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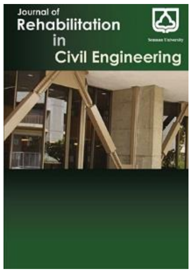

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Production Thematic Maps of Bearing Capacity of Shallow Foundation for Al-Basrah Soil Using Standard Penetration Data and GIS

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ABSTRACT

The Geographic Information System (GIS) is one of the modern database software which is used to collect, analyze, display, processing and produce geographic information maps for a specific objective. In addition, a statistical analysis can be generated within GIS on specific data to produce quantitative results. In this study, the GIS utilized to produce thematic maps showing the variation of bearing capacity of shallow foundation in Al-Basrah province soil. All the features mentioned above illustrate the importance of GIS exploring more valuable results such as the bearing capacity of shallow foundation from the results of standard penetration tests (SPT) conducted in Al-Basrah province soil. The total number of boreholes drilled was 135 distributed irregularly in the study area. In each borehole, three SPTs were performed at depths of 1.5, 6, and 9.5 m measured from the existing ground level (EGL). The results of the study can be summarized by the production of thematic maps showing the variation of the bearing capacity of the soil over the whole area of Al-Basrah city correlated with several depths. These maps can be used by different local authorities to predict soil bearing capacity and choose a suitable type of foundation. In addition, it can be utilized to assess the foundations of existing and irregularly constructed buildings and to assess the extent of the risks of failure and collapse.

1. Introduction

Standard Penetration Testing (SPT) is one of the most popular and widely used tests in this field around the world [1-3]. This test is a strong indicator of the geotechnical properties of the soil, such as density, shear strength, and soil compressibility. Despite of the considerable importance of the measured N values, several corrections can need to be applied to improve the applicability of using these values to estimate and calculate the geotechnical properties of any kind of soil. Many studies have suggested these corrections based on particular observations to remove the uncertainty in the N-scale values, but the selection of appropriate corrections is vital to avoid adding unnecessary soft-domain or lab-computed data. In addition, the optimization of the selected patches depends mainly on the field conditions of the tests, such as the dimensions and characteristics of the equipment used in the tests and the diameter and depth of the wells. All these conditions should be evaluated by the geotechnical engineer before implementing and certain values [1-3].

Many studies are correlating corrected SPT values with different soil geotechnical properties such as density, unpigmented shear strength, shear wave velocity, and liquefaction potential. Nevertheless, the results of these correlations are still considered preliminary and cannot be used for detailed foundation design [4-11]. The main goal aim of this study is to create thematic maps that show the difference in bearing capacity of soil along with geographic coordinates and depth. Therefore, to achieve the study aim and to explore the relationship between the bearing capacity of the soil and geographic GIS software has been implemented to serve this purpose. The SPTs were carried out in 135 boreholes (BHs) where coordinates are recorded for each location. The depth of these BHs is up to that 10 m from EGL, and the location of these BHs is selected to cover most of Al-Basrah Province area. The soil in this city varies from soft clay to silty clay and occasionally silty sand. The latest results provide a clear and easy method for calculating the bearing capacity of shallow foundations in Al-Basrah, which gives a good indication for preliminary design without the need for field or laboratory tests.

2. Corrections of Standard Penetration Test

A standard penetration test (SPT) is one of the field tests suggested for various soil types, especially when sampling and laboratory testing are problematic. The soil resistance to penetration of a split spoon sampler to a distance of 300 mm under constant frequent blows of a standard hammer (N-value) is characterized as the SPT. The measured N-value, which is subject to several adjustments to comply with the standard testing process, is used to interpret SPT results [12]. A variety of circumstances can influence the measured N-values from SPTs. These factors have the potential to increase or reduce N-values, which will have a substantial impact on the soil's predicted geotechnical properties.

The geotechnical properties of soil estimated from the SPT values are mostly underestimation, which means a conservative property of soil will be obtained from SPT results. As a result, many modifications to the SPT values may be done to make them more accurate, resulting in more reliable and widely accepted geotechnical properties of soil estimated using SPT data [13]. The diameter and depth of the borehole (BH), the type of hammer, the diameter of the rod, and field parameters such as confining pressure and groundwater table (GWT) can influence the corrections. According to Fletcher, the following factors can influence the measured N-values:

- Variation in the weight of hammer and height of drop;
- Using heavy drill rods with a diameter greater than 1 inch;
- The length of the drilling rod exceeds 50 m;
- Using a damaged split spoon sampler;
- Failure to place the sampler on undisturbed soil;
- Careless in counting the number of blows.

In empirical correlations, soil's geotechnical and geophysical properties are assessed using corrected SPT values ($N_{1(60)}$). [14]. Equation 1 indicates the necessary corrections that must be considered to the measured blow count to produce the corrected SPT values ($N_{1(60)}$).

$$N_{1(60)} = N'.C_W.C_N.C_E.C_B.C_R \quad (1)$$

$$N' = 15 + \frac{1}{2}(N - 15) \quad \text{for } N > 15 \quad (2)$$

Where

$N_{1(60)}$ = Correct for the theoretical free-fall hammer with 60% energy;

N'= Correct for the GWT [15-17];

N = SPT value measured in the field;

C_N = Overburden pressure correction factor;

C_E = Transmitted energy to the SPT rod correction factor;

C_B = Correction factor for the diameter of the borehole;

C_R = The length of SPT rod correction factor;

$$C_N = \frac{200}{100+\sigma'_o} \quad (3)$$

where σ'_o represents the effective overburden pressure in kPa. The dry and saturated unit weights of soil are 15 kN/m^3 and 17 kN/m^3, respectively, because the soil layers at all investigated sites vary from silty clay to soft clay. The energy correction factor (C_E) is equivalent to 0.8–1.0 in the literature. To account for the hammer's verticality and free fall distance, the energy correction factor is calculated to 0.6 in this study [13,15]. For rod lengths greater than 6 m, the correction factor rod (C_R) can be taken unity; for rod lengths less than 3 m, C_R = 0.75 is recommended. In this investigation, C_R is set to unity to keep things simple [11]. The borehole diameter adjustment should be considered when the BHs having diameter larger than 12 cm, in this study the diameter of the drilling was 10 cm, so the correction factor (C_B) was taken (1). The measured N-value decreases as the confining pressure decrease as a result of increasing the borehole diameter. It's worth mentioning that many of these considerations are overlooked during site studies [1–3].

3. Study Area and Field Tests

The study area is the governorate of Al-Basrah, which was established in 636 AD and is located in southern Iraq at 30°30′29.1672″N and 47°47′0.5604″E on the Global Positioning System (GPS). This province is considered one of Iraq's most important cities due to serval factors. Firstly, it has the only and the main port in the country which is located in the south of the city and called UM QASER port. Secondly, it has numerous oil fields which make Al-Basrah one of the richest cities in the world. Boreholes were drilled to a depth of 10 meters below the ground level, with a ground surface elevation of approximately 5 meters above the sea level.

Boreholes were drilled throughout the study area, particularly along the two sides of Shatt Al-Arab River, which runs northwest to southeast through the city. The quality and level of the groundwater table significantly impact the magnitude of the allowable bearing capacity of the shallow foundation. The fieldwork had been conducted over a large area of Al-Basrah governorate; the drilled BHs were mostly conducted in available free lots, which reflected the non-uniform distribution of BHs in the study area. Also, BHs must be drilled in undeveloped properties to prevent conflicts with property owners and the restricted space available in the built area. To avoid any issues during drilling, the crew began by locating existing facilities such as sewage pipes, electrical cables, freshwater pipelines, and telephone, and internet connections within the study area.

The BHs were drilled with a flying auger with a diameter of 10 cm and extended to a depth of 10 m below ground level. Several SPTs were performed using an automatic hammer along the depth of BHs. On a Google Earth satellite view, Figure 1 shows drilled BHs distribution. In addition, Figure 2 shows the study area and distribution of BHs. The SPTs data were used to compute the bearing capacity of shallow foundation. Furthermore, after 24 hours of drilling, the GWT was measured in the field, and the density of the soil was calculated experimentally for each well. Because the groundwater level in some BHs had not risen after 24 hours, the GWT has no value in Table 1 and has no impact on the calculated bearing capacity. Table 1 shows the N-values measured from SPT tests conducted at several depths (1.5, 6, and 9.5 m below EGL) and the GWT for 135 BHs. Conducting successful SPTs in some BHs and at specific depths, such as BHs 80 and 84 in Table 1, were difficult due to the appearance of layers of very soft soil.

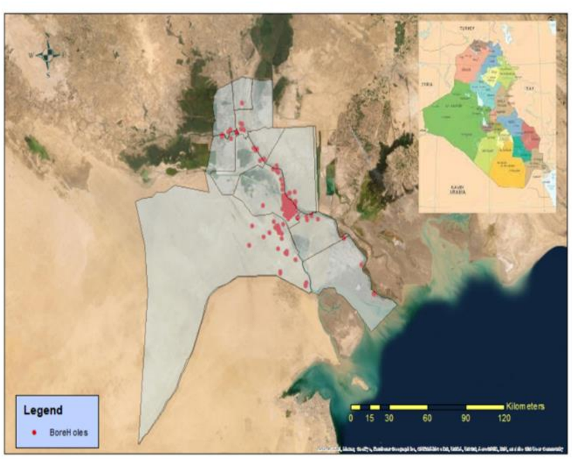

Figure 1. Distribution of drilled BHs on the satellite map.

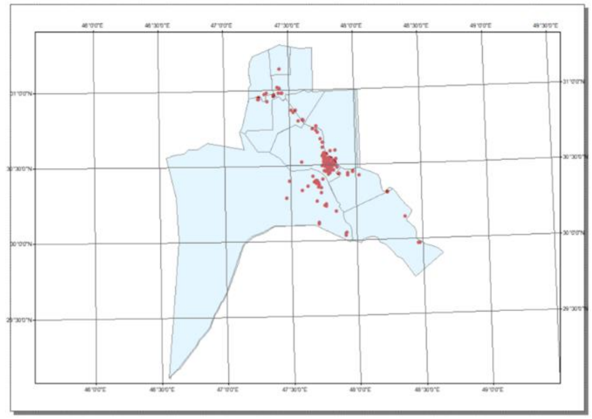

Figure 2. Locations of borehole used in the analysis.

4. Geographic Information System (GIS)

GIS is a science of collection, introduction, processing, analysis, display, and output geographic information system and qualifying for specific objectives [18]. This definition includes the ability of systems to introduce geographic information (maps, images, spacecraft) and descriptions (names, tables), process (mistakes), storage, retrieval, analysis (and statistical analysis), and displayed on the computer screen via reports and graphics [19,20]. The input process starts from identifying the database master plan for each feature class connected with its specific location and coordinates. Some of the information can be added manually. In contrast, other kinds of information can be directly extracted from the raster or satellite maps which can dramatically reduce the input process time and cost. The statistical features of the GIS can assist in examining the relationships between different sets of data for certain feature classes or between different feature classes [20,21]. Geographic information system (GIS) has great value in many applications, and it is considered a comprehensive system that has been developed with the development of advanced technology, and among these applications is the use of GIS in surveying engineering and civil engineering in all its branches [22].

Table 1. Coordinates, GWT, and measured SPT-value of BHs.

BH No.	GPS Coordinates		GWT (m)	N-Value			BH No.	GPS Coordinates		GWT (m)	N-Value		
	Latitude Degree	Longitude Degree		1.5 m	6 m	9.5 m		Latitude Degree	Longitude Degree		1.5 m	6 m	9.5 m
1	30.46324	47.76481	1.2	2	2	2	69	30.984759	47.3323	0.9	2	2	2
2	30.677667	47.737333	0.5	3	2	2	70	30.457774	47.983043	0.5	5	2	2
3	30.353224	47.736546	1	10	20	50	71	30.945994	47.270258	1	6	2	2
4	30.866987	47.548848	1	7	2	2	72	30.357404	47.715029	1	6	25	50
5	30.943651	47.263842	2.25	7	2	2	73	30.985692	47.422968	1	2	2	2
6	30.498979	47.846098	1.25	23	5	2	74	30.513353	47.819846	1	10	2	2
7	30.452369	47.979893	2.1	4	2	6	75	30.532567	47.780909	1.2	8	2	2
8	30.384517	47.715239	-	41	33	28	76	30.32028	47.73586	-	23	29	34
9	30.65027	47.750105	0.25	2	2	2	77	30.42647	47.67592	-	19	16	10
10	30.97454	47.31532	2	10	7	2	78	30.36121	47.63705	1	22	26	40
11	31.01347	47.427324	1.5	10	8	2	79	30.46789	47.83228	2	3	3	2
12	30.929563	47.337608	1	2	2	2	80	30.52529	47.59003	0.5	-	-	6
13	30.618512	47.751902	3	8	4	2	81	30.743122	47.678118	2	2	2	2
14	30.802983	47.608714	2	7	2	2	82	30.05258	47.92583	0.5	2	2	2
15	30.5068	47.835369	1.2	4	2	2	83	30.24478	47.77606	-	31	29	27
16	30.492526	47.815992	0.5	4	4	2	84	30.40101	47.49674	0.5	-	41	43
17	30.561206	47.770233	0.75	6	4	2	85	30.575532	47.76834	1.5	2	2	2
18	30.511275	47.824614	2	8	4	2	86	30.04477	47.91889	1.5	2	2	2
19	30.549429	47.813952	1.2	3	3	4	87	30.19468	47.84551	-	15	24	34
20	30.519017	47.784783	1	10	10	2	88	30.49137	47.7696	1.5	8	4	2
21	30.503642	47.805022	1.95	8	3	7	89	30.43096	48.03027	2.5	2	2	2
22	30.5143	47.844199	1.2	2	2	2	90	29.582635	48.27309	1.25	2	2	2
23	30.451235	47.808062	0.25	7	3	3	91	30.487565	47.802265	1.5	8	2	3
24	30.476148	47.80068	1.25	6	2	3	92	30.43907	47.793667	0.5	3	2	3
25	30.398134	47.708611	1.5	14	18	35	93	30.498611	47.746389	0.5	2	2	2
26	30.524343	47.761026	1.5	8	4	3	94	30.558264	47.761877	0.5	2	2	2
27	30.542873	47.791312	1.5	12	6	3	95	30.410137	47.750771	-	11	19	30
28	30.545661	47.775351	2.1	8	2	5	96	30.548722	47.790806	0.75	8	3	3
29	30.528592	47.800295	0.8	9	6	3	97	30.483453	47.810493	1.5	8	2	5
30	30.444847	47.876889	1.2	2	2	2	98	30.511952	47.767686	1.5	8	4	4
31	30.562611	47.752161	1.8	7	2	2	99	30.514264	47.835641	1.2	8	5	3
32	30.46125	47.775306	1.0	6	2	3	100	30.504509	47.795087	0.95	8	2	2
33	30.492161	47.8001	1.4	10	4	3	101	30.468246	47.820135	2.1	18	13	2
34	30.528288	47.828266	1.25	8	7	11	102	30.380307	47.702145	10	34	38	35
35	30.542023	47.853618	0.25	7	6	4	103	30.759306	47.7045	0.25	6	2	2
36	30.490531	47.780647	1.63	8	4	4	104	30.261936	47.704736	-	9	10	17
37	30.574453	47.753307	0.5	6	2	2	105	30.485403	47.811495	1	4	3	2
38	30.388941	47.683118	1.0	12	25	50	106	30.467966	47.813826	0.6	4	4	2
39	30.5079	47.777086	0.5	8	3	3	107	30.465589	47.780119	2.1	8	3	3
40	30.369006	47.721302	10	13	18	26	108	30.28501	47.47257	1.2	8	2	3
41	30.448513	47.941167	3.5	5	2	2	109	30.543719	47.761162	2.2	8	3	4
42	30.516736	47.805846	0.9	8	2	3	110	30.315603	48.242598	2.5	2	2	2
43	30.79525	47.573028	0.25	2	2	2	111	30.541672	47.785828	0.7	9	6	5
44	30.545003	47.804686	0.5	6	3	4	112	30.538565	47.793098	1	10	4	2
45	30.123251	47.71726	-	50	45	42	113	30.548753	47.800998	1.1	7	6	4
46	30.506425	47.759875	0.5	4	4	6	114	30.524387	47.798975	1.1	4	4	2
47	29.973944	48.468417	-	2	2	2	115	30.578647	47.781908	1	2	2	2
48	30.719042	47.718392	1.25	6	2	2	116	30.524472	47.847061	1	6	4	2

BH No.	GPS Coordinates		GWT (m)	N-Value			BH No.	GPS Coordinates		GWT (m)	N-Value		
	Latitude Degree	Longitude Degree		1.5 m	6 m	9.5 m		Latitude Degree	Longitude Degree		1.5 m	6 m	9.5 m
49	30.594667	47.809473	2.1	10	8	2	117	30.114687	47.715509	-	50	48	46
50	30.458433	47.791947	1.2	4	2	4	118	30.233761	47.760731	1	46	40	35
51	30.98478	47.44377	1.0	8	7	2	119	29.971258	48.476035	1	2	2	2
52	30.489653	47.823968	3	8	3	4	120	30.44163	47.869875	2.2	6	2	2
53	30.483358	47.859833	2.1	2	2	2	121	30.732536	47.703688	1.25	6	2	2
54	30.399438	47.695805	-	33	22	35	122	30.805461	47.601909	2	6	2	2
55	30.33382	47.59058	-	50	45	42	123	30.855089	47.53756	2	2	2	2
56	30.506131	47.816672	2.1	8	2	5	124	30.981152	47.449086	0.25	7	2	2
57	30.3117	48.24045	1.5	2	2	2	125	30.971853	47.382546	0.25	2	2	2
58	31.020338	47.416235	1	8	2	2	126	30.956501	47.271284	0.25	4	2	2
59	30.431172	47.942036	4	2	2	2	127	31.015355	47.429864	0.5	8	2	6
60	30.583858	47.758782	3.2	12	8	2	128	31.144262	47.43092	2.5	2	7	2
61	30.032503	47.919989	2.5	19	23	14	129	30.149344	48.373275	1	2	2	2
62	30.22773	47.773719	-	29	25	30	130	30.513148	47.82633	1.25	4	2	2
63	30.963884	47.387458	2.6	10	2	2	131	30.541316	47.812604	1.5	7	2	2
64	30.541292	47.854056	2.1	5	10	2	132	30.510489	47.805907	2	3	2	4
65	30.540332	47.772309	1.2	10	4	5	133	30.5145	47.80936	0.5	3	3	3
66	30.870981	47.52157	1.25	2	2	2	134	30.598381	47.848881	1	5	2	2
67	30.583779	47.75878	1.25	5	2	2	135	30.4876	47.7983	2.1	14	3	2
68	30.480276	47.785883	0.5	8	5	5	-	-	-	-	-	-	-

The integration between GIS and the science of civil engineering has provided many techniques for the purpose of representing the earth's surface with three-dimensional models of any study area in the world [23]. These models are created using many techniques, for example, field survey, photogrammetry, satellite images, laser scanning, and others. These techniques made it easier for those interested in studying the characteristics of the study area, such as geotechnical, topographic, and hydrological properties, and others. These techniques may differ in their accuracy, cost, and time [24]. It is possible to decide which land will be the most bearable if the information on the bearing capacity of an area's soil can be linked to aerial photos of the location, along with some tabular data on soil, geology, and inclination trends. This study can be aided by a geographic information system, which can employ data from a variety of sources in a variety of formats. Different data locations can be marked in the two axes (X and Y) to reflect latitude and longitude or other systems of coordinates [20,21].

5. Bearing Capacity of Soil

In general, the bearing capacity of soil is the key to geotechnical specialists, as most of the geotechnical project is based on the bearing capacity of the soil. Heterogeneity, the laying of soil layers leads to a large variation in the bearing capacity of soil values, which requires more effort, time, and cost to perform a reliable soil investigation. In some cases, the structural loads are minor and do not require careful soil investigations.

Therefore, available approximate equations based on numerical or regression analyses can be used with reliable confidence to estimate soil bearing capacity. The results of SPTs can also be used to evaluate the allowable bearing capacity of soil in most soil investigation reports and for preliminary design purposes.

This test has an international reputation and is well-known in most countries, so it can be conducted by individuals with little experience at different depths within drilled BHs [25-27]. The total number of drilled BHs was 135; however, only 95 BHs were considered as valid and were employed in the present study to decrease numerical dispersion generated by high variations in SPT values in some regions, which impacted the reliability of regression analysis results obtained with GIS software.

The bearing capacity of the soil was determined at depths of 1.5, 6, and 9.5 m in 95 BHs drilled at a depth of 10 m below current ground level and distributed through Al-Basrah city. Following the corrections, the allowable bearing capacity of the soil was determined to use the results of SPTs conducted at different depths for each borehole. When determining the allowable bearing capacity of the soil, a high safety factor of 3 is assumed due to the soil heterogeneity, high groundwater table, and high concentrations of organic matter and waste.

The overburden correction factor (C_N), as given by Equation 4, the energy correction factor (C_E), which is equal to 0.7, and the groundwater correction (C_W), as determined in Equations (2) or (3), are the main corrections used to the measured SPT values in this study. The corrected N-values can be used to calculate the bearing capacity of the soil. Table 2 shows the borehole coordinates as well as the calculated allowable bearing capacity of soil based on raft footing. Eqs. 4 to 9, given below, are used to calculate the ultimate bearing capacity of the soil, with a safety factor of 3. Due to a large amount of space required to show such data, the large amount of data used in calculating the ultimate bearing capacity for different depths in 95 BHs will not be presented in this study [28,29].

$$q_{ult.net} = \frac{N_{1(60)}}{0.08}\left(\frac{B+0.3}{B}\right)^2 F_d\left(\frac{S_e}{25}\right) \quad (4)$$

Equation (5) can be approximated for a raft foundation with a large width:

$$q_{ult} = \frac{N_{1(60)}}{0.08} F_d\left(\frac{S_e}{25}\right) \quad (5)$$

$$F_d = 1 + 0.33\left(\frac{D_f}{B}\right) \leq 1.33 \quad (6)$$

where:

$q_{ult.net}$ = the net ultimate bearing capacity of the soil (kN/m^2);

B = the foundation's width or diameter (m);

The soil settlement (S_e) is in mm. It is assumed to be 25 mm in this study [30]. Additionally, $D_f/B = 1$ is assumed, resulting in a higher value for D_f and q_{all}. The following equations can be used to calculate the allowable bearing capacity of soil

$$q_{all} = q_{all.net} + \gamma' D_f \quad (7)$$

$$q_{all.net} = \frac{q_{ult,net}}{FS} \quad (8)$$

$$q_{all} = \frac{q_{ult,net}}{FS} + \gamma' D_f \quad (9)$$

where

q_{all} = the allowable bearing capacity of soil;

qult.net = the net ultimate bearing capacity;

γ' = the effective unit weight= (γ_{sat}-γ_w);

D_f = the depth of footing placement; and

FS = the safety factor (assumed to be 3.)

Table 2. Coordination of drilled BHs and allowable bearing capacity of soil calculated based on corrected N-values of SPTs.

BH No.	Depth (m)	$N_{1(60)}$	q_{all} (kN/m^2)	BH (No.)	Depth (m)	$N_{1(60)}$	q_{all} (kN/m^2)	BH No.	Depth (m)	$N_{1(60)}$	q_{all} (kN/m^2)
1	1.5	2.33	23.7	39	1.5	9.78	64.99	91	1.5	9.14	48.79
	6	1.85	53.38		6	2.88	59.08		6	1.82	53.22
	9.5	1.59	77.12		9.5	2.46	81.96		9.5	2.35	81.34
2	1.5	3.67	31.11	40	1.5	9.55	63.73	92	1.5	3.67	31.11
	6	1.92	53.77		6	11.35	106.05		6	1.92	53.77
	9.5	1.64	77.41		9.5	14.77	150.14		9.5	2.46	81.96
3	1.5	11.81	76.26	41	1.5	5.05	38.79	93	1.5	2.45	24.34
	6	16.33	133.65		6	1.65	52.27		6	1.92	53.77
	9.5	26.07	212.8		9.5	1.44	76.28		9.5	1.64	77.41
6	1.5	26.72	84.83	42	1.5	9.52	63.52	94	1.5	2.45	24.34
	6	4.61	68.66		6	1.88	53.54		6	1.92	53.77
	9.5	1.59	77.1		9.5	2.42	81.7		9.5	1.64	77.41
7	1.5	4.4	35.16	44	1.5	7.34	51.44	95	1.5	8.08	55.58
	6	1.76	52.91		6	2.88	59.08		6	11.98	109.54
	9.5	4.58	93.7		9.5	3.28	86.51		9.5	17.04	162.73
8	1.5	30.13	94.27	46	1.5	4.89	37.89	96	1.5	9.61	64.06
	6	20.81	100.8		6	3.84	64.4		6	2.84	58.87
	9.5	15.9	112.37		9.5	4.93	95.61		9.5	2.43	81.8
9	1.5	2.49	24.58	49	1.5	11	71.73	97	1.5	9.14	61.45
	6	1.94	53.92		6	7.05	82.22		6	1.82	53.22
	9.5	1.66	77.51		9.5	1.53	76.77		9.5	3.92	90.04
13	1.5	8.33	56.93	50	1.5	4.66	36.62	98	1.5	9.14	61.45
	6	3.37	61.83		6	1.85	53.38		6	3.64	63.29
	9.5	1.47	76.45		9.5	3.18	85.93		9.5	3.14	85.69
15	1.5	4.66	36.62	52	1.5	8.33	56.93	99	1.5	9.33	62.46
	6	1.85	53.38		6	2.53	57.16		6	4.62	68.73
	9.5	1.59	77.12		9.5	2.94	84.6		9.5	2.39	81.52
16	1.5	4.89	37.89	53	1.5	2.2	22.97	100	1.5	9.48	63.34
	6	3.84	64.4		6	1.76	52.91		6	1.87	53.51
	9.5	1.64	77.41		9.5	1.53	76.77		9.5	1.61	77.22
17	1.5	7.21	50.74	54	1.5	24.25	77.98	101	1.5	19.8	65.64
	6	3.78	64.11		6	13.87	81.58		6	11.46	106.65
	9.5	1.62	77.3		9.5	19.88	123.38		9.5	1.53	76.77
18	1.5	8.85	59.85	55	1.5	36.75	112.6	102	1.5	24.99	80.02
	6	3.54	62.78		6	28.38	121.77		6	23.96	109.54
	9.5	1.53	76.81		9.5	23.85	134.4		9.5	19.88	123.38
19	1.5	3.5	30.16	56	1.5	8.8	59.54	104	1.5	6.61	47.44
	6	2.77	58.49		6	1.76	52.91		6	6.31	78.09
	9.5	3.18	85.93		9.5	3.82	89.47		9.5	9.66	121.81
20	1.5	11.81	76.26	59	1.5	1.96	21.67	105	1.5	4.73	36.97
	6	9.33	94.86		6	1.61	52.06		6	2.8	58.66
	9.5	1.6	77.2		9.5	1.41	76.12		9.5	1.6	77.2
21	1.5	8.88	60.01	60	1.5	12.34	79.19	106	1.5	4.86	37.7
	6	2.66	57.91		6	6.68	80.17		6	3.81	64.28
	9.5	5.38	98.13		9.5	1.46	76.38		9.5	1.63	77.36
22	1.5	2.33	23.7	62	1.5	21.31	69.84	107	1.5	8.8	59.54
	6	1.85	53.38		6	15.77	86.82		6	2.64	57.8
	9.5	1.59	77.12		9.5	17.04	115.52		9.5	2.29	81
23	1.5	8.71	59.06	64	1.5	5.5	41.26	109	1.5	8.74	59.24

BH No.	Depth (m)	$N_{1(60)}$	q_{all} (kN/m^2)	BH (No.)	Depth (m)	$N_{1(60)}$	q_{all} (kN/m^2)	BH No.	Depth (m)	$N_{1(60)}$	q_{all} (kN/m^2)
	6	2.92	59.3		6	8.82	92		6	2.63	57.72
	9.5	2.49	82.12		9.5	1.53	76.77		9.5	3.04	85.16
	1.5	6.97	49.42		1.5	11.66	75.38		1.5	10.85	70.93
24	6	1.84	53.35	65	6	3.69	63.61	111	6	5.69	74.68
	9.5	2.38	81.49		9.5	3.98	90.33		9.5	4.07	90.85
	1.5	16	99.45		1.5	5.81	42.98		1.5	11.81	76.26
25	6	15	126.27	67	6	1.84	53.35	112	6	3.73	63.83
	9.5	19.61	176.97		9.5	1.59	77.1		9.5	1.6	77.2
	1.5	9.14	61.45		1.5	9.78	64.99		1.5	8.21	56.31
26	6	3.64	63.29	68	6	4.79	69.71	113	6	5.57	74.01
	9.5	2.35	81.34		9.5	4.11	91.06		9.5	3.19	86.01
	1.5	13.71	86.79		1.5	6.11	44.66		1.5	4.69	36.8
27	6	5.45	73.37	70	6	1.92	53.77	114	6	3.71	63.72
	9.5	2.35	81.34		9.5	1.64	77.41		9.5	1.6	77.16
	1.5	8.8	59.54		1.5	7.09	50.07		1.5	2.36	23.88
28	6	1.76	52.91	72	6	18.67	146.58	115	6	1.87	53.48
	9.5	3.82	89.47		9.5	26.07	212.8		9.5	1.6	77.2
	1.5	10.78	70.52		1.5	11.81	50.07		1.5	7.09	50.07
29	6	5.66	74.51	74	6	1.87	53.48	116	6	3.73	63.83
	9.5	2.43	81.77		9.5	1.6	77.2		9.5	1.6	77.2
	1.5	2.33	23.7		1.5	9.33	41.79		1.5	36.62	112.27
30	6	1.85	53.38	75	6	1.85	53.38	118	6	26.13	115.55
	9.5	1.59	77.12		9.5	1.59	77.12		9.5	20.06	123.88
	1.5	7.85	54.27		1.5	16.9	81.04		1.5	6.56	47.12
31	6	1.79	53.06	76	6	18.29	119.15	120	6	1.75	52.86
	9.5	1.55	76.88		9.5	19.31	148.56		9.5	1.52	76.73
	1.5	7.09	50.07		1.5	7.35	51.51		1.5	4.65	36.54
32	6	1.87	53.48	77	6	1.26	50.13	130	6	1.84	53.35
	9.5	2.41	81.64		9.5	1.14	74.6		9.5	1.59	77.1
	1.5	11.5	74.53		1.5	18.73	88.65		1.5	8	55.12
33	6	3.66	63.4	78	6	17.05	111.56	131	6	1.82	53.22
	9.5	2.36	81.4		9.5	19.07	133.17		9.5	1.57	77
	1.5	9.29	62.29		1.5	3.32	29.18		1.5	3.32	29.18
34	6	6.45	78.87	79	6	2.66	57.87	132	6	1.77	52.96
	9.5	8.73	116.66		9.5	1.53	76.81		9.5	3.07	85.31
	1.5	8.71	59.06		1.5	0	-		1.5	3.67	31.11
35	6	5.83	75.47	80	6	0	-	133	6	2.88	59.08
	9.5	3.32	86.72		9.5	4.22	91.71		9.5	2.46	81.96
	1.5	9.07	61.03		1.5	22.78	86.54		1.5	5.91	43.52
36	6	3.61	63.16	83	6	18.29	103.95	134	6	1.87	53.48
	9.5	3.12	85.59		9.5	15.33	119.29		9.5	1.6	77.2
	1.5	7.34	51.44		1.5	2.29	23.45		1.5	15.4	53.45
37	6	1.92	53.77	85	6	1.82	53.22	135	6	2.64	57.8
	9.5	1.64	77.41		9.5	1.57	77		9.5	1.53	76.77
	1.5	14.18	89.35		1.5	9.14	48.79		-	-	-
38	6	18.67	146.58	88	6	3.64	63.29	-	-	-	-
	9.5	26.07	212.8		9.5	1.57	77		-	-	-

6. GIS Modeling of SPT Data

To produce a thematic map indicating the variance in the allowable bearing capacity of shallow foundation at several depths in the research region, GIS was used to process the data of SPTs conducted at 135 BHs. Because of the high variance and maybe a singularity in the results of SPTs conducted at several depths in 135 BHs, it's important to avoid using extreme SPT values when calculating the allowable bearing capacity of shallow foundation with GIS. These extremes could be the consequence of a small number of BHs being drilled in particular sections of the study area or a large difference in the geotechnical properties of soil in some locations of the study area.

There are two interpolation procedures that can be used to produce a thematic map showing soil bearing capacity point data. Firstly, the deterministic interpolation procedures, which contains four methods Inverse Distance Weighted (IDW) method, Local Polynomial Interpolation (LPI) method, Radial Basis Functions (RBF) method, and Global Polynomial Interpolation (GPI) method. These methods generate a layer reliant on either the similarity or the grade of homogeneousness of the inspected points. Secondly, the geostatistical interpolation procedures containing the Ordinary Kriging (OK) method and the Empirical Bayes Kriging (EBK) method can be used for the point feature class. These two methods are statistically influential interpolation methods based on the spatial correlation, which manages the distance or the direction between model points and makes them a good choice to clarify surface spatial variation [31]. Despite the importance of the aforementioned methods, the IDW method has be considered as the best method to produce the allowable bearing capacity final map that can be used for preliminary engineering design [32]. Figures 3 to 5 illustrate the thematic maps for soil bearing capacity variation at depths 1.5, 6, and 9.5 m for 95 BHs.

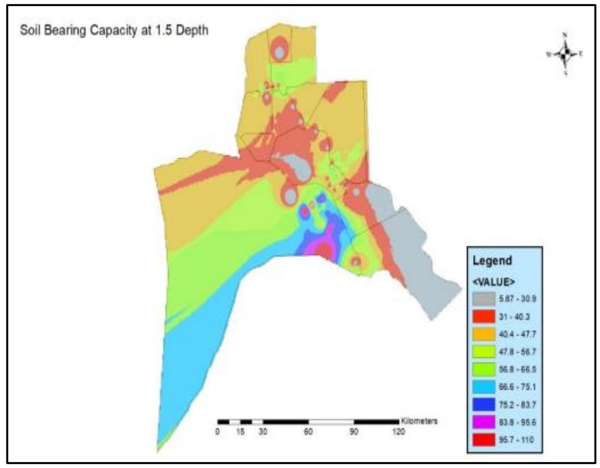

Figure 3. Thematic map showing the variation in the allowable bearing capacity of shallow foundation at depth of 1.5 m.

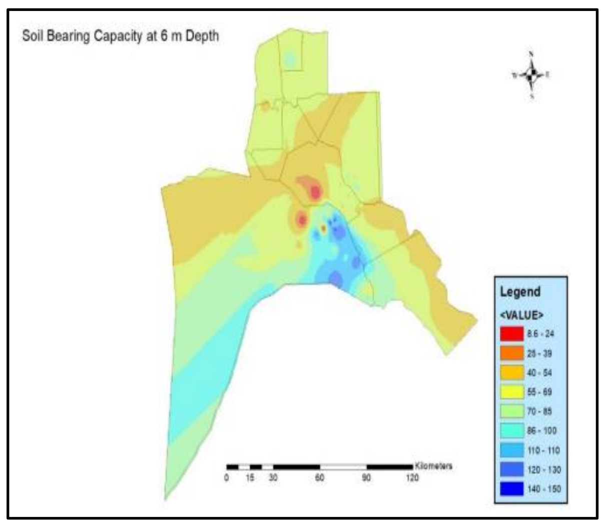

Figure 4. Thematic map showing the variation in the allowable bearing capacity of shallow foundation at depth of 6 m.

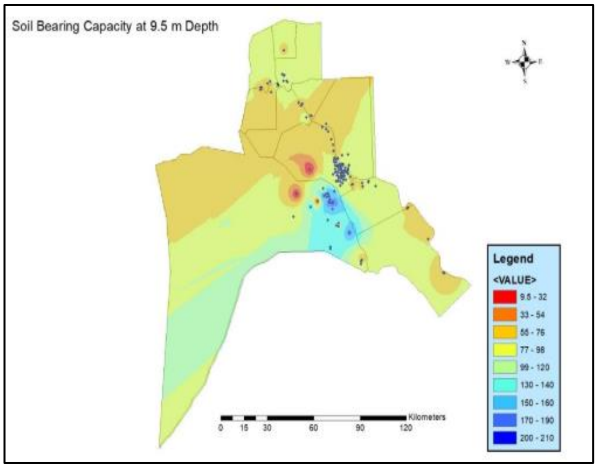

Figure 5. Thematic map showing the variation in the allowable bearing capacity of shallow foundation at depth of 9.5 m.

The extracted thematic map of the SBC by the IDW method specifies that the allowable Bearing Capacity ranges between 5 to 110 kN/ m^2 at a depth of 1.5 m and 8 to 150 kN/m^2 at a depth of 6 m and 9.5 to 210 kN/m^2. Al-Basrah city center bearing capacity range between 40 to 70 kN/m^2. Generally, some areas have the weakest SBC starting from Abu Al-Khaseeb district heading south to Al-Faw city which is located on the Gulf. In addition, some marches areas and agriculture are located north of Al-Basrah city.

Considerably, the bearing capacity reached a high level in some areas located in the west part of Al-Basrah province, such as Al-Zubair district, where the SBC reached 210 kN/m^2 at level 9 m. This sympathetic map propositions a significant base knowledge for the study area; also, it helps to understand the data visually. In addition, implementing these maps will support reduced expenditures along with time and effort. The additional benefit of creating thematic maps with geotechnical data for soil is to guide the designers and authorities to choose the best alternative for any project design, the most appropriate foundation design, and the proper soil treatment needed.

7. Conclusions

From the output results of this research, the following points can be drawn

- The SPTs carried out in the study area reflect broad view of the differences in the allowable bearing capacity of soil across Al-Basrah governorate.
- GIS software can be used to create thematic maps showing the changes in the allowable bearing capacity of shallow foundation as a function of geographic coordinates. This technique can be considered one of the promising sustainable techniques.
- The suggested thematic maps can be used easily to find the allowable bearing capacity of shallow foundation will save time and money, especially for small scale projects.
- The SPTs data showed increasing the bearing capacity of foundation with increasing the depth. Also, its noted that southern regions of Al-Basrah governorate are weak in comparison with northern regions.
- Thelocal authorities in Al-Basrah can use these maps to calculate the bearing capacity of shallow foundations by knowing the coordinates of site.
- Theproduced maps can be utilized easily to assess the foundations of existing and irregularly constructed buildings and to assess the extent of the risks of failure and collapse that maybe occure due to random construction of buildings.

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