS soil maps are anticipated to positively influence the next geotechnical work. The results revealed a significant variance in shear resistance across the depths of the Khalis area, with the soil's strength ranging from weak to medium in the first layer and increasing downward with depth. So, we recommend not going for more than three multi-story buildings unless doing a site investigation on the site and making sure it is suitable for that or using a pile foundation. This study aims to give geotechnical engineers and designers a first impression of the type of soil and help them quickly make decisions in terms of the type of foundations and the number of floors for multi-story buildings.

Keywords: Bearing capacity, SPT, U ndrained shear strength, GIS, Angle of friction.

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1. Introduction

In nature, soils exist in different places and are distributed differently. The kind of rock, the minerals that make up the rock, and the local climatic system all influence the kind of soil. Earth's surface is utilized for the construction of civil engineering projects or as a building material. Civil engineering construction's stability is impacted by the geotechnical qualities of the soil. Most soil geotechnical characteristics interact with one another [1].

The primary objective of investigating the subsurface of a construction site is to ascertain the geotechnical characteristics of the soil underneath the building. In 2020, Muhammad and Al-Bayati produced a digital geotechnical map of Salah al-Din Governorate using geographic information systems. These maps included various geotechnical characteristics, as 24 points were analyzed, each containing three boreholes to a depth of up to 10 meters [2].

Using the capabilities of geographic information systems and remote sensing methods, [3] created a digital geotechnical map of the city of Dhir Qir,

* Corresponding author: abdullahsameer838@gmail.com

utilizing the ERDAS tool to examine the reflectance characteristics of the soil surface. Afterward, laboratory test results were gathered for the wells in the research area [3].

Geographic information systems (GIS) and artificial neural networks (AANs) [4] to analyze and model the geotechnical properties of soil in the city of Erbil. Three distinct depth levels (1.5 m–3.5 m, 3.5 m–6.5 m, and 6.5 m–9.5 m) were covered by the data from 102 wells to observe and assess soil characteristics.

Geotechnical data were collected from some geotechnical investigation reports that were conducted in some selected locations in the city of Al-Hillah, within the Babil Governorate, in 2022. [5], described the geotechnical characteristics of the soil profile in this location. There was a distribution of both horizontal and vertical soil qualities (mechanical and physical). Additionally, a connection between mechanical and physical qualities is made.

In the study of Al-Maliki et al. [6], the authors produced a map of the bearing capacity of the cities of Najaf and Kufa on geographic information systems, where 464 wells were collected for the two cities and analyzed at a depth of 0–2 meters.

Al-Obaidi et al. [7], conducted a study on the geotechnical characteristics of Basra's soil. Basra's soil was classified into two regions: the eastern region consists mainly of soft and medium-cohesive soil, and the western region represents sandy soil.

In the study of Al-Taie [8], studied a portion of the Basra soil in the lab and outdoors. Situated southwest of Basra, in the Al-Zubair district, lies the study area. At a maximum depth of thirty meters, 39 wells were dug in three different places within the area. A set of numbers that represented the average values of soil attributes vs. depth was plotted using the data that was gathered.

Following the distribution of the principal geotechnical features in the city center of Basra [9], created a variety of geotechnical maps of the area using GPS and GIS techniques.

In the study of Pekan et al. [10], where SPT data and soil classes were used to prepare a 3D map on GIS of that region. [11] improved our understanding of the subsurface geology, rock heights, and geotechnical characteristics of the different soil types present in the research region by developing a GIS-based 3D SPT model.

In the study of Al-Ani et al. [12], 51 Surfers Paradise soil research reports' geotechnical documents were gathered and imported as digital layers into ArcGIS 10, where they were transformed into forms suitable for GIS evaluation. With this approach, geotechnical characteristics were categorized on digital maps (GIS). Whereas, [13] the chemical parameters of the soil in Kirkuk - Iraq was analyzed, in 2020 and used the weighted interpolation approach to construct geotechnical maps of the area.

Muhammad et al. [14], the authors studied the spatial distribution of soil type, Standard Penetration Test (SPT) N values, bearing capacity, groundwater depth, and shear wave velocity using the database of 65 wells in the GIS program (Geographic Information System). The data were analyzed and interpreted using geostatistical contouring techniques (such as kriging and inverse distance weighting). The geological database of the vast soils of Sulaymaniyah City in Iraq was an example of how several strategies for producing digitally interpolated maps using GIS may be applied [15].

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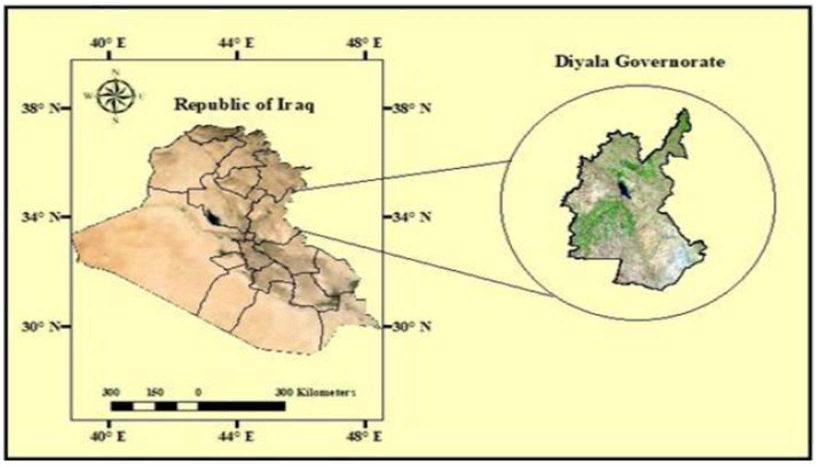

Fig. 1 The geographical location of the study area (Diyala) [16]

1.1 The objectives of the study

Using geographic information systems, this study aimed to create geotechnical maps that would analyze the soil of Al-Khalis District, one of the five districts of the Diyala Governorate, and determine its undrained shear strength. This was done with consideration for the fact that most of the city's soil is clay, which makes determining its bearing capacity easy. This study aids engineers in most places in gaining a preliminary understanding of the soil. Decisions on the kind of foundation and the maximum number of levels that may be constructed in the study area are made easier by the city locations.

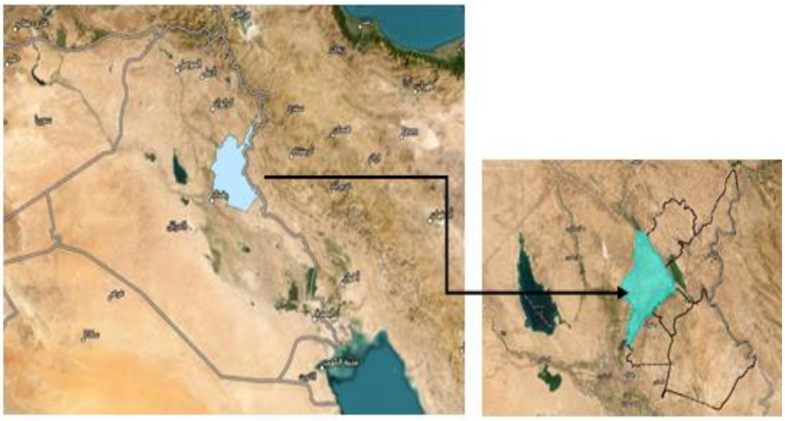

Fig. 2 Al-Khalis District, one of the five districts of Diyala Governorate.

1.2 Study area

The Diyala Governorate is situated in eastern Iraq, around 57 kilometers northeast of Baghdad. Its borders are as follows: Iran to the east, Wasit Governorate to the south, Kirkuk Governorate to the northeast, Baghdad Governorate to the west, and Salah al-Din Governorate to the north. Diyala Governorate occupies 17,617 square kilometers or about 4% of the total area of Iraq. The Diyala Governorate is situated between latitudes 31°45' north and 33°30' north and between longitudes 44°30' east and 46°45' east. The Diyala Governorate has an extremely varied geography, which includes: Mountain ranges: which are found along the province's northeastern border with Iran. Plains: Situated on the banks of the Diyala River, they make up most of the governorate. Valleys: The Nahr Valley and the Diyala River Valley are situated in the governorate's southern region as shown in Fig. 1. The city of Khalis is in the northwest of Diyala Governorate in Iraq, about 55 kilometers from the capital, Baghdad. It is the center of Al-Khalis's district as shown in Fig. 2.

2. Materials and Methods

This paper adheres to the necessary methodological procedures by gathering a vast amount of data, including soil classification, cohesion, internal friction angle, and unit weight, to determine clay soil's shear resistance, as well as the outcomes of on-site tests, particularly the governorate-wide SPT examination, which were utilized as the source information for geotechnical maps as shown in table 1.

2.1 Data Collection

This study employed data from the Al-Ahmad Structural Testing Laboratory, the Diyala Governorate's Scientific Services Office, and the Engineering Consulting Office. and the Engineering Consulting Office. The soil was categorized using these tests once data collection was complete, and the clay soil's shear strength, cu and since shear resistance is equal to the bearing's capacity divided by two, it is extracted through bearing capacity and since shear resistance is equal to the bearing's capacity divided by two, it is extracted through bearing capacity.

Table 1: The SPT is examined by extracting the bearing capacity using the value of n, as stated in the [17]

Consistency		N_{70}	$q_{(u)}$ KPa	Remakes
Very soft	NC-Young clay	0-2	<25	Squishes between fingers when squeezed
Soft	NC-Young clay	3-5	25-50	Very easily deformed by squeezing
Medium	NC-Young clay	6-9	50-100	??
Stiff	Increasing OCR-Aged cemented	10-16	100-200	Hard to deform by hard squeezing
Very stiff	Increasing OCR-Aged cemented	17-30	200-400	Very hard to deform by hand squeezing
Hard	Increasing OCR-Aged cemented	>30	>400	Nearly impossible to deform by hand

2.2 Software

The purpose of applying the Geographic Information System (GIS) is to manage, retrieve, store, display, and analyze various types of geographic and spatial data. Data has been developed related to the classification of clay soil and undrained shear strength for the clay soil of Al-Khalis District at 4 depths (1-2 m, 2-3 m, 3-4 m, 4-8 m), and the geographical coordinates of all points were taken. The borehole data was then entered into the geographic information systems program, Arc GIS Pro 3.0, to produce geotechnical maps.

3. Results and Discussion

Fig. 3 shows the undrained share strength from 1-2 m below natural ground level for Khalis's district initially we must state that the boreholes are located across the east-south border and there are few boreholes located otherwise of the area we can see there is a small spot of high strength cu located approximal in the north which is in the blue color which has undrained.

Sheare strength is larger than 100 kPa and no other place was found to have high strength the area of this spot is rather small compared with the area of the Khalis district we can see that a large area of weak soil located in the east south border which has undrained shearer strength lower than 35 kPa which is soft soil in this spot it's not recommended to build a multi-story building more than 2 multi stories The middle and west of the district have an undrained shear strength higher than soft soil. It contains firm soil, so it is recommended to build about three multi-story buildings. Also, in the upper north, there is a spot of very weak soil above the high-strength soil.

Fig. 4 shows the undrained shear strength of clay at a depth of 2-3 m below natural ground level. We can see that the location of the high strength has not changed, and the soft soil has decreased to the lower south part and disappeared from the eastern part, indicating that the strength of the soil has rather increased with depth, and these characteristics belong to the normally consolidated soil. There is a small area in the middle and in the west part that has a rather higher strength, which is considered a stiff shear strength, indicating an increase in undrained shear strength with depth. The small area of undrained shear strength located in the upper north has not changed with depth. So, in this case, in the middle and the west, if someone is located to increase the story building, he must dig to a depth of 2-3 m and put the foundation. The dominant area of this map is firm to high.

Fig. 5 shows the undrained shear strength of clay at a depth of 3–4 m below the natural ground level. We can see a drastic increase in undrained shear strength with a disappearance of the high spot of the shear strength located in the north being shifted to the middle area, and there appear to be stiff cu values near the middle west and south regions. Also, there is a high-strength spot near the lake at a depth of 3–4 m. The author recommends not taking this spot into account because it is near the lake. We can see that the shear strength has increased, which is one of the characteristics of normally consolidated soil. The weak soil that has been located along the south and east borders has disappeared to be replaced by firm soil.

Fig. 6 shows the undrained shear strength of clay at a depth of 4–8 m below natural ground level. We can see that this GIS map is very similar to the first map, which had a depth of 1-2 m. The spot of high undrained shear strength returned to the north, and the weak soil returned to appearance for the east and south borders, and the dominant area was soft to firm. This indicates that the deep foundation is useless here. any pile in this depth will work as a friction pile not end bearing pile. The high-strength spot appeared back again in the north, so in this case, this layer cannot be relied on because it is fluctuated through depth, so it cannot be relied on as stiff soil in the design of the foundation.

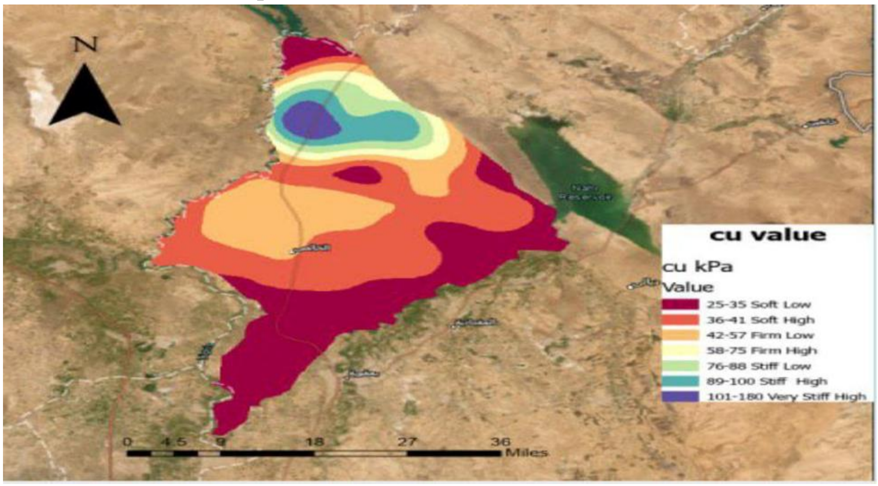

Fig. 3 Distribution of undrained shear strength of clay at first layer calculated at depth 1-2 m below ground level.

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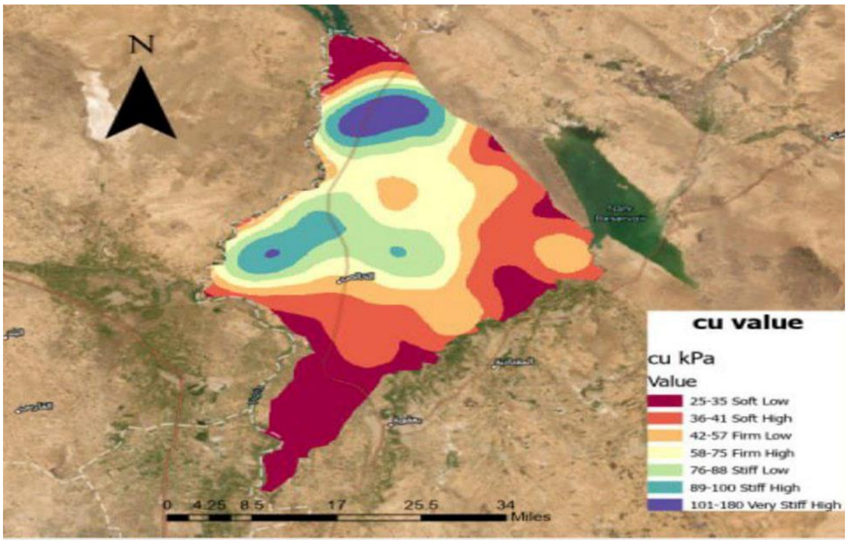

Fig. 4 Distribution of undrained shear strength of clay at second layer calculated at depth 2-3 m below ground level.

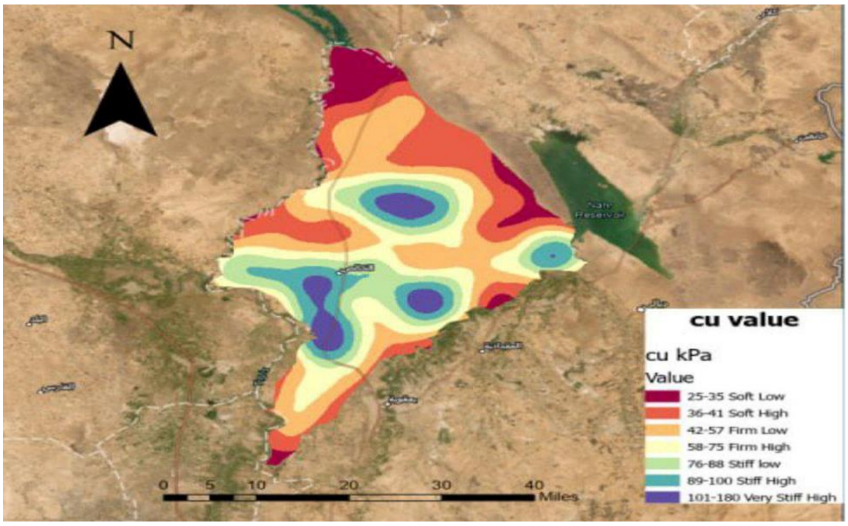

Fig. 5 Distribution of undrained shear strength of clay at third layer calculated at depth 3-4 m below ground level.

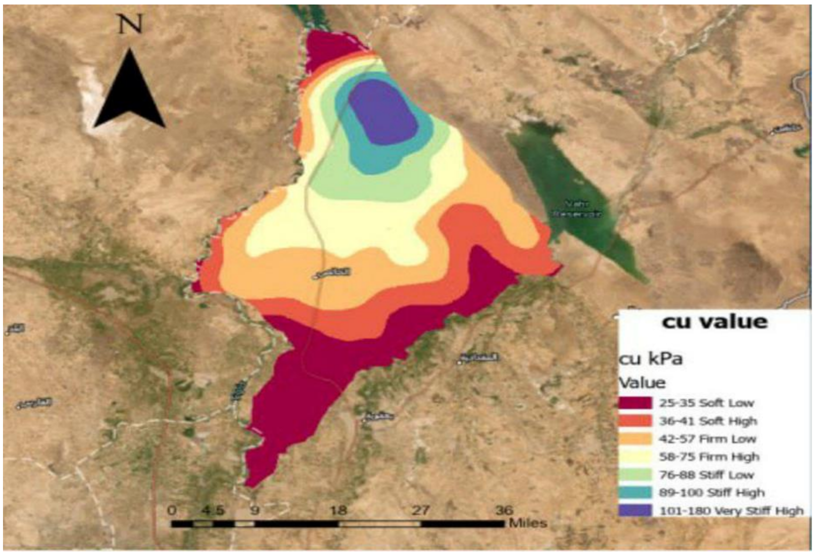

Fig. 6 Distribution of undrained shear strength of clay at fourth layer calculated at depth 4-8 m below ground level

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Tables Below (2, 3, 4 and 5) described the parameters extracted from the soil reports for the pure district and at four depths, where the real points were divided and analyzed into four depths, based on this data, the program determined the parameters for the estimated points and at the four depths of the district

Table 2: Shows the actual points of pure soil and soil properties for depths of 1-2 m.

Site	Depth 1	USCS	Cu kpa	Ø	y
BH74	1-2 m	CH	40	0	20.22
BH75	1-2 m	CH	38	0	20.31
BH76	1-2 m	CL	40	0	17.31
BH77	1-2 m	CL	35	0	17
BH78	1-2 m	CL	60	0	17.5
BH79	1-2 m	CL	90	0	19.85
BH80	1-2 m	CL	75	0	19.21
BH81	1-2 m	CL	70	0	19.12
BH82	1-2 m	CL	102	0	19.82
BH83	1-2 m	CL	70	0	18.26
BH84	1-2 m	CL	150	0	20.02
BH85	1-2 m	CL	125	0	20.05
BH86	1-2 m	CL	140	0	20.1
BH87	1-2 m	CH	105	0	20.03
BH88	1-2 m	CH	110	0	19.98
BH89	1-2 m	CH	100	0	18.5
BH90	1-2 m	CL	60	0	17.71
BH91	1-2 m	CL	30	0	18.3
BH92	1-2 m	CL	40	0	17.21
BH93	1-2 m	CL	15	0	17.05
BH94	1-2 m	CL	20	0	17.3
BH95	1-2 m	CL	50	0	17.35
BH96	1-2 m	CL	63	0	17.44
BH97	1-2 m	CL	85	0	18.52
BH98	1-2 m	CL	52	0	18.85
BH99	1-2 m	CL	82	0	18.5
BH100	1-2 m	CL	50	0	20.03
BH101	1-2 m	CL	20	0	20
BH102	1-2 m	CL	70	0	20.23
BH103	1-2 m	CL	120	0	20.45
BH104	1-2 m	CL	40	0	20.4
BH105	1-2 m	CL	120	0	20.47
BH106	1-2 m	CH	75	0	19.98
BH107	1-2 m	CH	70	0	19.89
BH108	1-2 m	CH	75	0	19.95

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Table 3: Shows the actual points of pure soil and soil properties for depth 2-3 m.

Site	Depth 2	USCS	Cu kpa	Ø	y
BH74	2-3 m	CH	45	0	20.13
BH75	2-3 m	CH	50	0	20.22
BH76	2-3 m	CL	45	0	17.2
BH77	2-3 m	CL	40	0	17.12
BH78	2-3 m	CL	75	0	18.3
BH79	2-3 m	CL	98	0	20.12
BH80	2-3 m	CL	80	0	20.02
BH81	2-3 m	CL	76	0	18.32
BH82	2-3 m	CL	105	0	20.12
BH83	2-3 m	CL	97	0	19.91
BH84	2-3 m	CL	105	0	20.25
BH85	2-3 m	CL	100	0	20.15
BH86	2-3 m	CL	145	0	20.33
BH87	2-3 m	CH	115	0	20.12
BH88	2-3 m	CH	120	0	20.25
BH89	2-3 m	CH	115	0	18.35
BH90	2-3 m	CL	70	0	18.3
BH91	2-3 m	CL	35	0	17.85
BH92	2-3 m	CL	45	0	17.5
BH93	2-3 m	CL	20	0	17.35
BH94	2-3 m	CL	25	0	17.23
BH95	2-3 m	CL	45	0	19.03
BH96	2-3 m	CL	55	0	18.3
BH97	2-3 m	CL	80	0	17.35
BH98	2-3 m	CL	65	0	19.5
BH99	2-3 m	CL	84	0	18.75
BH100	2-3 m	CL	55	0	20.15
BH101	2-3 m	CL	30	0	20.2
BH102	2-3 m	CL	85	0	19.98
BH103	2-3 m	CH	145	0	20.58
BH104	2-3 m	CH	45	0	20.35
BH105	2-3 m	CH	120	0	20.24
BH106	2-3 m	CL	90	0	20
BH107	2-3 m	CL	85	0	20.15
BH108	2-3 m	CL	85	0	20.2

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Table 4: Shows the actual points of pure soil and soil properties for a depth of 3-4 m.

Site	Depth 3	USCS	Cu kpa	Ø	y
BH74	3-4 m	CH	55	0	20.07
BH75	3-4 m	CH	60	0	20.13
BH76	3-4 m	CL	50	0	17.43
BH77	3-4 m	CL	48	0	17.33
BH78	3-4 m	CL	86	0	18.91
BH79	3-4 m	CL	105	0	20.18
BH80	3-4 m	CL	100	0	20.22
BH81	3-4 m	CL	90	0	19.82
BH82	3-4 m	CL	105	0	20.12
BH83	3-4 m	CL	98	0	19.93
BH84	3-4 m	CL	95	0	20.3
BH85	3-4 m	CL	96	0	20.25
BH86	3-4 m	CL	150	0	20.4
BH87	3-4 m	CL	125	0	20.23
BH88	3-4 m	CL	160	0	20.4
BH89	3-4 m	CL	145	0	18.65
BH90	3-4 m	CL	82	0	19
BH91	3-4 m	CL	42	0	17.65
BH92	3-4 m	CL	50	0	17.54
BH93	3-4 m	CL	25	0	17.5
BH94	3-4 m	CL	30	0	17.4
BH95	3-4 m	CL	38	0	19.54
BH96	3-4 m	CL	50	0	18.75
BH97	3-4 m	CL	70	0	17.27
BH98	3-4 m	CL	70	0	19.95
BH99	3-4 m	CL	87	0	19.1
BH100	3-4 m	CL	62	0	19.98
BH101	3-4 m	CL	45	0	19.97
BH102	3-4 m	CL	105	0	20.23
BH103	3-4 m	CH	105	0	20.25
BH104	3-4 m	CH	56	0	20.33
BH105	3-4 m	CH	115	0	20.36
BH106	3-4 m	CL	105	0	20.5
BH107	3-4 m	CL	95	0	20.53
BH108	3-4 m	CL	98	0	20.32

Table 5: Shows the actual points of pure soil and soil properties for depths of 4-8 m.

Site	Depth 4	USCS	Cu kpa	Ø	y
BH74	4-8 m	CH	60	0	19.93
BH75	4-8 m	CH	65	0	20.05
BH76	4-8 m	CH	58	0	17.67
BH77	4-8 m	CL	53	0	17.82
BH78	4-8 m	CH	90	0	19.95
BH79	4-8 m	CH	108	0	20.56
BH80	4-8 m	CH	135	0	20.34
BH81	4-8 m	CL	102	0	20.04
BH82	4-8 m	CH	108	0	20.21
BH83	4-8 m	CH	105	0	20.1
BH84	4-8 m	CL	86	0	20.45
BH85	4-8 m	CL	60	0	20.4
BH86	4-8 m	CL	156	0	20.46
BH87	4-8 m	CL	145	0	20.4
BH88	4-8 m	CL	140	0	20.23
BH89	4-8 m	CL	170	0	19.65
BH90	4-8 m	CL	35	0	19.25
BH91	4-8 m	CL	30	0	17.98
BH92	4-8 m	CL	44	0	18.3
BH93	4-8 m	CH	30	0	18.25
BH94	4-8 m	CH	35	0	17.65
BH95	4-8 m	CH	35	0	19.87
BH96	4-8 m	CL	40	0	17.37
BH97	4-8 m	CL	65	0	17.15
BH98	4-8 m	CL	80	0	18.8
BH99	4-8 m	CL	95	0	19.34
BH100	4-8 m	CH	70	0	20.45
BH101	4-8 m	CH	50	0	20.5
BH102	4-8 m	CH	120	0	20.65
BH103	4-8 m	CH	95	0	20.02
BH104	4-8 m	CH	60	0	20.15
BH105	4-8 m	CH	106	0	20.05
BH106	4-8 m	CL	160	0	20.85
BH107	4-8 m	CL	105	0	20.75
BH108	4-8 m	CL	135	0	20.88

4. Conclusion

This study aims to give geotechnical engineers and designers a first impression of the type of soil and help them quickly make decisions in terms of the type of foundations and the number of floors for multi-story buildings.

1. This study focused on producing geotechnical maps of soil properties and strength, specifically the undrained shear strength, to complete the Geographic Information Systems (GIS) program.

2. These maps are used to give a first impression of the type of soil and estimate the number of floors in the building and the foundation.

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3. Through the results, it was found that the first layer, which was at a depth of 1-2 m under the natural ground level, was the dominant layer of weak to medium soil, and the strength began to increase gradually with depth when descending to the second layer, which was between 2-3 m, and reached its peak in the third layer. Its depth ranged from 3 to 4 m, as the prevailing soil in that layer was medium to strong, with undrained shear strength ranging between 42 and 150 kPa.
4. After descending deeper into the fourth layer, things returned to the same as in the first layer, and the weak to medium clay layer prevailed.
5. At the end of the summary, we can say that the district of Khalis contains firm soil. and cannot be relied on for high multi-story buildings unless a detailed site investigation is done on the spot, indicating otherwise.

References

[1] Mahmoud, M. I., Dessouky, M. I., Deyab, S., & Elfouly, F. H. (2007). Comparison between haar and daubechies wavelet transformions on FPGA technology. International Journal of Aerospace and Mechanical Engineering, 1(2), 141-145.

[2] Sahib, Mohammed & Hasan, Musaab & Satea, Khaldoon. (2020). Geotechnical maps for Salah Al-Deen-Iraq. IOP Conference Series: Materials Science and Engineering. 737. 10.1088/1757-899X/737/1/012224.

[3] Kasim, A. A., (2014), "Building Geodatabase for Geotechnical Properties of Thi-QarGovernorate Area Using Modern Digital Techniques ", M. Sc. Thesis, University of Technology, Baghdad, Iraq.

[4] Baqi, Zhvan & Karabash, Zuheir & Cabalar, Ali. (2023). Analyzing Geotechnical Characteristics of Soils in Erbil via GIS and ANNs. Sustainability. 15. 4030. 10.3390/su15054030.

[5] Salih, Mustafa Musa, Jawad, Faris Waleed, Al-Ameri, Abbas Fadhil Ibrahim and Abdulhameed, Ali A."Geotechnical correlations of soil properties in Hilla City – Iraq" Open Engineering, vol. 12, no. 1, 2022, pp. 729-742. https://doi.org/10.1515/eng-2022-0335

[6] Almaliki, Laheab & Al-Mamoori, Sohaib & Khaled, El-Tawil & Hussain, Hussain & Al-Ansari, Nadhir & Jawad Al Ali, Mohammed. (2018). Bearing Capacity Map for An-Najaf and Kufa Cities Using GIS. Engineering. 10. 10.4236/eng.2018.105018.

[7] Al-abboodi, Ihsan & Hamoody, Ahid & Saleh, Samoel. (2020). Geotechnical Features of Basrah City, Iraq. 20. 1-7. 10.33971/bjes.20.2.1

[8] A. J. Al-Taie, "Profiles and geotechnical properties forsome Basra soils", AL Khwarizmi Engineering Joumal.Vol. 11. No. 2, pp. 74-85. 2015.

[9] M. M. Kadhim, N. K. S. Al-Saoudi, and A. R. T Ziboon,"Digital geotechnical maps of Basrah city usinggeographicalinformationsystemstechnique Engineering & Technology Joumal, Vol. 31, pp. 599-617,2013.

[10] 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

[11] Balasubramani D P& Dodagoudar G. R. (2020). Modellingthe spatial variabilityStandard of Penetration Test eters is andarddwater data for Chennai City using kriging and product-summodel. Geomechanics and Geoengineering, 114.doi:10.1080/17486025.2019.1707884.

[12] H. Al-Ani, L. Eslami-Andargoli, E. Oh, G. Chai, categorizing geotechnical properties of surfers Paradise soil using geographic information system (GIS), Int. J. GEOMATE 5 (2) (2013) 690-695, https://doi.org/10.21660/2013.10.3114a.

[13] M. Hassan, A. Sulyman, A. M. Noori, and A. A. Al-attar, "Study and GIS-BasedMapping of Soil Chemical Properties in Kirkuk City, Iraq." 2020, doi: 10.4108/ay soil at any eai.28-6-2020.2298163.

[14] Muhammad Daniyal and Ghulam Mohyuddin Sohail and Hafiz Muhammad Awais Rashid, GIS-Based Mapping of Geotechnical and Geophysical Properties of Lahore Soils, 2022.

[15] Kamal Ahmad Rashed and Alle Abdulrahim Hussein, (2020). GIS as A Tool for Expansive Soil Detection at Sulaymaniyah City.

[16] Adeeb, H. Q., & Al-Tamimi, Y. K. Change on detection of vegetation cover and soil salinity using GIS technique in Diyala Governorate, Iraq. Scientific Review Engineering and Environmental Sciences, 2021(1)).

[17] Joseph E. Bowles, FOUNDATION ANALYSIS AND DESIGN, Fifth Edition (1997).