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Spatial Distribution of Engineering Soil Properties in the Northern Region of the Dead Sea, Jordan

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ABSTRACT

The main thrust of this research paper is to present a spatial distribution for the engineering soil properties in the northern region of the Dead Sea, Jordan, using Arc GIS (geographic information system). Also, this study aimed at recommending possible foundation type and depth of embedment of proposed structures within the study area to comfort engineers in conducting the intended preliminary geotechnical reports by offering GIS maps for the study area. This study was carried out in two stages, where data was collected from 222 boreholes and test pits were related to the existing engineering structures in the first stage and then geo-statistical interpolation was conducted using kriging GIS technique as a second stage. GIS maps, including standard penetration test (SPT) maps, cohesion maps, friction angle maps, bearing capacity maps and pile capacity maps, were extracted based on soil data collection, analysis and characterization of the study area at different depths. As a result, for map data extraction using GIS, maps for engineering soil properties and allowable bearing capacity at depths of 3m, 6m and 10m were created. Also, pile capacity maps were created for diameters of 305mm, 406mm and 610mm for piles of 10m and 15m lengths within the study area.

KEYWORDS: GIS, Soil properties, Spatial distribution, Zonation, Kriging.

INTRODUCTION

The Dead Sea has attracted attention from ancient times as it does today. Tourist activity is concentrated in the northeastern part of the Dead Sea, where many hotels are concentrated. The region contains good infrastructure and many private projects (resorts, restaurants and hotels). Due to the increasing attention from the Jordanian authorities and investors to the Dead Sea area, plenty of projects have been carried out, especially with the increasing number of tourists coming from either local or international destinations. Consequently, to meet the requirements of the growing number of tourists, new infrastructure projects are planned to be carried out at this blooming region. For companies, it is used to be the norm to give a study on the budget to be spent on new projects. For such a budget to be reliable, preliminary geotechnical reports usually need to be conducted to check adequacy and give recommendations about the most suitable foundation types based on soil stratification and available geotechnical data of the intended area and, consequently, to include them in the proposed budget.

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Describing geotechnical data and analyzing its spatial distribution have played a key role in managing soils for several land uses. To this end, many geotechnical engineers studied these properties due to increasing demand in several applications, such as construction, infrastructure and environmental projects. One of the best ways to organize and analyze data is to use a Geographic Information System (GIS). This technique helps in visualizing and explaining data in order to understand the relationships between variables and patterns.

Many studies have been conducted using GIS as an efficient tool in manipulating geotechnical engineering data. Sugimoto (2007) defined GIS as a digital cartographic database that contains the locations and characteristics within a specific region, with additional data about conditions at these locations. GIS has been recently used in different fields. Rusko et al. (2010) mentioned many applications using GIS, such as natural resource management, environmental applications (data on rocks, water and soil) and land management.

Using (GIS) and Global Positioning System (GPS) and based on existing soil reports, Mhaske and Choudhury (2009) developed a methodology for mapping the important properties of soil, such as specific gravity, wet density, moisture content and dry density in a trial to help soil exploration agencies and practicing geotechnical engineers to make immediate decisions on soil suitability as foundation material in Mumbai city. In a similar study, Orhan and Tosun (2009) used the results of geotechnical engineering properties of soil laboratory as a database in GIS; then, soil classification, uniaxial compression strength and standard penetration test zonation maps were created at different depths in Turkey.

Al-Ani et al. (2013) proposed that GIS-based zonation maps would provide a better overview of bed rock elevations, subsurface geology and geotechnical properties of different soil types found in Australia. In order to reduce the high seismic risk of Tehran, Razmyar and Eslami (2016) collected geological data and analyzed geotechnical data obtained from boreholes in the study area in order to prepare geotechnical zoning maps.

Based on the above mentioned introduction, this study aims at collecting geotechnical data from different projects in the study area and analyzing soil data collected from available geotechnical reports and boreholes in the study area. Also, it is the purpose of this study to give recommendations about possible foundation type and possible depth of embedment which may help geotechnical firms in conducting preliminary geotechnical reports within the study area by offering GIS maps for the study area that offer type of foundation and geotechnical properties of the soil.

STUDY AREA AND GENERAL GEOLOGY

General

This study was carried out in the northern region of the Dead Sea (Jordan), which is considered the lowest spot on Earth; currently, about 410 m below sea level. It covers about 23 km^2 and is located between latitude 32°36'14.50"N to 33°13'56.99"N and longitude 44°52'01.65"E to 45°20'52.70"E (Fig. 1).

Geological Formation of the Study Area

According to information obtained from geological maps of the Ministry of Energy and Mineral Resources, this study area is seen as covered by alluvial fan sediments composed of boulder, cobbles and limestone with clayey-silty sand filling the spaces between the coarser fractions. In addition, the general study area belongs to Lisan formation of the Jordan Valley Group of Quaternary period and Pleistocene epoch. This formation consists predominantly of millimeter-to-centimeter-laminated, very weak, friable, low-density, white, calcareous mudstone with alternating white marl, greenish brown clay and evaporates as shown in Fig. 2.

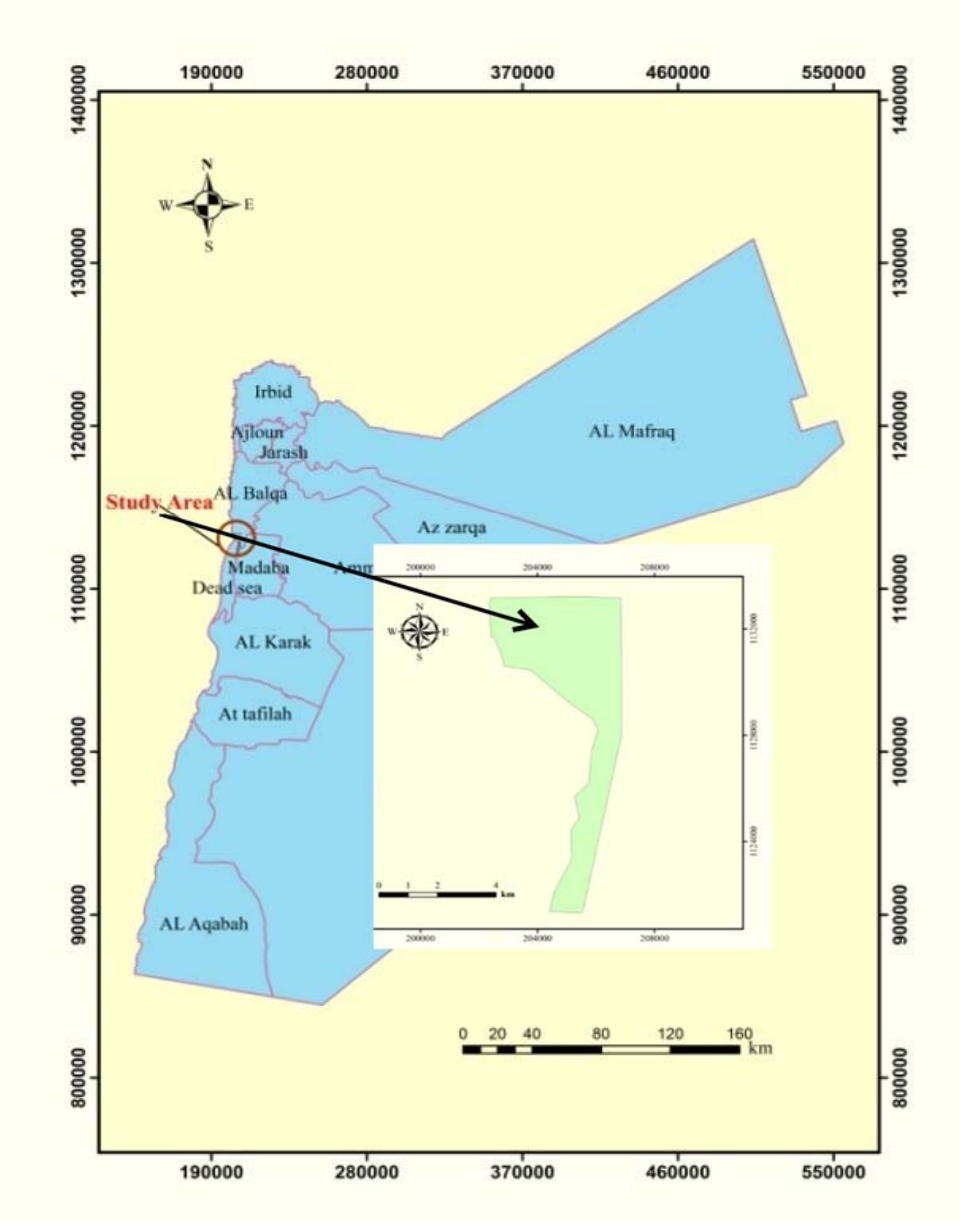


Figure (1): Jordan map and the study area location

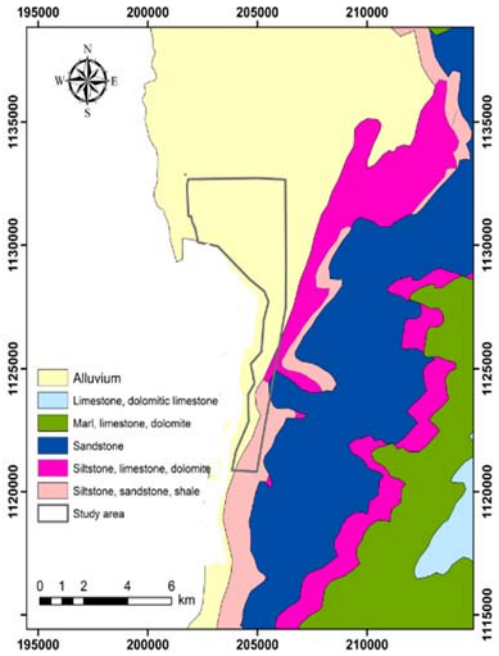


Figure (2): The geological formation of the study area

RESEARCH METHODOLOGY AND ANALYSIS

This study is carried out in two stages: the first is accomplished by using a geotechnical technique, while the second is accomplished by using GIS technique.

Stage One: The geotechnical technique includes data collection and data analysis, using specific formulae and empirical correlations. The data collected includes data obtained from fourteen (14) geotechnical reports. Each report showed the location of each borehole, its elevation, depth, laboratory tests, *in-situ* tests, chemical analysis and groundwater conditions. Moreover, the reports contained geological maps and general site characteristics of the Dead Sea region, which included information about climatic conditions (temperature, humidity, rainfall and wind), geological history and seismicity.

The data was collected from various sources including engineering offices in Amman (e.g. Arab Center for Engineering Studies), Royal Jordanian Geographic Centre, Jordan Development Zones (JDZ) Company, Jordan Investment Commission (JIC) and Ministry of Energy and Mineral Resources.

The most important step in this research is data analysis, which follows data collection. In this step, we used specific formulae to determine engineering soil properties, such as plasticity index, soil classification and depth of embedment.

Due to relative lack of information in this research, some parameters were determined using empirical correlations; those included plasticity description, shear strength parameters (undrained shear strength and friction angle) and allowable bearing capacity. Many empirical correlations among soil properties have been found. Nassaji and Kalantari (2011) used SPT to determine undrained shear strength of fine grained soil using a multi-linear regression analysis from SPSS software in the eastern and southern parts of Iran. Daoud et al. (2016) utilized the Amended Theil Inequality Coefficient (ATIC) method to evaluate geotechnical correlation that relates compression index with the initial void ratio according to investigation reports collected from Egypt, UAE, Iraq and Indonesia.

In this research, friction angles were derived based

on the empirical relations between SPT and the friction angle results of Meyerhoff (1956) as shown in Table 1. Furthermore, in Table 2, correlation between unconfined compression strength (q_u) and SPT results (Terzaghi and Peck, 1948) was used to obtain the undrained cohesion values (c_u).

Table 1. Correlations between friction angle and SPT results (Meyerhoff, 1956)

N-value	Friction angle ϕ (degree)
< 4	< 30
4-10	30-35
10-30	35-40
30-50	40-45
> 50	> 45

Table 2. Correlation between unconfined compression strength (q_u) and SPT results (Terzaghi and Peck, 1948)

N-value	q_u (kN/m^2)
0-2	< 25
2-4	25-50
4-8	50-100
8-15	100-200

The final step in this stage is recommendation of the type of foundation and depth of the embedment lengths in the study area.

Fang (2013) explained that shallow foundations are selected when the soil has moderately good strength, except for the raft foundation which is good in poor conditions of soil and useful to control differential settlement. Additionally, raft foundation is used if the structure walls are so close to each other that they would cause individual footings to overlap. In the current study, raft foundation is the type selected in the study area, with recommended settlement of 25 mm and factor of safety equal to 3. Also, the allowable bearing capacity values were calculated according to Das (2015). Moreover, a geotechnical engineer would recommend a deep foundation due to some reasons having to do, for example, with large design loads and poor soil at shallow depths. Driven steel piles are used in deep foundations to transfer the structure load to stronger soil strata, so this type is recommended in this research and the pile capacity values were calculated based on Das (2015), too.

Stage Two: In this part, all the required parameters were tabulated in excel spread sheets, including their X, Y locations which were obtained from the data source. Data was converted into digital points as shape files. The point shape files were used to create surfaces by using interpolation tool box. The software offers different geo-statistical interpolation techniques: Inverse Distance Weighted (IDW) method, trend method, density method and kriging method. Mathematical descriptions and differences between these methods were described by Mitas and Mitasova (1999) and Chai et al. (2011). Ordinary kriging method which produces strongly smoothed model results is used in this research to extract geotechnical maps.

RESULTS AND DISCUSSION

GIS maps were extracted based on soil data collection, analysis and characterization of the study area at different depths as follows:

- SPT (N-value) zonation maps.
- Cohesion maps.
- Friction angle maps.
- Allowable bearing capacity maps.
- Pile capacity maps.

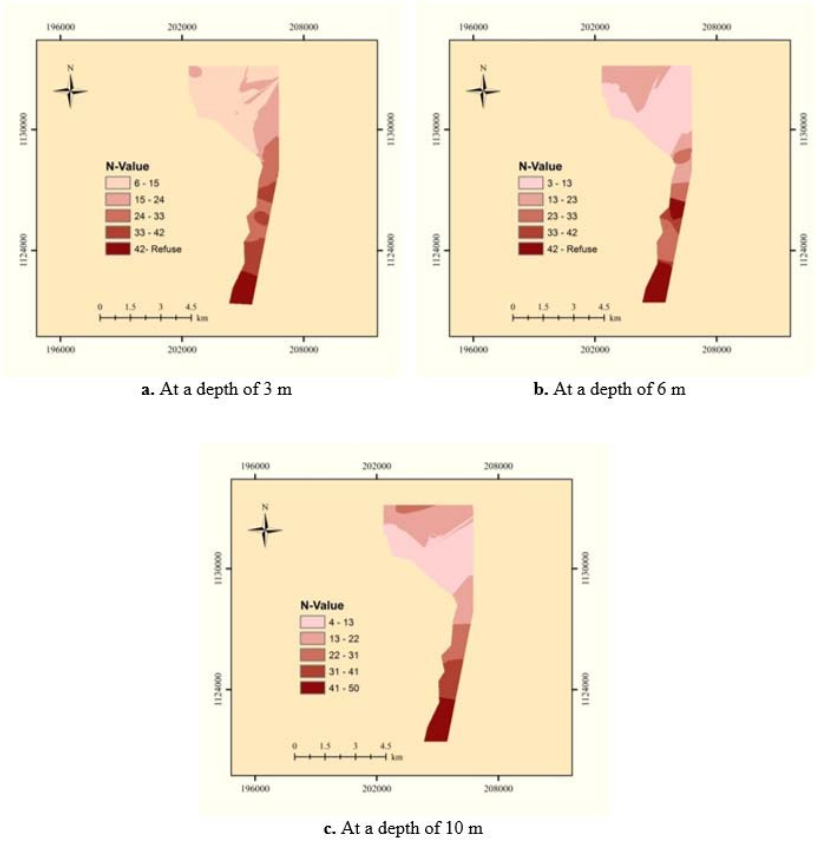
SPT (N-value) Zonation Maps

The zonation maps showed the variation of N-value with depth (Fig. 3) as follows: at a depth of 3m, the N-value ranged from 6 to more than 50 blows, while it decreased at a depth of 6m and ranged from 4 to 50 blows, then it ranged also between 4 and 50 blows at a 10-m depth.

Further, the soil could be classified according to the empirical relations between consistency and SPT results (Terzaghi and Peck, 1948) as shown in Table 3. In addition, the empirical relations between soil packing and SPT results (Meyerhoff, 1956) are shown in Table 4. So, high values of N indicated very dense sand or hard clay, whereas low values reflected very loose sand or very soft clay.

Cohesion Maps

Maps of cohesion values show the following: at a 3-m depth, the maximum cohesion values ranged from 72 kN/m^2 to 96 kN/m^2. There was an increase with depth up to 6 m; then, there was a slight decrease at a depth of 10 m due to differences in soil types as shown in Fig. 4.



a. At a depth of 3 m

b. At a depth of 6 m

c. At a depth of 10 m

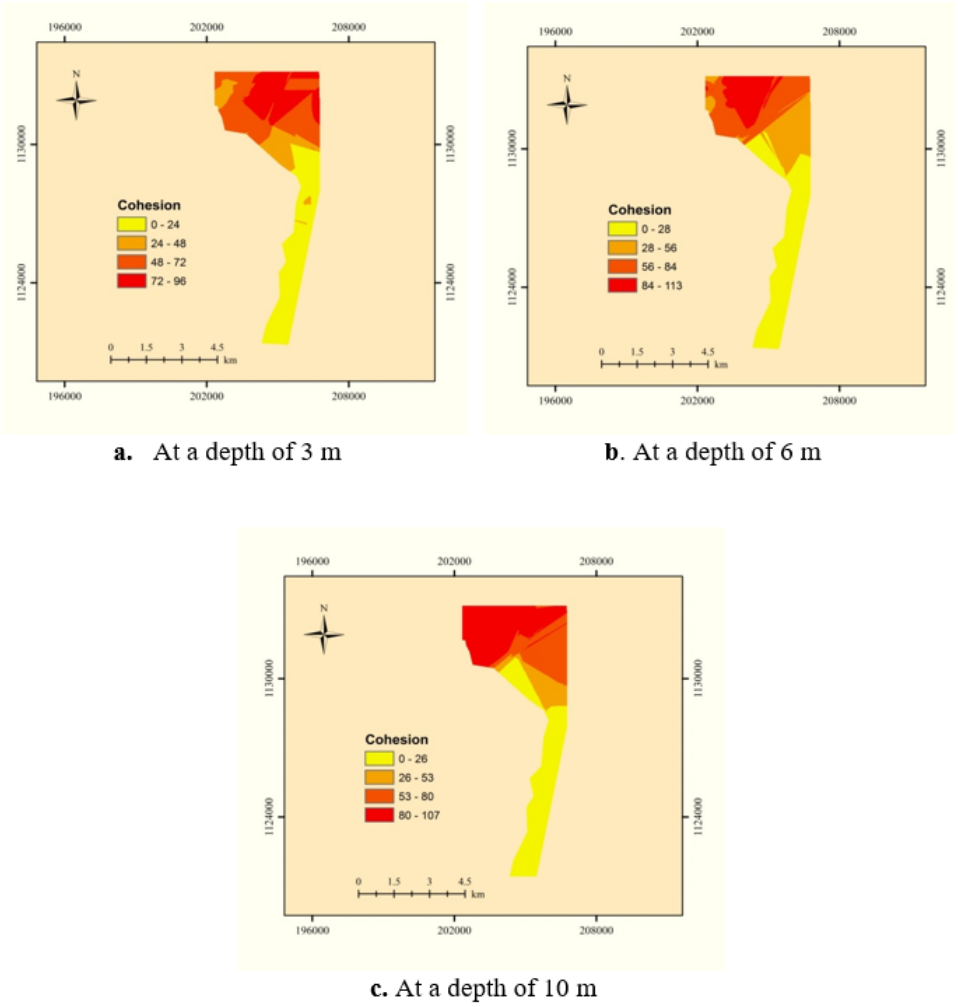
Figure (3): SPT (N-value) maps at different depths

Table 3. Correlation between consistency of cohesive soil and SPT results (Terzaghi and Peck, 1948)

N-value	Consistency
0-2	Very soft
2- 4	Soft
4-8	Medium
8-15	Stiff
15-30	Very stiff
< 30	Hard

Table 4. Correlation between soil packing and SPT results (Meyerhoff, 1956)

N-value	Soil packing
> 4	Very loose
4-10	Loose
10-30	Compact
30-50	Dense
< 50	Very dense



a. At a depth of 3 m

b. At a depth of 6 m

c. At a depth of 10 m

Figure (4): Cohesion maps at different depths (kN/m^2)

Friction Angle Maps

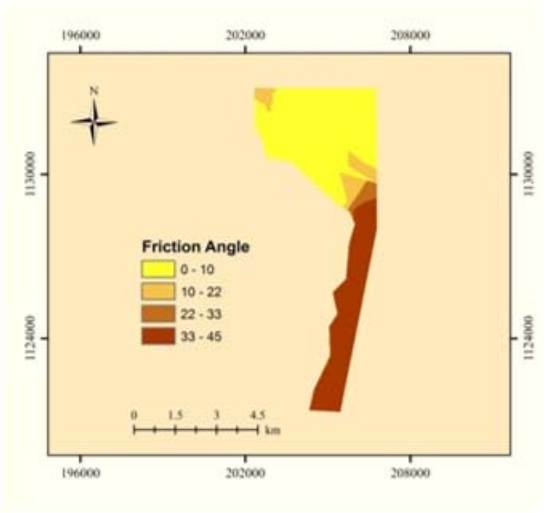
Three maps of friction angle were created at depths of 3 m, 6 m and 10 m as shown in Fig. 5. There was a clear transition from low values in shallow depths to high values in the deepest layers. Generally, the friction angle values ranged from 0º to 22º for clayey soil and from 22º to 48º for sandy types.

Allowable Bearing Capacity Maps

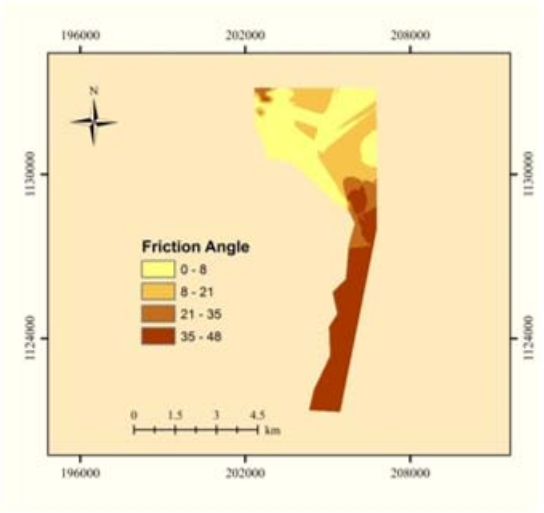
Several maps of allowable bearing capacity were created within the study area at each depth (3 m, 6 m and 10 m). These maps depended on the width of raft foundation B and length to width ratio L/B. According to Fig. 6, at a 3-m depth, the allowable bearing capacity ranged from 64 kN/m^2 to 194 kN/m^2 for cohesive soils and from 567 kN/m^2 to 699 kN/m^2 for cohesionless soils. Moreover, it ranged between 48 kN/m^2 and 169 kN/m^2 for cohesive soil and between 586 kN/m^2 and 758 kN/m^2 for cohesionless soil at a 6-m depth. At a depth of 10m, the allowable bearing capacity values in cohesive soil were approximately between 58 kN/m^2 and 189 kN/m^2, while they ranged from 586 kN/m^2 to

794 kN/m^2 in cohesionless soil. Furthermore, the suitability of the location to use raft foundations at 3m, 6m and 10m depths was shown in Fig. 7.

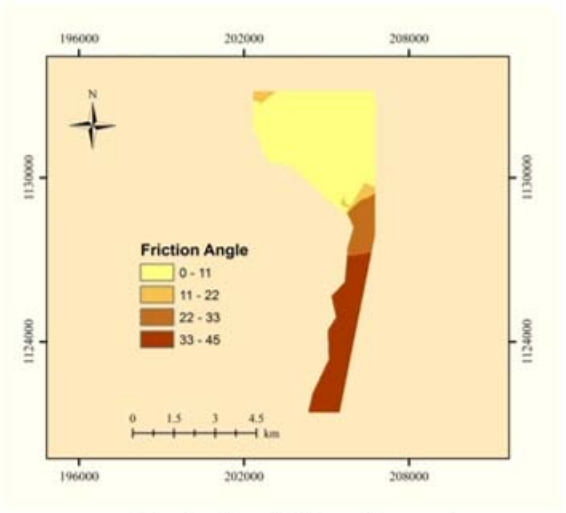
According to the three different variations of suitability rating maps, an overlapping map for using raft foundations at any depth was evaluated in Fig. 8.



a. At a depth of 3 m (degree).

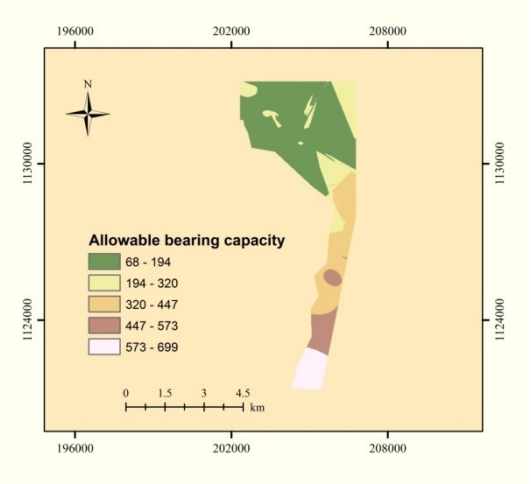


b. At a depth of 6 m (degree).

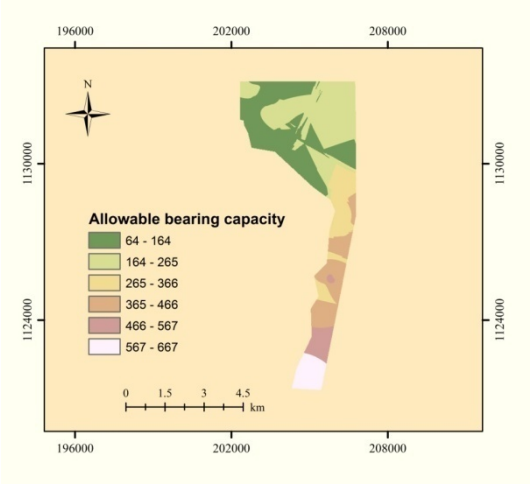


c. At a depth of 10 m (degree).

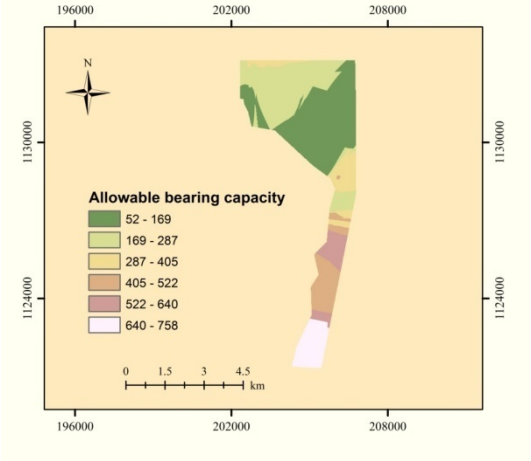
Figure (5): Friction angle (ϕ) maps at different depths



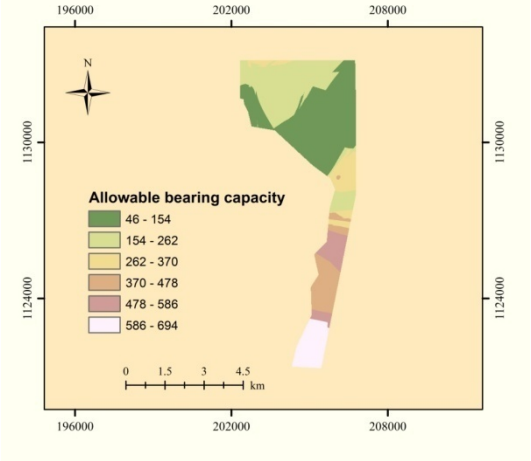
a. D_f =3 m, L/B=1 &B=12 m



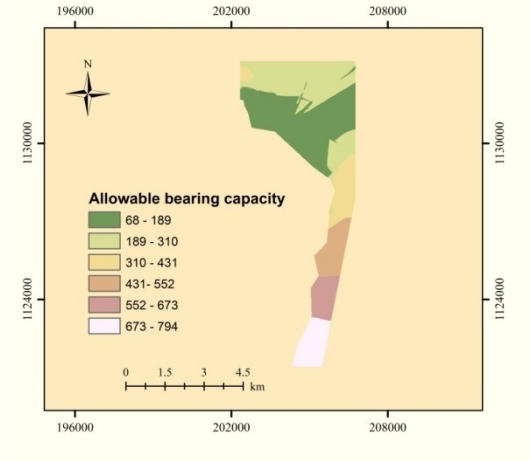
b. D_f =3 m, L/B=1& B=30 m



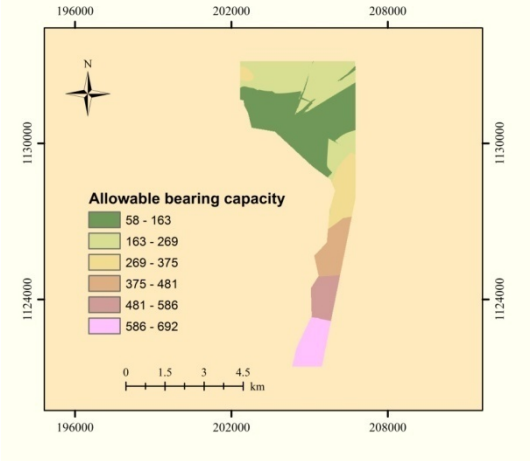
c. D_f =6 m, L/B=1 &B=12 m



d. D_f =6 m, L/B=1 & B=30 m

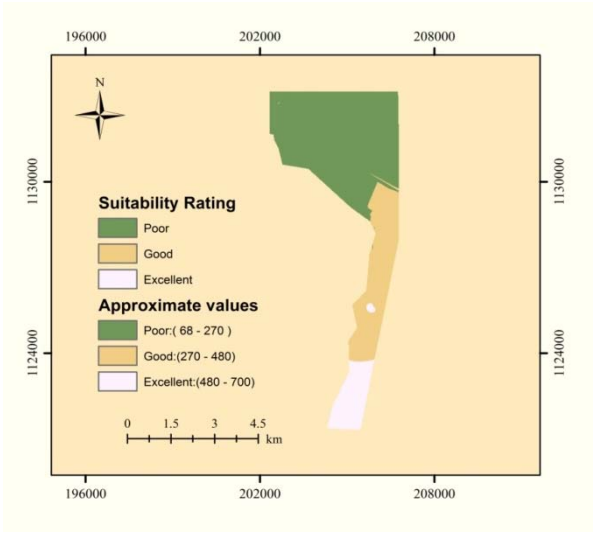


e. D_f =10 m, L/B=1 &B=12 m

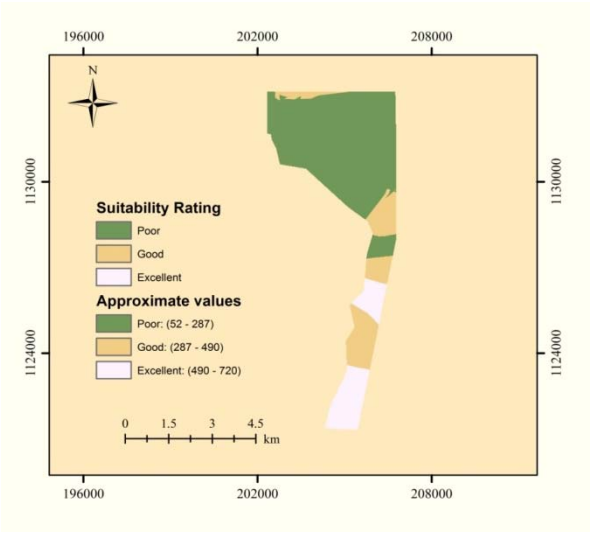


f. D_f =10 m, L/B=1 &B=30 m

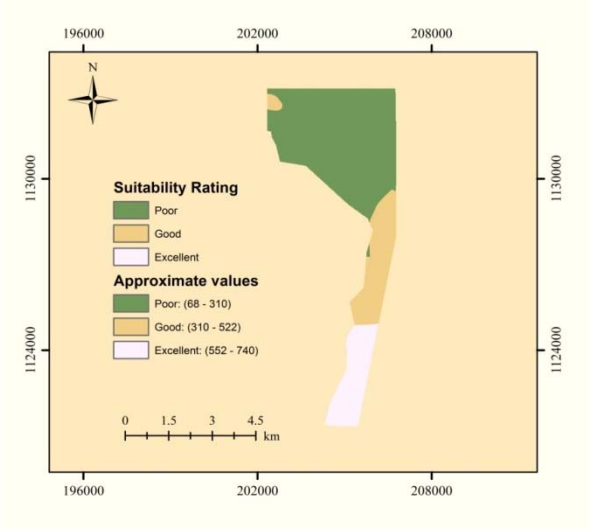
Figure (6): Allowable bearing capacity maps with various widths and different depths (kN/m^2)



a. At a depth of 3 m



b. At a depth of 6 m



c. At a depth of 10 m

Figure (7): The suitability of the location for using raft foundations at different depths and their approximate values of q_{all} (kN/m^2)

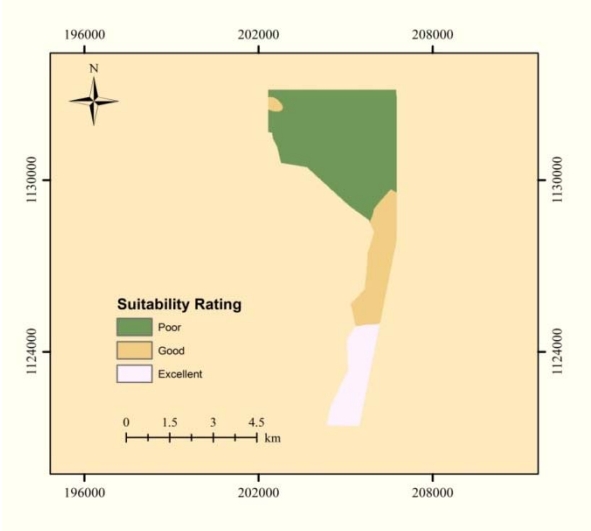


Figure (8): The suitability of the location for using raft foundations at any depth

Pile Capacity Maps

Six maps of pile capacity were created for pipe pile lengths of 10m and 15m with pile diameters of 305 mm, 406 mm and 610 mm for each length. It can be clearly seen that pile capacity values increased when pile diameter increased. The values ranged as follows:

- For a pipe pile length of 10 m, pile capacity ranged from 177 kN to 750 kN for a 305-mm pipe diameter, from 279 kN to 1191 kN for a 406-mm pipe diameter and from 491 kN to 2400 kN for a 610-mm diameter, as shown in Fig. 9.
- For a pipe pile length equal to 15 m, pile capacity ranged from 423 kN to 693 kN for a 305-mm pipe diameter, from 372 kN to 1337 kN for a 406- mm diameter pipe with a maximum range from 549 kN to 3664 kN for a 610-mm diameter, as shown in Fig. 10.

However, it should be noted that due to the limited number of data points available for pile capacity at deep layers, kriging estimation might be unreliable in such cases, but still it might be a good help for engineers in preliminary investigations.

APPLICABILITY OF THE GENERTAED MAPS THROUGH HYPOTHETICAL EXAMPLES

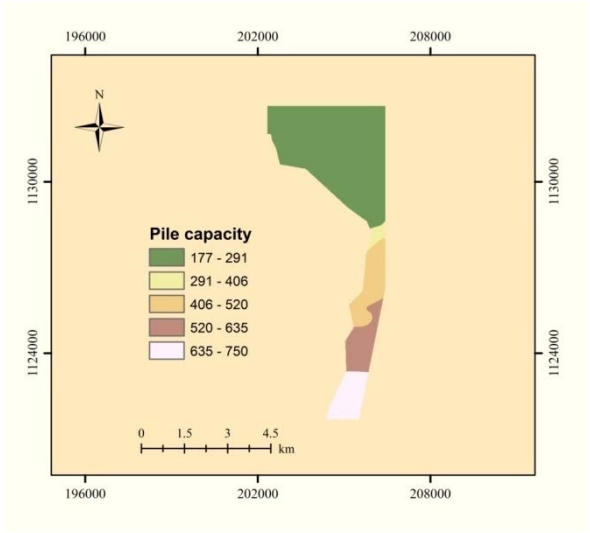
Example One (Raft Foundation Design)

Site A was chosen to build a hotel consisting of six floors and two underground levels. For the proposed project, the following recommendations were considered: the mean value of cohesion at this location and a depth of 6 m was about 14 kN/m^2 and the mean value of friction angle was about 41º. Furthermore, the recommended type of foundation was raft and net allowable bearing pressure is depending on the architectural requirements, for example, q_{all}= 269 kN/m^2 for B= 30 m and L/B = 1 (Fig. 11).

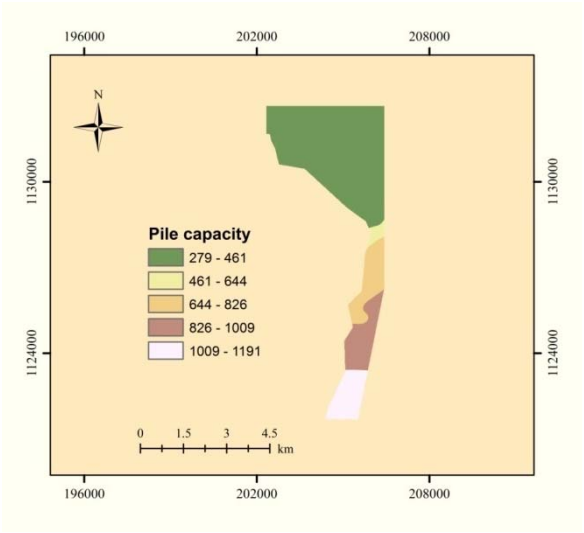
Example Two (Pile Foundation Design)

Site B was chosen to build a high-rise building of 15 stories in addition to three levels of underground parking. Loads that have to be taken into consideration when designing high-rise buildings are: vertical loads (self-weight, live loads and finishing loads) and horizontal loads (wind). These loads are transferred to the foundation. As raft foundation is not sufficient to transfer the previous loads into ground with an

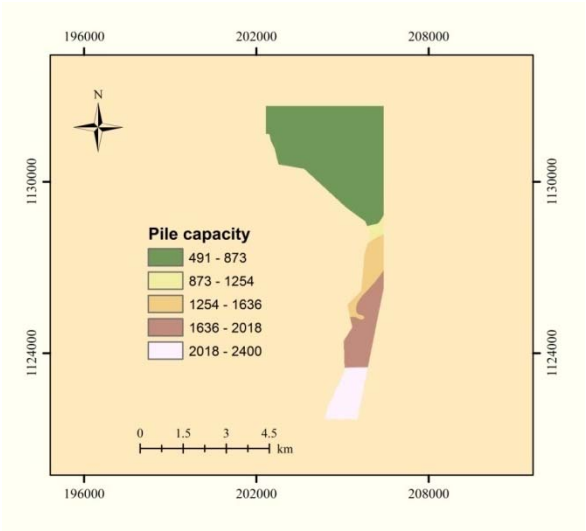
adequate factor of safety, piles are often used. The initial design step is determination of loads by structural engineers and the second one is choosing the allowable capacity of a single pile. It was understood that the building had three levels of underground parking. Thus, the foundation would be placed roughly at 9m below the ground surface. Two choices were suitable for the previous case as follows: case one: choosing length of pile (L=10m) and one of the diameters 305 mm, 406 mm and 610 mm with pile capacities of 291 kN, 461 kN and 873 kN, respectively (Fig. 12). The second case: choosing length of pile (L=15m) and one of the diameters 305 mm, 406 mm and 610 mm with pile capacities of 466 kN, 565 kN and 1171 kN, respectively, as shown in Fig. 13.



a. 305-mm diameter

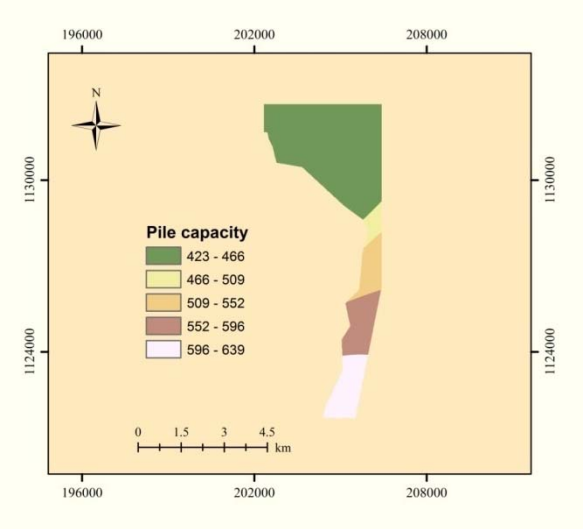


b. 406-mm diameter

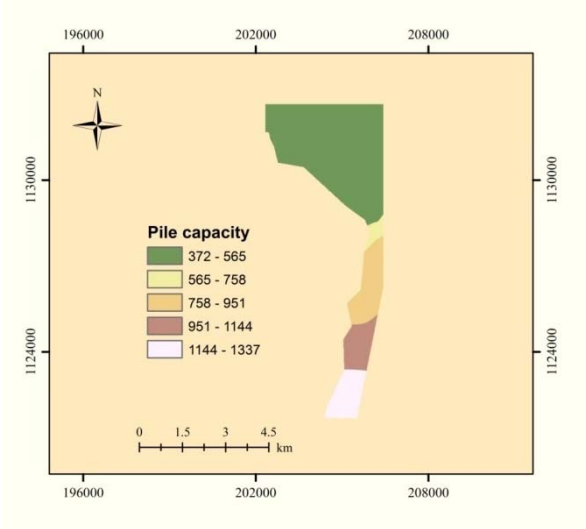


c. 610-mm diameter

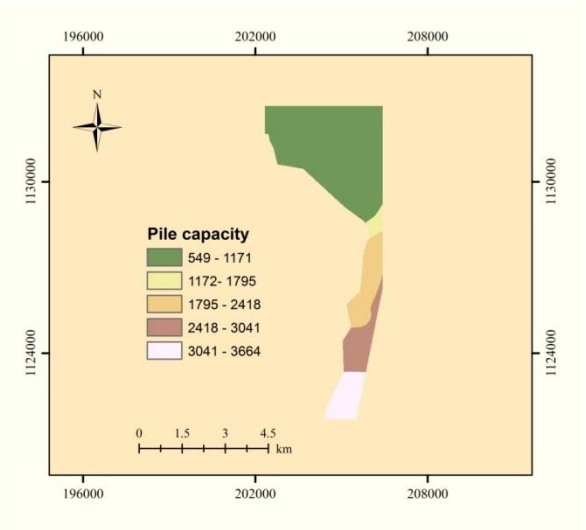
Figure (9): Pile capacity maps for 10-m pile length at different pile diameters (kN)



a. 305-mm diameter

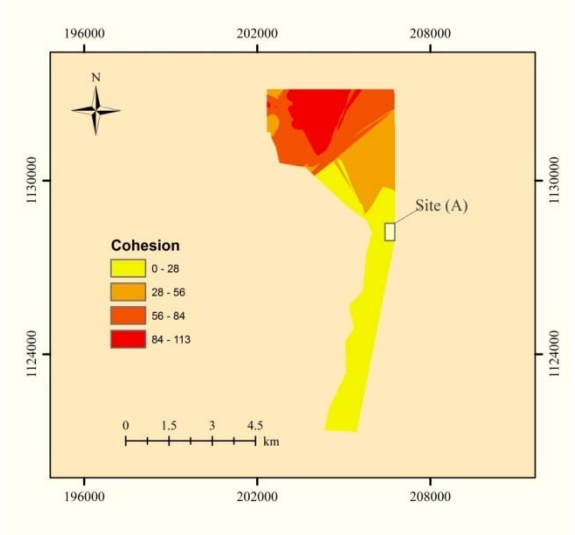


b. 406-mm diameter

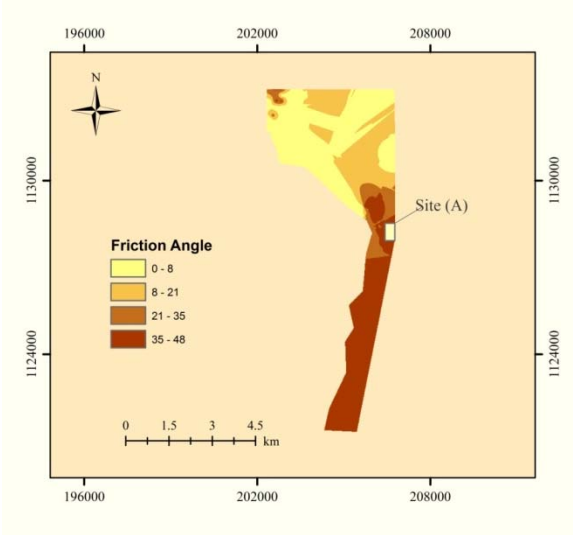


c. 610-mm diameter

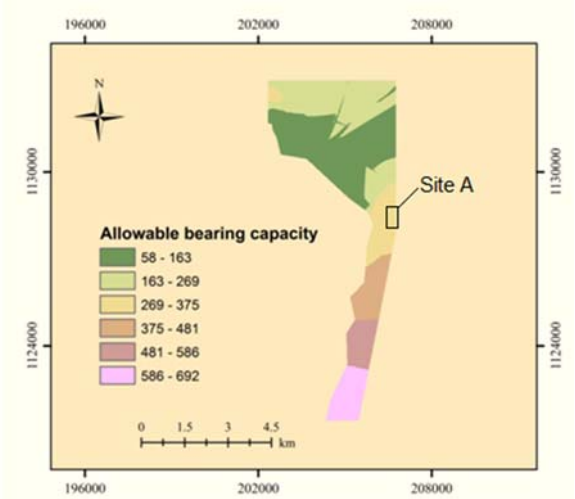
Figure (10): Pile capacity maps for 15-m pile length at different pile diameters (kN)



a. Cohesion value (kN/m^2)

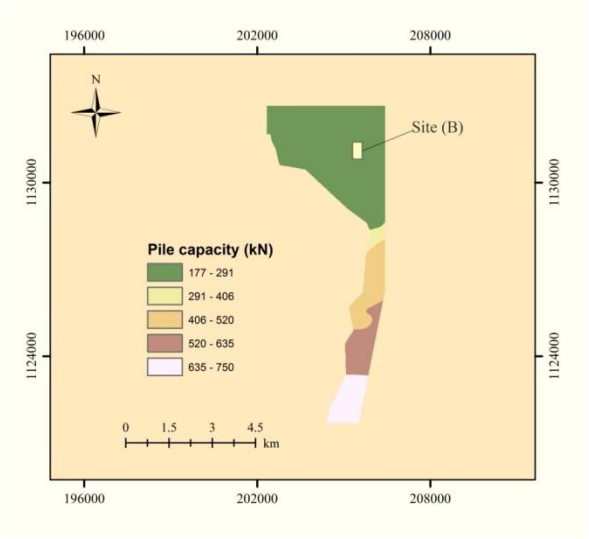


b. Friction angle (ϕ) (degree)

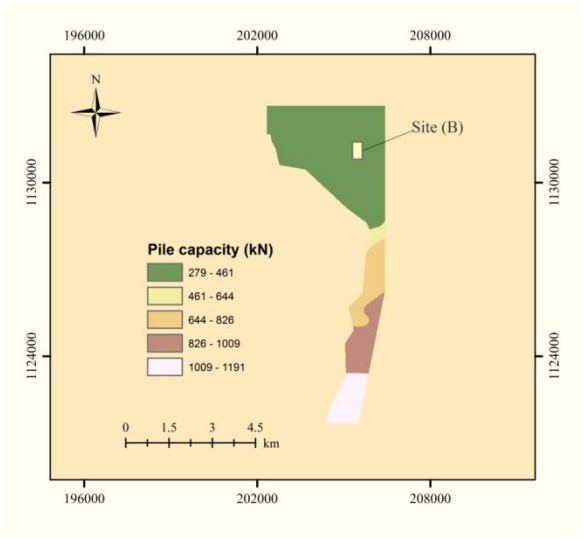


c. Allowable bearing capacity (q_{all}) (kN/m^2)

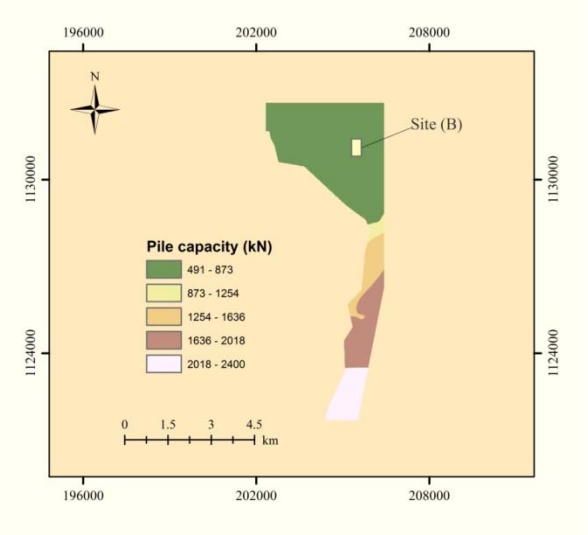
Figure (11): The recommendation values for site A



a. D=305 mm.

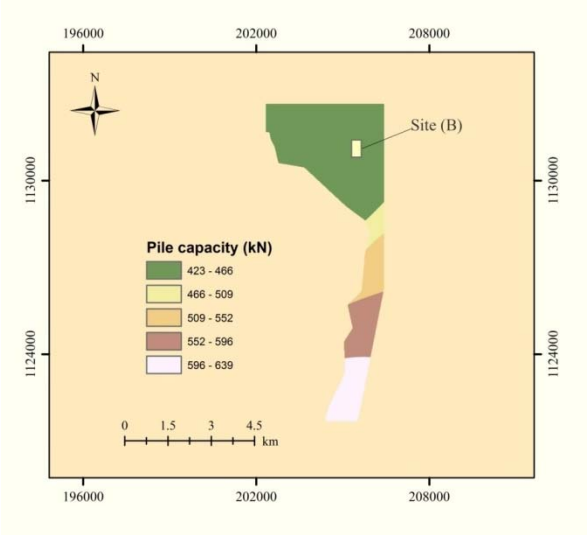


b. D= 406 mm

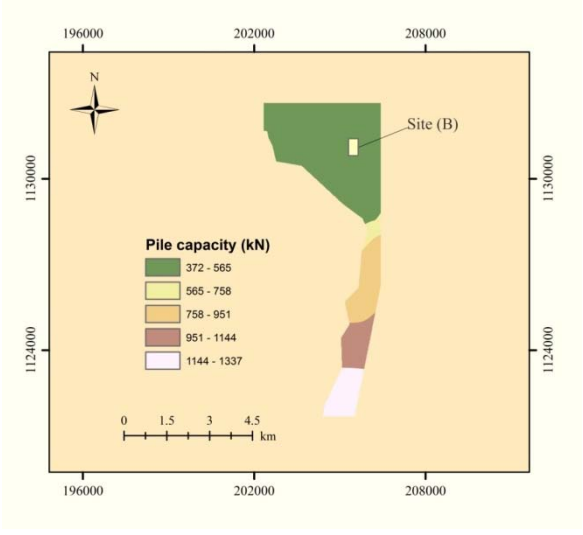


c. D=610 mm

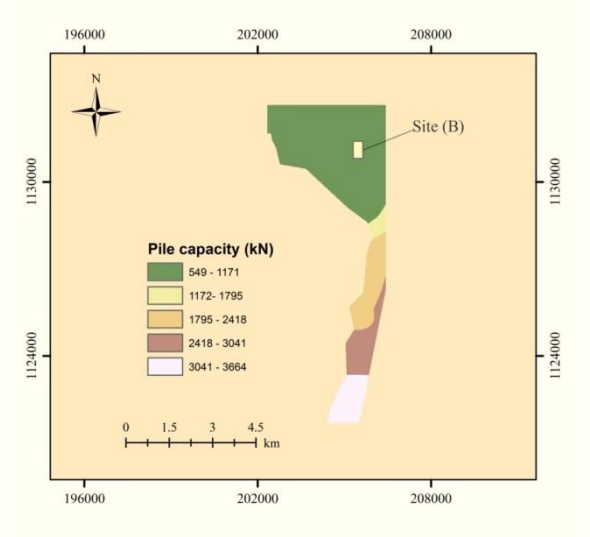
Figure (12): Pile capacity values of L=10m and various diameters at site B (kN)



a. D=305 mm



a. D=406 mm



c. D=610 mm

Figure (13): Pile capacity values of L=15m and various diameters at site B (kN)

CONCLUSIONS

Based on the analysis of data collected from soil investigation reports, from extracted maps for the strength of soil, the allowable bearing capacity and pile capacity, the following conclusions are drawn:

- The cohesion values showed various ranges for soil in the study area depending on depth. At a 3-m depth, cohesion was about 12 kN/m^2– 120 kN/m^2, while it was about 18 kN/m^2-195 kN/m^2 at a 6-m depth and approximately 18 kN/m^2- 250 kN/m^2at a depth of 10 m.
- Friction angle (ϕ) values of the soil in the study area vary with depth. At a 3-m depth, friction angle (ϕ) ranged between 32º and 48º and at a depth of 6 m, the friction angle (ϕ) ranged between 30º and 49º. Furthermore, at a depth of 10m, it ranged between 27º and 45º.
- For low-rise buildings, raft foundation was recommended and the allowable bearing capacity (q_{all}) depends on the depth of embedment that can be used. At a depth of 3 m, 381 kN/m^2 might be used, while 403 kN/m^2 may be used at a depth of 6m. Moreover, allowable bearing capacity of 429 kN/m^2 can be used at a 10-m depth.
- For high-rise buildings, driven pipe piles can be used with the following pile capacities depending on the length of pile and its diameter: for a pile length of 10 m and D = 305 mm, pile capacity was about 463 kN, while it was about 735 kN for D = 406 mm and the same length of pile. Furthermore, pile capacity was about 1445 kN for D = 610 mm and a 10-m length. In contract, for a pile length of 15m and D=305 mm, pile capacity was about 531 kN. For D = 406 mm, pile capacity was about 865.5 kN and for D = 610 mm, it was about 2106 kN for a 15-m pile length.
- It should be noted that using geotechnical maps presented in this work does not cancel the need for conducting comprehensive and deep soil investigations, especially for proposed giant projects. However, the use of the maps presented herein is intended to reduce the number of tests and to give an idea about the nature of the soil site.

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