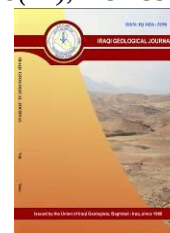




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Spatial Analysis for Characterizing the Surface Geotechnical Properties of Selected Soils in Baghdad City

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Abstract

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The soil is the main support to buildings and infrastructure. Unfavorable soil conditions may cause structural damage or settlement problems. The aim of this research is to assess and conduct a spatial analysis of the chosen geotechnical soil properties in the various regions within Baghdad City to determine more suitable areas to build or areas that could pose a potential geotechnical hazard. The samples of undisturbed soil were taken in 27 holes and the results of the soil sample tests were obtained from the National Center of Construction Laboratories, Ministry of Construction, Housing, Municipalities and Public Works, Iraq and were performed to determine compression properties, original void ratio, water table and the concentration of sulfate ion. Key soil parameters such as water content, density and compression ratio were determined using linear equations. A spatial analysis, Inverse Distance Weighted technique was applied model geotechnical soil properties. This method allows visualizing the spatial variability of the soil conditions and providing zones with more or less preferable or critical geotechnical properties. Soil is categorized according to the results of NCCL on the basis of soil composition which was determined by means of a spatial analysis of these points: based on the results, soil is clayey soil whose density lies between 15 and 17 KN /m³ and medium -low compressibility. In some areas there were comparatively high groundwater levels which were witnessed near the depth of drilling. This increase requires dewatering to prevent structural failure, settlement and damages can be experienced in the foundation of soil structure that ultimately impacts the overall cost of construction. Spatial mapping was used to indicate the regions where groundwater condition and soil properties might need dewatering or extra geotechnical factors prior to construction.

Keywords: Geotechnical engineering; Initial void ratio; Moisture content; Compression ratio

1. Introduction

In civil engineering, most construction projects, such as buildings, highways, etc., are constructed on or beneath the natural ground surface. Therefore, evaluating the engineering properties of soil is essential to determine the suitability of the site and to provide reliable parameters for foundation design and construction (Babaoglu and Simms, 2020). Understanding the geotechnical characteristics of subsurface soils is particularly important for structures subjected to high loads or deep zones of influence, such as bridges, dams, and multi-story buildings (Das, 2011).

The foundation performance depends directly on the soil geotechnical properties (e.g., plasticity, compressibility, strength, void ratio, water content, sulfate concentration and ground water level). Highly compressible soils such as soils may have settled considerably after construction and this is dangerous and can cause the collapse of the construction (Mauff et al., 2017). Conversely, coarse-grained soils tend to work better with the load because they are less compressible and their drainage is enhanced (Das, 2000; Coduto, 1999). Assessment of these properties thus becomes critical in design planning as well as construction planning.

The important geotechnical parameters (compression index (C_c), initial void ratio (e_0), groundwater level, and sulfate content) are especially significant in forecasting behavior of soil under load. They assist engineers in making estimates of settlement, bearing capacity, slope stability, and embankments and earth structure performance (Bowles, 1996; Das, 2011; Thaker et al., 2021). Nonetheless, such properties are seldom constant across a city, local geology, groundwater, and other environmental conditions can exhibit a lot of variation.

Over the past few decades, Baghdad has experienced a high rate of urban growth and is currently experiencing high demand in residential, commercial, and infrastructure development. In spite of this development, there is still little comprehensive geotechnical information of the whole city. There is a difference in soil conditions across different districts, and this can have an impact on the cost of construction, the safety of foundations and the structural performance over the long term. Determining the regions with difficult soil conditions and those that can be constructed on is thus important in the planning and engineering design of cities.

This research looks at the spatial variability of the sampled geotechnical properties in Baghdad. A total of 27 sites were used in the analysis of data and included laboratory-tested parameters like initial void ratio, the groundwater level, compression index, and sulfate concentration, and some parameters were estimated based on the available relationships. The distribution of these properties was mapped by spatial interpolation with the Inverse Distance Weighted (IDW) method. The findings will help to gain a better picture of the behavior of soils throughout the city, allowing engineers to plan more cost-effective and safe construction projects, and remind them that site-specific investigations are still needed.

2. Field Works

2.1. Study Area and Materials Used

The soil samples used in the current study were collected from 27 locations at a depth of 1 m in Baghdad City, Iraq. The positions of the sites were determined using GPS. The study area extends between longitudes 44°34' and 44°57'8", and latitudes 33°19' and 32°8'02", as illustrated in Fig. 1 and Table 1.

A hole was excavated to the same depth at all sampling locations. Shelby tubes were used to obtain the soil samples. After collection, the samples were placed in plastic bags with corresponding labels for testing.

2.2. Laboratory Works

The laboratory works included the three main parts, as listed below:

2.2.1. Laboratory test

The laboratory test results were obtained from the National Center for Construction Laboratories (NCCL) at the Ministry of Reconstruction, Housing, Municipalities and Public Works in Baghdad, Iraq. Undisturbed soil samples were collected at random using a Shelby tube to a depth of 1 m. The measured

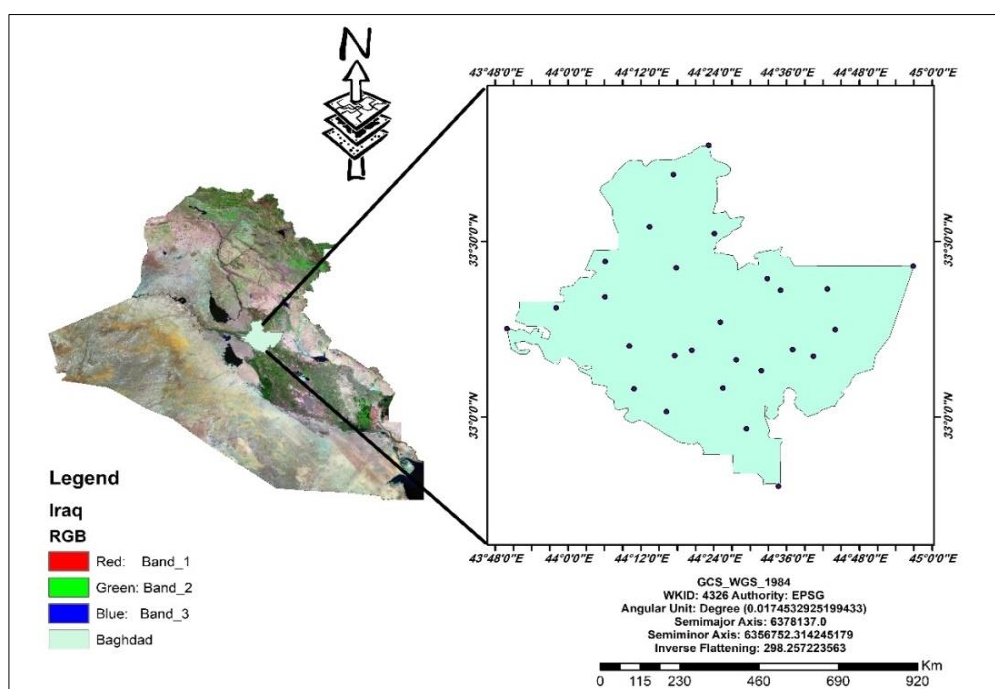


Fig. 1. stellate image with shape file of selected areas, showing the sampling points

parameters include groundwater level, initial void ratio (e_0), compression index (C_c), and sulphate ions (according to guideline No. 65 of 2017(NCCL, 2017)).

Table 1. GPS of the selected study area in Baghdad City

Area	Latitude	Longitude	Area	Latitude	Longitude
A1	33.19	44.34	A15	33.192	44.617
A2	33.175	44.293	A16	33.173	44.674
A3	33.202	44.168	A17	33.132	44.531
A4	33.08	44.181	A18	32.966	44.49
A5	33.311	43.967	A19	33.163	44.462
A6	33.082	44.425	A20	33.27	44.418
A7	33.015	44.27	A21	33.342	44.101
A8	33.425	44.297	A22	33.542	44.224
A9	33.691	44.289	A23	33.443	44.102
A10	33.523	44.402	A24	33.775	44.386
A11	33.394	44.547	A25	33.43	44.948
A12	33.361	44.584	A26	33.252	43.832
A13	33.365	44.712	A27	32.802	44.578
A14	33.249	44.734			

2.2.2. Mathematical equations

For the purpose of providing a more comprehensive description of soil properties and a more accurate interpretation of soil behavior and its suitability for construction works, and considering that these parameters are important and fundamental in soil characteristics, mathematical equations were used to calculate them, and these properties are as follows:

- Water content (wc)%

Based on a linear equation, the water content (wc) of clay soils was theoretically calculated using the initial void ratio as a function. This equation can be used mathematically to determine content of moisture and demonstrates that the values are closest to field water content (Robit et al., 2023).

$$e_0 = 0.0197w_n + 0.2143 \quad (1)$$

Where: e_0 = void ratio and w_c : water content

- Unit Weight (γ)

In this study, which was also established using Equation 2, based on initial void ratio (e_0), of specific gravity of clay (2.75, normally values of clay soils), and the unit weight of water (9.807 KN/m³).

$$\gamma = \frac{G.S.}{1 + e_0} * \gamma_{water} \quad (2)$$

Where: γ = bulk density; G.S. = specific gravity; e_0 = initial void ratio and γ_{water} = unit weight of water.

- Compression Ratio (CR)

The compression ratio is defined mathematically by Equation (3) (Gregory et al., 2006).

$$CR = \frac{C_c}{1 + e_0} \quad (3)$$

Where e_0 = initial void ratio; C_c = compression index

- Parameters Spatial Analysis

There are several spatial interpolation methods, such as Inverse Distance Weighting (IDW), kriging, and kernel smoothing interpolation with barriers. This study was focused on using one spatial interpolation technique (IDW) in modeling optimum areas of building construction. Inverse Distance Weighting (IDW) is a fast deterministic and exact interpolator (Wajood et al., 2021; Al-Ramahi et al., 2022). Regarding model parameters, there are limited options. It may be a helpful approach to analyze an interpolated surface first. IDW can form bull's-eye patterns around data locations; however, prediction error is not tested (Nassif et al., 2020). The data does not involve any assumptions, and hence it was selected to represent the data.

3. Results and Discussion

The geographic coordinates (latitude and longitude) of the chosen study area (A) in Baghdad, Iraq, are explained in Table 1. Resumption of the results and interpretation of the important geotechnical parameters are as follows:

3.1. Water Content

The water content values of soil samples were arranged between (20 to 28) %, as indicated in Table 2 and Fig. 2 and the IDW method was used for spatial analysis purposes. The water content explained are lower than 50 %, thus the water content of clay soils at the site is a moderate and acceptable value and it has no detrimental impacts on the construction process. Also, soil water content is an important parameter in soil spatial analysis because it significantly affects soil bearing capacity and compressibility, as well as the settlement of structures. It is closely related to soil compressibility, since soils with higher moisture content tend to become softer and more compressible. As a result, they are more susceptible to settlement under loads. In addition, moisture content is regarded as a spatially variable parameter, as it differs from one location to another. This variation reflects the natural and hydrological conditions of the soil, making it an important factor in spatial soil analysis.

3.2. Unit Weight

In this study, soil density ranged between 1.5 and 1.7 g/cm³ as presented in Table 2. Then the spatial analysis is illustrated in Fig. 3. Soils with densities ranging from 16.545 to 16.146 are considered to have high density. Clay soils with high density are generally more cohesive, well-compacted, and have better load-bearing capacity. However, it should be noted that high density in clay soils may lead to reduced permeability, resulting in greater water retention, which can cause swelling when the moisture content in the soil increases.

Table 2. Results of soil properties

Property Area	Water content (w_n) %	Ground-water level (m)	Initial void ratio (e_0) %	Compression index (Cc) %	Compression ratio (CR) %	Sulphate ions SO ₄ %	unit Wight γ (KN/m ³)
A1	21	1.5	0.63	0.22	0.134	0.71	16.545
A2	20	1.6	0.61	0.25	0.155	0.66	16.751
A3	27	2.4	0.75	0.21	0.120	2.1	15.411
A4	24	2.2	0.69	0.2	0.118	2.3	15.958
A5	25	1.7	0.7	0.2	0.117	2	15.864
A6	26	1.5	0.72	0.25	0.145	1.1	15.679
A7	28	2.5	0.76	0.21	0.119	3.2	15.323
A8	25	1.39	0.69	0.23	0.136	3.65	15.958
A9	25	0.8	0.71	0.18	0.105	2.3	15.771
A10	26	0.7	0.73	0.16	0.092	3.06	15.589
A11	24	1.55	0.68	0.18	0.107	2.4	16.053
A12	23	2.5	0.67	0.19	0.113	3.66	16.149
A13	25	3.08	0.7	0.2	0.117	2.13	15.864
A14	26	3.33	0.72	0.2	0.116	2.13	15.679
A15	26	2.8	0.71	0.15	0.087	3.33	15.771
A16	26	2.32	0.73	0.16	0.092	2.89	15.589
A17	28	0.83	0.77	0.19	0.107	3.83	15.236
A18	28	1.5	0.77	0.21	0.118	0.67	15.236
A19	27	1.36	0.75	0.2	0.114	3.3	15.411
A20	21	0.80	0.63	0.17	0.104	1	16.545
A21	23	3.5	0.67	0.18	0.107	2.1	16.149
A22	24	2.7	0.69	0.31	0.183	2.9	15.958
A23	25	0.71	0.7	0.28	0.164	1.3	15.864
A24	25	0.8	0.71	0.28	0.163	2.9	15.771
A25	23	2.5	0.67	0.2	0.119	3.66	16.149
A26	24	1.7	0.69	0.2	0.118	2	15.958
A27	28	2.5	0.77	0.21	0.118	0.67	15.236

On the other hand, soils with medium to low densities, ranging from 15.236 to 15.679 kg/m³, are more susceptible to compression and uneven settlement, especially under heavy loads over time. Therefore, such soils may require soil improvement and the selection of an appropriate foundation type to avoid any future settlement problems. In addition, a spatial analysis of soil density results was conducted across the different study areas, due to its importance in geotechnical studies. It illustrates the variation in density across different locations within the same region providing a comprehensive view and a better understanding of the soil properties. This, in turn, enables a more precise selection of the appropriate type of foundation or the required soil improvement treatments to enhance soil properties and avoid any settlement or failure of structures. Consequently, it aids in identifying, areas with high density, low density, and non-homogeneous zones that may not be apparent when relying on a limited number of samples.

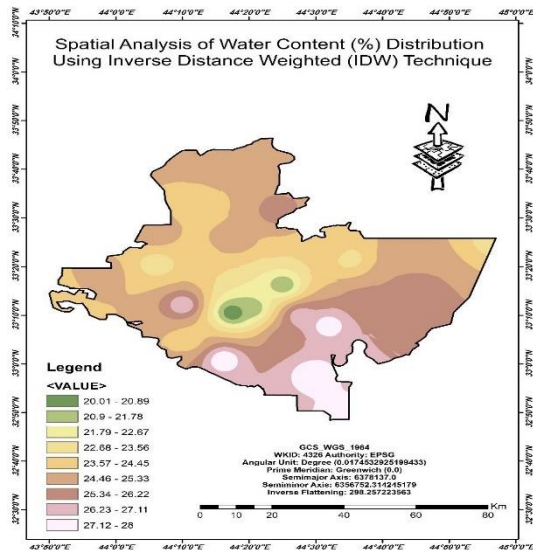
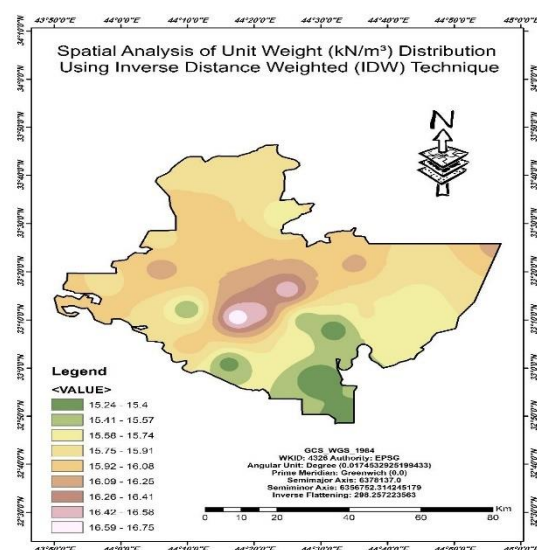


Fig. 2. Spatial analysis of water content (%) of soil

Fig. 3. Spatial analysis of unit weight (KN/m³) of soil

3.3. Groundwater

The results of the groundwater tests conducted in this study, as illustrated in Table 2 and Fig. 4, show that groundwater level ranged between 0.71 m and 3.33 m below the existing ground level. Where the groundwater level at depth greater than 2.7 m is generally considered acceptable for construction purposes and does not require special treatment to control groundwater measures. In certain parts of the chosen area, groundwater table is below 1 m below the ground surface (from 0.70 and 0.83 m). So that construction in these areas should be carefully designed. Dewatering process or raised foundation is required for portions of the structure under the water level to prevent any scouring may occurred in the foundation, where the construction of the structures in soil with a high level of groundwater results in a strong impact on the soil stability and the underground structures. The soil shear strength in the site may reduce as a result of increasing the groundwater level, therefore may lead to reduction in the shear strength of the foundation soil under the structures, consequently may cause an increase in soil pressure on the underground portions of wall structures, which due to the buoyancy phenomenon, lifts the lighter structures.

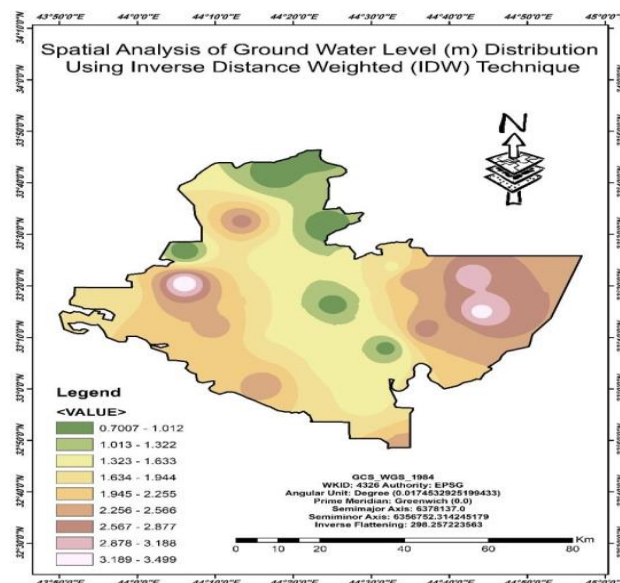


Fig. 4. Spatial analysis of groundwater level (m)

It is worth noting that estimating and understanding the groundwater level in this study is very important because it directly affects the compressive strength of the soil and the stability of its foundations. When the groundwater level rises, buildings are more susceptible to settlement risk, as the soil becomes more saturated and its load-bearing capacity decreases. Furthermore, it should be noted that most areas of Baghdad are located on recent riverine deposits, so the groundwater level is often shallow and varies depending on the season, rainfall, and irrigation activities. Consequently, the groundwater level is not spatially constant and differs from one area to another, for example, depending on proximity to the river or location within the city. This highlights the importance of spatial analysis and the use of more accurate methods to estimate groundwater levels, providing better support for foundation design in a scientific and safe manner.

3.4. Initial Void Ratio

The results of initial void ratio values of soil samples ranged between 0.63 and 0.67 as presented in Table 2 and illustrated in Fig. 5. As known in geotechnical studies, the typical values of void ratio of clay range between 0.3 and 1.5 and these values may be higher in organic soils. Therefore, the initial void ratio of clayey soil in this study falls within the clayey soil normal range; consequently, these soils in terms of initial void ratio, are considered a medium density, which indicates moderate compressibility and reasonable bearing capacity and do not require any improvement; however, further geotechnical testing is still required to comprehensively evaluate their engineering properties. In literature analysis, approved there is initial void ratio (e_0) and compression index of the clayey soils has approximately positive linear relationship, and thus, it becomes less complicated to understand the compression characteristics of the clayey soils by the engineers

3.5. Compression Index

The soil compressibility values range from 0.16 to 0.31 as presented in Table 2 and illustrated in Fig. 6. Soils are considered to have low compressibility when the compression index is less than 0.20, which results in relatively small settlement, while soils with values greater than 0.30 are classified as highly compressible, leading to large and potentially hazardous settlement.

Based on the test results, the studied soils can generally be classified as having low to moderate compressibility. This indicates that moderate settlement is expected under typical structural loads, such as those from ordinary buildings or shallow foundations. However, for heavy or large loads, a detailed settlement analysis is required, and ground improvement techniques or suitable foundation systems may be necessary.

Additionally, spatial analysis was used to provide a comprehensive understanding of variation in soil compressibility across the study area.

3.6. Compressibility Ratio

In this study, therefore, compressibility ratio of clay soils is arranged between 0.0877 to 0.1834 and classified as low to moderately compressibility, the compression ratio is 0.0510 (clarification system) the soil is lightly compressibility (compression ratio is 0.10-0.20), moderately compressibility (compression ratio is 0.20-0.35) and highly compressibility (compression ratio is 1). Fig. 5. A brief summary of these parameters is given in Table 2, which give an initial geotechnical estimate of compressibility behavior of the soil. It should be remembered, though, that these results are but an early characterization exercise of the geotechnical problem, and further geotechnical studies, such as consolidation tests and settlement analyses, are advisable for structural design and construction planning.

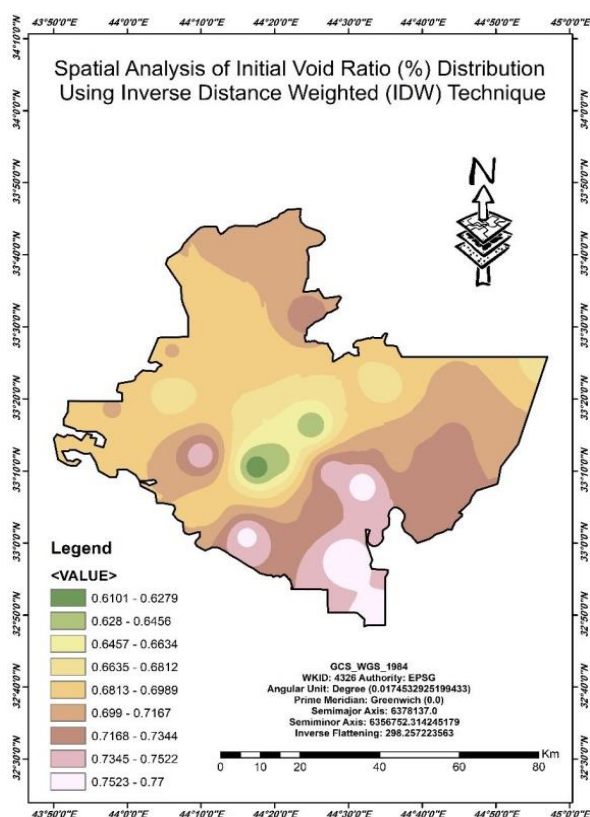


Fig. 5. Spatial analysis of initial void ratio (%) of soil

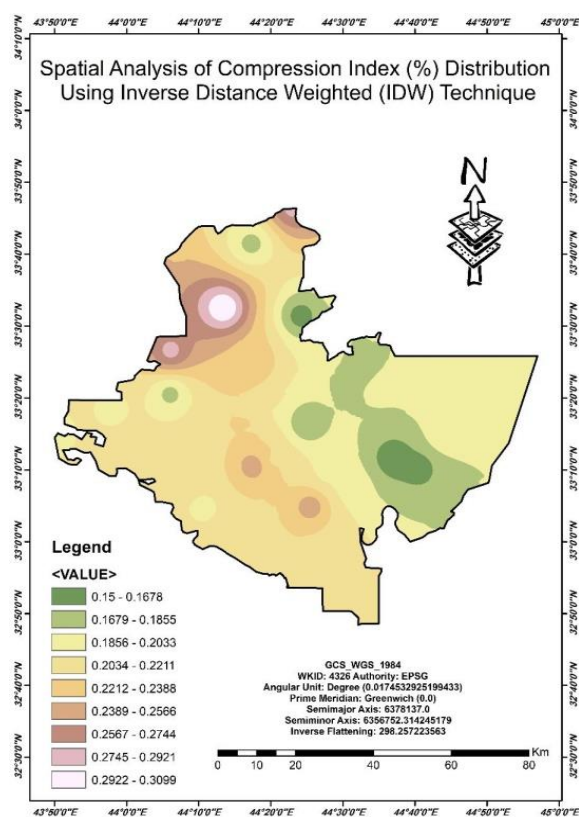


Fig. 6. Spatial analysis of compression index (%) of soils

3.7. Sulphate Ions

The sample results of the test of sulfate ions range between 0.66% and 3.66%, which were indicated in Table 2 and were presented in Fig. 8. The findings demonstrate that there is a considerable fluctuation in the amount of sulfurate in the soils of the study area, that is, moderate to severe levels. Based on Iraqi standards, the level of sulfate more than 2 percent is regarded as a very aggressive sulfate environment. These conditions are quite significant threat to structural design because of the presence of high level of sulfates which can react with concrete and deteriorate as well as crack and expand gradually losing strength with time. Therefore, understanding how much of the soil contains ions is significant to the engineers when coming up with a structure foundation that is to be established on a voided damages, where An engineer must be fully aware of the seasonal variation in sulfate concentration, as conducting soil tests in a single season may provide inaccurate results regarding the actual condition of the soil throughout the year. Therefore, it is necessary to determine the range of seasonal sulfate variation, since an increase in sulfates during a specific season can lead to the deterioration of concrete structures. Understanding these seasonal changes in sulfates helps in implementing protective measures for structures, either by using sulfate-resistant materials or by improving foundation design. This is why in order to be durable in the long run, it is advisable to employ sulfate-resistant cement, add appropriate admixtures and ensure that the cover of concrete is high to ensure that structural aspects are not affected by sulfate.

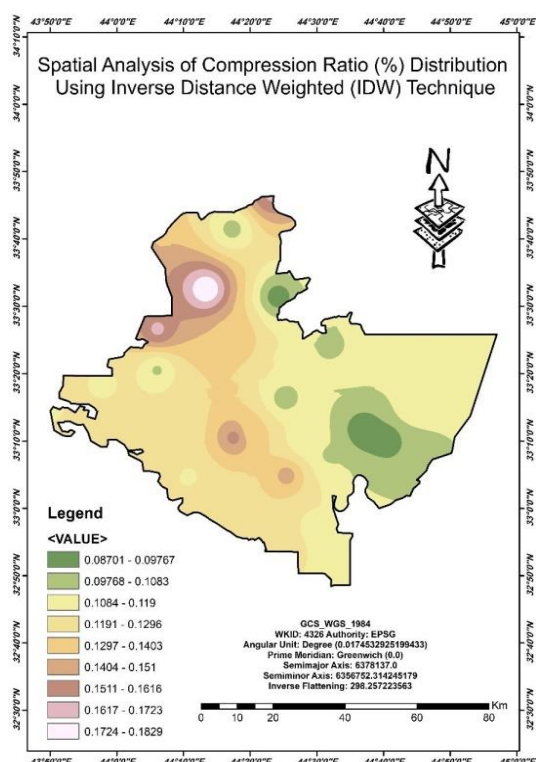


Fig. 7. Spatial analysis of compression ratio (%) of soil

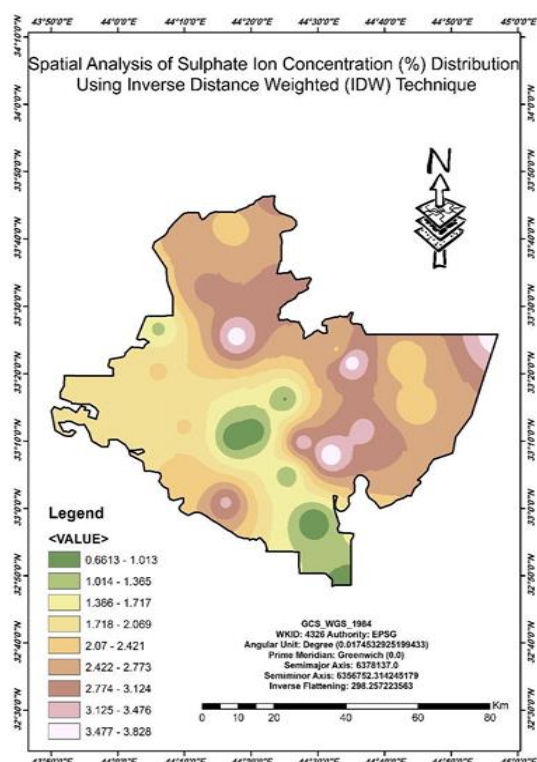


Fig. 8. Spatial analysis of sulphate ions (%) of soils

Using the results obtained on the study area as shown in Table 2, it is noted that in certain places, there is a high groundwater table that necessitates dewatering methods or adequate drainage systems. The areas have high levels of sulfate and thus in this case, use sulfate-resistant cement, low permeability concrete or concrete add and apply appropriate admixtures. Moreover, some zones are highly compressible hence high settlement and thus need ground improvement or utilization of deep foundations like pile or raft foundations.

This work is regarded as a preliminary investigation and it is an initial geotechnical database. More detailed geotechnical studies are strongly suggested, such as in-depth testing at deeper levels and at the other site, to have a more precise definition of the situation of the subsurface, and to make the study area construction feasibility reliable.

4. Conclusions

- The results of geotechnical soil properties were provided by the National Center of Construction Laboratories (NCCL) of various locations (27 points) with a depth of 1 m beneath the ground surface, which are within Baghdad City. The geotechnical properties of the soil samples collected were then analyzed using Inverse Distance weighting (IDW) spatial interpolation method. According to the analysis and the results of the obtained soil properties, it is possible to make the following conclusions:
- The moisture level of the clay soils at depth 1 m is 20 percent to 28 percent, which implies that moisture is moderate and is generally satisfactory to use in construction. The computed unit weight values are between 15 and 17 KN/m³. It is reflective of coherent clay soils with comparatively sufficient density in the majority of locations. The depth of groundwater table is between 0.71 m and 3.33 m at the surface. In certain places, the groundwater is shallow with levels below 1 m and this might need to be dewatered and engineering thought must be put in before construction. The first void ratio (e_0) is between 0.63 and 0.77, which is within the normal range of natural clay soils that signify rather stable soil conditions in most of the locations.

- The compression index (C_c) lies between 0.15 and 0.31 with compression ratio between 0.0877 and 0.1834, which are low and moderate compressibility of the soil. These values indicate that the soils can undergo moderate consolidation with structural loads. The concentration of sulfate ions is between 0.66 and 3.66 per cent, implying low to high levels of sulfate in the soils which might have minimal influence on construction materials in most regions and high influence in other regions.
- The IDW interpolation method of spatial analysis has been able to provide a visual representation of how the geotechnical parameters varied within the study area. It is regarded as a valuable instrument to determine and can be useful in soil studies. Although these findings, the results are only a rough geotechnical test and field studies and laboratory tests in addition to more depths are required before the actual design and construction of big infrastructure projects.

Author Contributions: CRediT

Zainab A. Hameed: Conceptualization, Methodology, Investigation, Writing– original draft, resources. Shatha F. Hassan: Conceptualization, methodology, project administration, writing- review and editing. Abdulrahman B. Ali: Conceptualization, methodology, data curation, formal analysis, software.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this study.

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Data Availability

The data used in this study were obtained from a third party and are not publicly available. Access to these data may be obtained from the data owner, subject to their restrictions

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