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RESEARCH ARTICLE

GEOTECHNICAL INVESTIGATION AND MAPPING OF JAZAN CITY, KSA USING GIS

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ABSTRACT

This paper deals with the geotechnical maps of Jazan city showing the physical and mechanical properties, hence, determine the bearing capacity of the soil in Jazan city and its extensions. Chemical properties of soil are used to identify the site's environmental conditions of soil at sites of Jazan city – Kingdom of Saudi Arabia (KSA). Geographic Information Systems (GIS) are used in geotechnical engineering applications, GIS can be utilized as a part of the geotechnical site investigation to create a site map. In this study paper the GIS is used to estimate the missing data of the Jazan city for geotechnical mapping. Also, GIS is used for information coordination, determining the Geotechnical area, analysis, investigation, and establishing the layout of Jazan geotechnical maps. The study area is located in the city of Jazan between the eastern border 42.653°E, 16.935°N and western border 42.353°E, 16.907°N has been selected as a case study. Data on the soil at sites are taken from 22 boreholes in Jazan city in order to carry out geotechnical investigations. Borehole logs are carried out in different locations in Jazan city such as Dehaga, Alshwajrah, Almagaria, and Almaaboj, geotechnical investigations have been recorded that water content in the soil is high on at the west part closed to the sea and is decreasing at north and south parts, but the water content is very low at the central part. The level of groundwater is up to 6 m above sea level in the western part of the study area and up to 0.5 m below the sea level at the study areas closed to the sea. The study showed that the soil in Jizan is silt, clay and sand soil. The study of mechanical properties of the soil showed that the soil of Jizan reaches cohesion of (c = 0.2 kg/ cm 2) and the angle of internal friction of soil reaches (Φ=31°). Accordingly, the unconfined compressive stress at failure (qu) is between 1.0 to 2.20 kg/cm.

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INTRODUCTION

Geotechnical investigation is always required for construction projects. The investigation may range from a simple investigation of the surface soils to detailed study of the soil and ground water conditions by means of boreholes, in-situ and laboratory tests. Only if troublesome foundation conditions such as layers of peat or loose-fill material are encountered would it be necessary to sink deep boreholes, supplemented by soil tests. A detailed site investigation involving deep boreholes and laboratory tests is necessary for heavy structure projects such as bridges, multi-storey buildings, or industrial plants. Even if the rock is known to be present at shallow depth it is advisable to excavate down to expose the rock in a few places to ensure that there are no zones of deep weathering or heavily shattered or faulted rock.

Geotechnical Studies of Jazan city area: The geotechnical aspects of Jazan soil have been studied by many researchers as (Eorle., 1989), (Shehata, 1989), (Rasheeduzzafar, et al. 1992),(Al-Aamoudi, 1992),(Al-Amoudi et al. 1992), (Ali H.Mahfouz, 2016), (Ali H.Mahfouz et al. 2016). The city of Jazan is situated on an elevated terrain underlain by a salt dome measuring 4 km^2 in area and reaching about 50 m above sea level, (see Figures 1.a, 1.b and 1.c). The salt dome is surrounded by vast areas of Sabkha flats and wind-blown sand stretching north and south for approximately 190 km. Sabkha sediments possess highly variable profile characteristics with regard to the soil composition.

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The subsoil profiles in the coastal zones (close to the shoreline) consist of loose fine sand, whereas the subsoil profiles of inland zones are characterized by very soft clay and silt with appreciable organic material. The location of Jizan city near the red sea is affected by the soil characteristics, because the city is located on a salt dome surrounded by low-lying flat terrain consisting of silty-sandy soils. Being on the sea-shore, water immigrates to the surface leaving a salt crust on the top surface, which is known as 'Sabkha' soil. This salt bearing soil and the salt dome affected the foundation performance in the area. (M. N. Fatani and A. M. Khan,1993).

The three zones characterize this soil profile include:

- Sabkha crust;
- Compressible Sabkha soil; and
- Sabkha base.

Sabkha is a salt-encrusted soil that possesses little bearing capacity with large settlements when the soil is wetted. The bearing capacity for a shallow footing on sabkha soil means is directly related to its diameter, the angle of internal friction and the sabkha layer thickness. For the sabkha soil layer thickness of 8 m, when the small angle of internal friction equal(24°and 27°), the bearing capacity is increased by an average of 13.3 % as the foundation diameter increased from 5 m to 7.5 m, for all values of sabkha layer thickness (Alnuaim, A. M., & El Naggar, M. H. 2014.) Its extreme salinity, which is about four to six times as much as seawater, and shallow groundwater, make the sabkha medium an aggressive environment for foundations and sub-structures of all types, leading to rapid deterioration of concrete due to sulfate attack and reinforcement corrosion (Ali, 2004). The sabkha crust is relatively thin, dry silt, and sand soil with an average thickness of about 2.0 m above the existing water table which is 1-2 m below the ground surface. This layer appears to be of a hard nature, but highly susceptible to loosen its strength instantaneously upon the saturation. The compressible sabkha complex is soft, loose material composed of soils varying from non-plastic silty, clayey fine sand to highly plastic organic clays and silts with thickness up to 8 m. The sabkha is a firm stratum consisting mainly of medium to dense sand with relatively high bearing capacity and low compressibility characteristics.

The Applications of GIS in geotechnical Engineering: Geographical Information Systems (GIS) are a too important tool for collecting, displaying, storing, data recovering, analyzing geographically references data. GIS is different from other Information Systems in so far as it contains geographically referenced data consisting of spatial data component which defines the location, and attribute data component which defines the characteristics (Chang, 2006).GIS represents a very important role in various aspects of geotechnical engineering including preliminary site investigations, identification of potential project barriers, interpolation for obtaining data at inaccessible locations,data visualization, data processing as well as preparation of post-processing graphs, reports and charts. Geotechnical information acquired from the site and laboratory tests is vital for a safe and economical design of building and infrastructure works, especially in earthworks development projects (Mohamad and Ghani, 2011).

Using GIS applications at all the stages of a Geotechnical engineering project helps the companies to save time and cost. Construction projects are considered successful when the are completed at specific time, within construction cost, and in accordance with specifications (Takim et al. 2002). In this study, GIS functions that are used in geotechnical investigation and is established the geotechnical model. This model is more useful for infrastructure projects such as highway, street, sewer pipeline networks, drinking water pipeline networks, telephone and telecommunications networks, and Bridge construction activities to increase project success rates. Using GIS functions and the geotechnical GIS model in infrastructural projects could help reduce the amount of administrative time (Dierkes & Howard, 2008).

RESEARCH OBJECTIVES

The main objective of this paper is to design a successful Geotechnical model for jazan city using GIS. By using the GIS model, very easy to make geotechnical maps of the study area, reports and graphs.

The secondary objectives are:

- To find energy sources like oil, natural gas, coal, work on the extraction and exploitation;
- To disclosure of ores and expansion in the production of various metal ores;
- To exploit groundwater as a measure of additional sources of water for irrigation and drinking. To find in soil formation, and related configuration of the soil and means of composition and factors that work to remove or install types, as well as contributing to the protection of the environment;
- To estimate the missing data of soil properties according to the data of soil at sites are taken from boreholes in Jazan city using GIS techniques;
- To facilitate access to building materials and construction; and
- To investigate the soil in projects of construction and reconstruction.

METHODOLOGY

The methodology of this paper includes three parts:

- The study area;
- Establishing of Geotechnical model using GIS; and
- Investigation of soil tests.

The Study Area: Jazan region is located in the southwest part of Saudi Arabia on the red sea (E: 42.0°-43.8° and N: 16.5°-17.0°). Its area is 13,500 km^2. Jazan region is part of the Saudi Arabia shield which is a part of the Precambrian crustal plate and consists of igneous and metamorphic rocks (Al-Farraj, 2008). It is located in an active zone of earthquakes classified as zone 2B with the maximum applied horizontal acceleration of 0.2 g(A. E. Hassaballa et al. 2017). In 2014, a magnitude-5.1 earthquake happened in the southwestern part of the Kingdom, 50 km northeast of Jazan, at a depth of 10 km followed by 37 aftershocks of magnitudes ranging from 0.94 - 5.1 in Richter scale (www.sgs.org.sa).

Figure (1): (a) Simplified geological Map

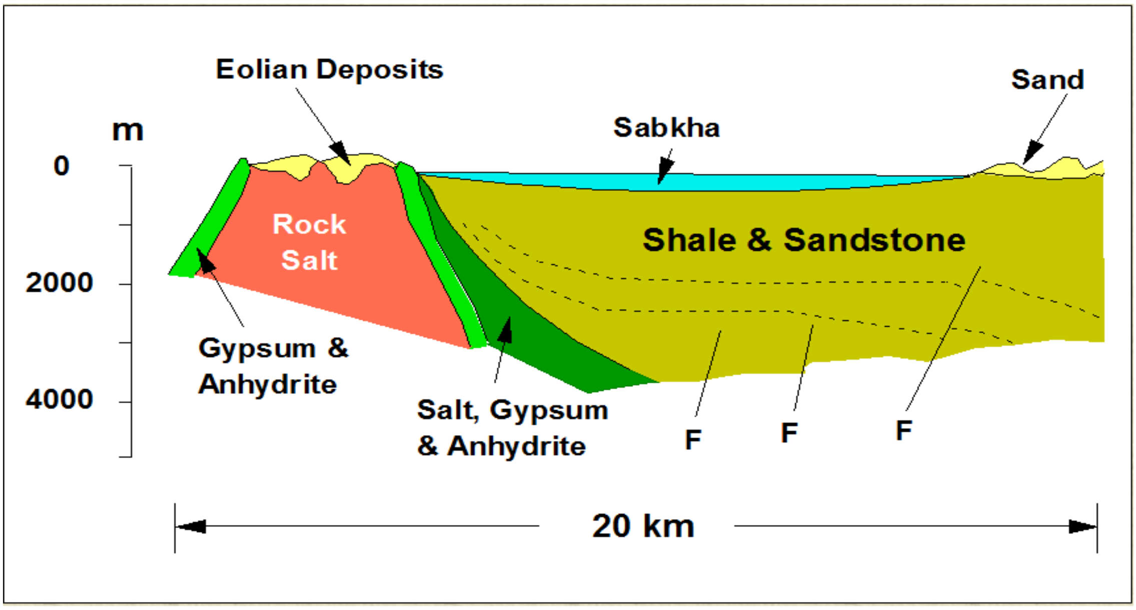

Figure (1) (b) Geologic section across Jazan (modified after Londry, 1979)

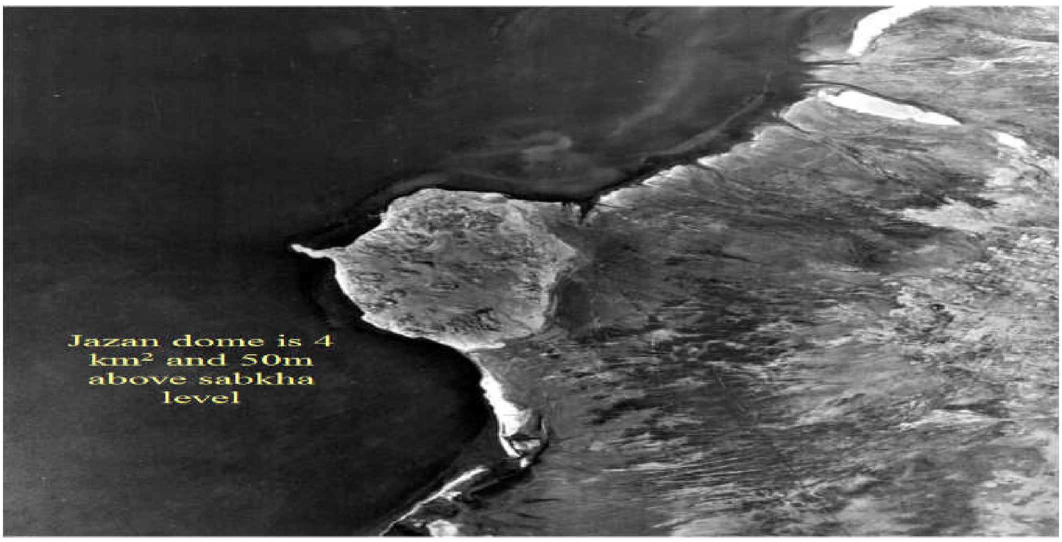

Figure (1) (c) Map of a salt dome in Jazan city

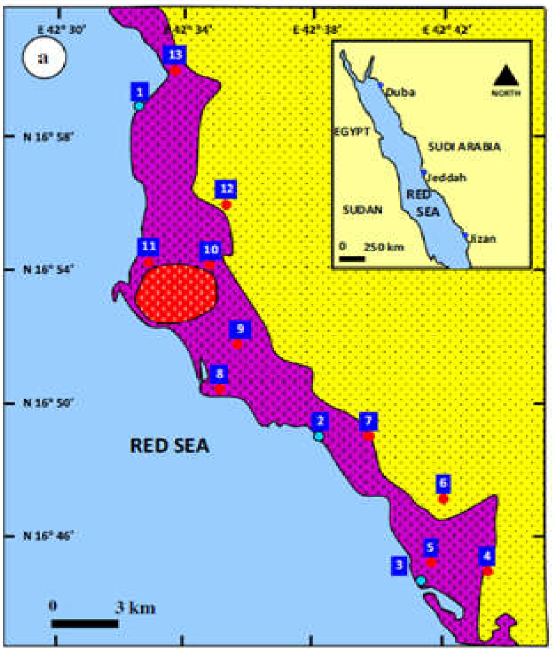

Figure (2): The base map of the study area (Mohammed H. Basyoni and Mahmoud A. Aref, 2015)

One of the major problems in geotechnical earthquake engineering is the phenomenon of liquefaction of loose to medium-dense sands below the water table (see figure 2). In a similar study, a series of maps using GIS software was carried out in order to illustrate the liquefaction potential in Kahramanmaras located on the seismically active zones of Turkey (A.F. Cabalar et al. 2019).

Establishing of Geotechnical Model using GIS: The geotechnical model of Jazan city includes of topographic maps, groundwater tables, mechanical properties, and physical properties. Establishing the geotechnical model of the study area is required a lot of processing method by using ArcGIS 10.1 Software. These methods are detailed in the following steps:

- Scanning the base map of geotechnical (See Fig.2);
- Georeferencing of the scanned base map;
- Map transforming from raster to vector by on-screen digitizing;
- Display of building layers such as salt dome, sabkha, sand soil, and the red sea;
- Data editing and correct the digitization error;
- Adding attribute data; and
- Finally, the geotechnical model had been established after the missing data were estimated by using ArcGIS version (10.1) interpolation methods{Spline, Inverse Distance Weighting (IDW), Natural Nighbor, and Kriging}. The following Figures (3,4,5, 6,7,8,9and 10) were derived from ArcGIS10.1 software, these figures respectively were shown: flow chart diagram of establishing the geotechnical model, the layout of Jizan city geotechnical mapping, the layout of the groundwater Level, layout of the contour map, the layout of the contour of the Standard Penetration Test(SPT), the layout of the contour of the hydrogen ions (PH) in the ground, the layout of the contour of the PH in the Soil, and the layout of the contour of the Sulfur trioxide(So_3).

RESULTS AND DISCUSSION

Soil Test Investigation in Jazan City: Sabkha is soils have high concentrations of salts. These soils originate due to capillary suction and intense evaporation in the coastal and inland flat plains of Saudi Arabia. Sometimes the salinity of the pore fluid reaches as higher than seawater due to leaching/ or dissolving salt domes. The high salt content has a great impact on the strength properties of soils and also on structures in contact with the soil. Salt-bearing soils are extensively found on the eastern coastal plains and at locations on the western coastal plains of KSA.

Sabkha deposits are usually very soft, problematic, susceptible to salt leaching, and not suitable for foundation support (Al-Amoudi et al. 1992). Sabkha soils have the following undesirable characteristics:

- Very soft, not good for foundation support;
- Loses strength upon wetting;
- Aggression toward concrete and steel;
- Salt leaching affects soil properties; and
- Subject to volume change, need improvement/ stabilization.

Sieve Analysis: Sieve analyses of soils in Jazan city to classify and clarify the different types of soils. Results of a sample of borehole locations are shown in Figures(11 and12). Sieve Analysis tests of boreholes logging are carried out in different locations in Jazan city such as Alshwajrah and Dehaigah.

Direct Shear test: The test has been conducted on soil samples collected from boreholes at different depths physical and mechanical properties of soil. The samples of soil are collected from four areas in Jazan city. According to the equation (Mohr-coulomb failure criteria) of shear strength, the cohesive strength and friction angle for the all sites borehole of the study area could be calculated :

$$\tau = C\sigma \tan \varphi$$

where,

τ– the shear stress
σ– the normal stress
c– cohesive strength
ϕ– the friction angle (Ranjan, G. and Rao, A.S.R. 2000). The test results of direct shear in Dehaigah, Almagariah, Alshwagra, and Almaaboj locations are shown in Tables (1,2,3 and 4) and figures (13, 14,15, and 16).

DISCUSSION OF RESULTS

In figure 4, geotechnical maps of Jazan city are established showing the chemical, physical, and mechanical properties of soil to identify sites environmental conditions of soil at sites of Jazan, physical properties of soil, and mechanical properties, this map not only shows the results in the specific location of boreholes, but also can introduce the results in different parts of the study area. The results of data are estimated in any parts of the study area, according to the facilities of ArcGIS 10.1 Software. The GIS spatial interpolations techniques (Spline, Inverse Distance

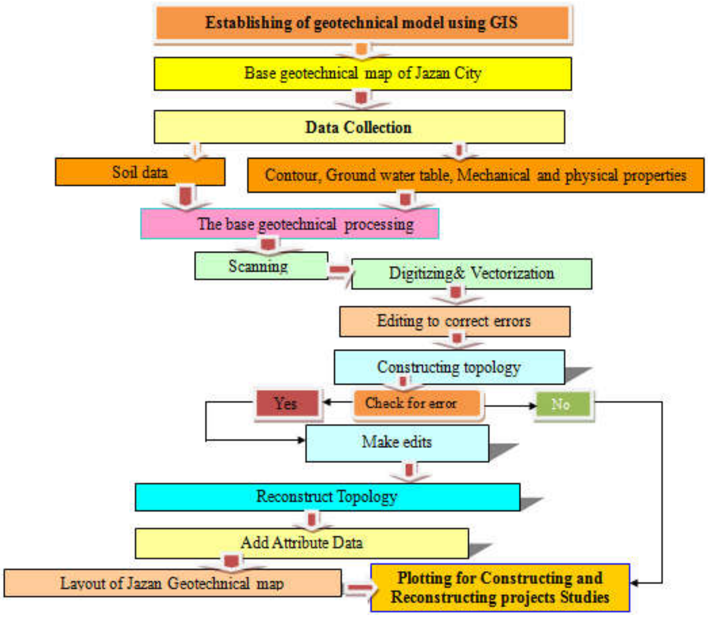

Figure (3): The flow chart diagram of the geotechnical map of Jazan city using GIS

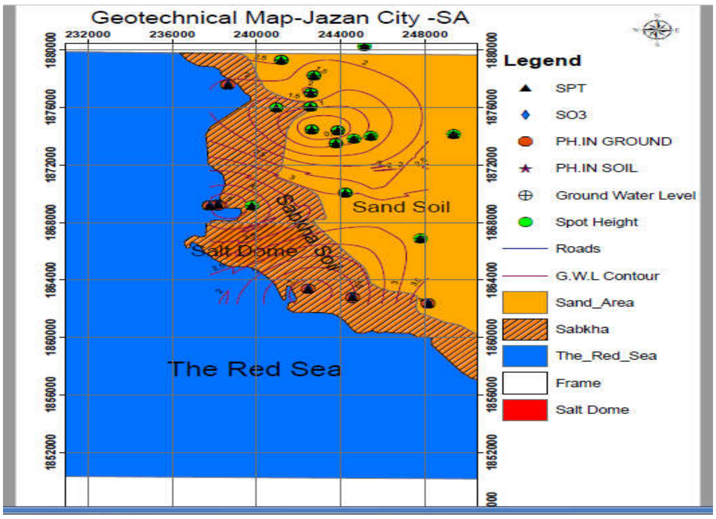

Figure (4). The layout of Jizan city geotechnical mapping (ArcGIS10.1)

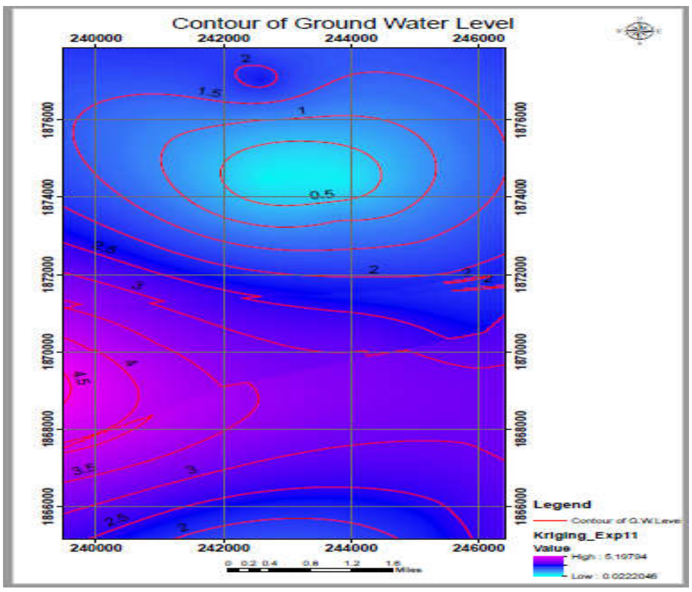

Figure (5). The layout of the groundwater level (is derived from ArcGIS 10.1)

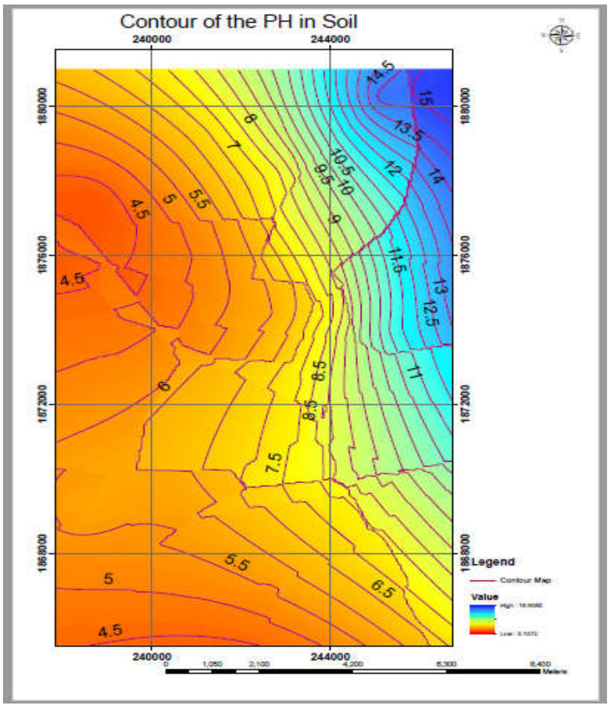

Figure (6): The layout of the contour map (is derived from ArcGIS 10.1)

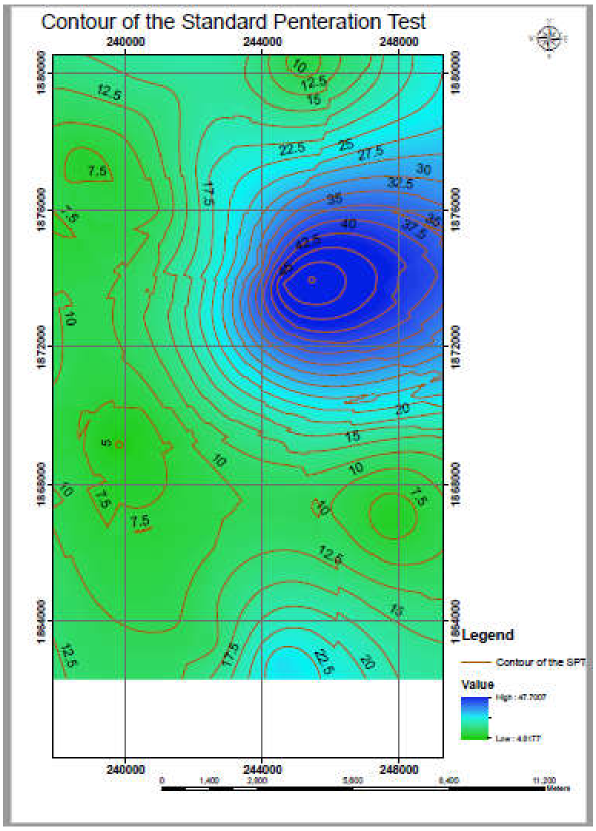

Figure (7). The layout of the contour of the Standard Penetration Test (SPT) is derived from ArcGIS 10.1).

Weighting (IDW), Natural Nighbor, and Kriging) estimate the all values of missing data at locations in all geotechnical maps, where measured values are not available. Spatial interpolation is widely used for creating continuous data collected at discrete locations (Nawal K.Ghazal et al. 2015). Accuracy in estimating points depends mainly on the input data (22 points) that have been taken from the borlehole locations in the study area.

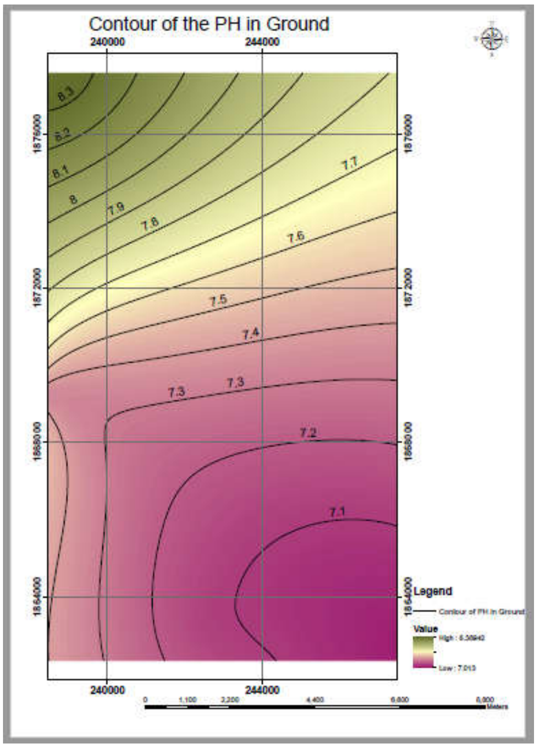

Figure (8):The layout of the contour of the hydrogen ions (PH) in the ground (is derived from ArcGIS 10.1).

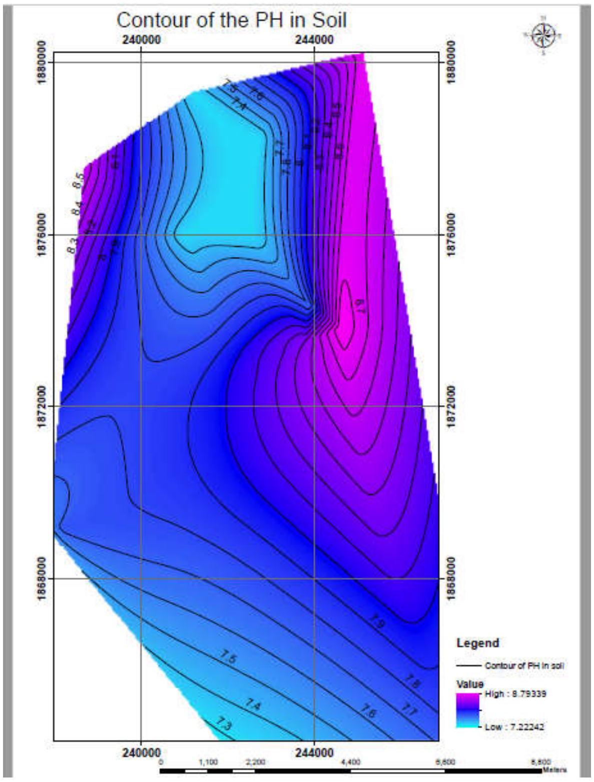

Figure (9). The layout of the contour of the PH in the Soil (is derived from ArcGIS 10.1)

In geotechnical engineering, GIS is used to determine the location of boreholes and establishes a site base map as it helps engineers or planners to do new investigation especially for new site locations (W. N. S. W. Mohamad and A. N. A. Ghani. 2011). Figures (17, 18, and 19) show the map and the graphs of the groundwater level include the actual and estimated data. This method of estimating data is selected as an example in geotechnical map.

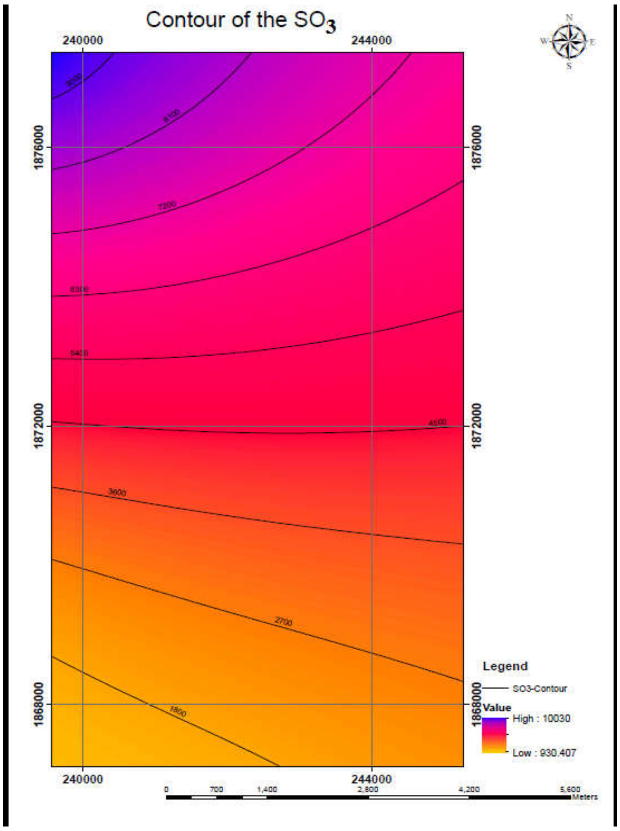

Figure (10):The layout of the contour of the So_3 (is derived from ArcGIS 10.1).

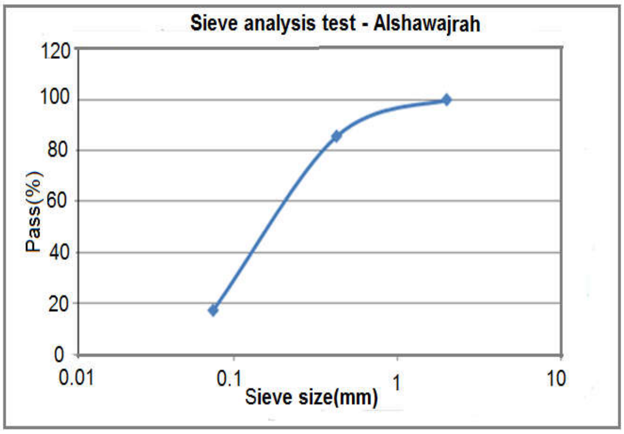

Figure (11) Sieve analysis of ALshawajrah borehole project

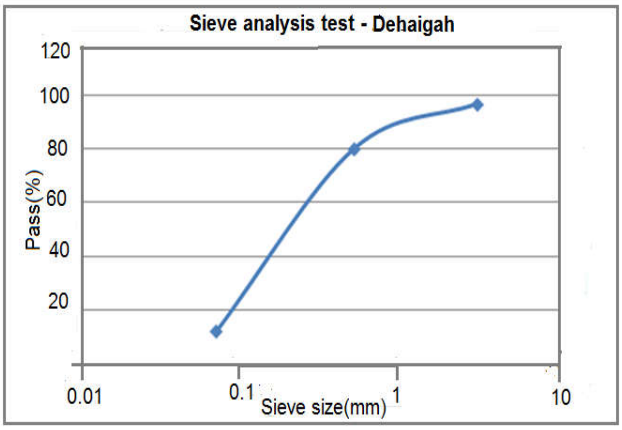

Figure 12 Sieve analysis of Dehaigah site borehole project.

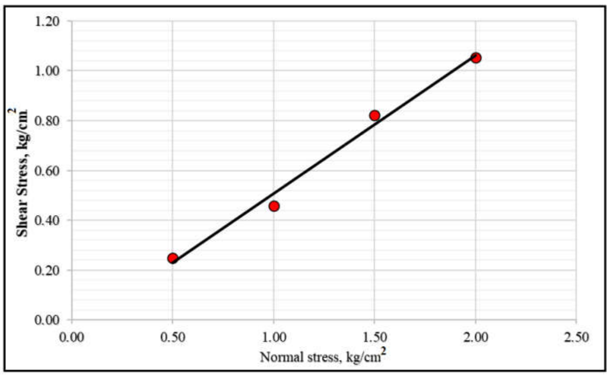

Figure (13) Direct shear at project of Dehaigah site borehole

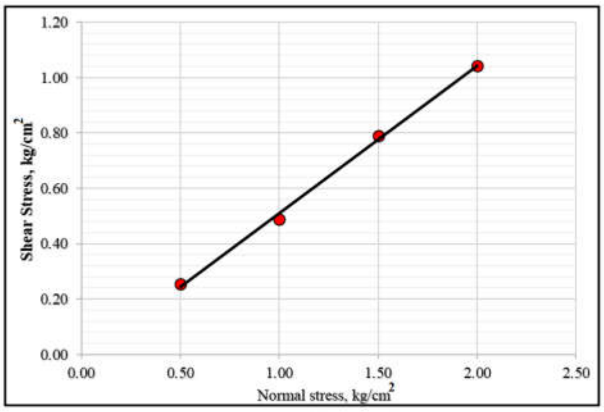

Figure (14). Direct shear at project of Almagariah site borehole

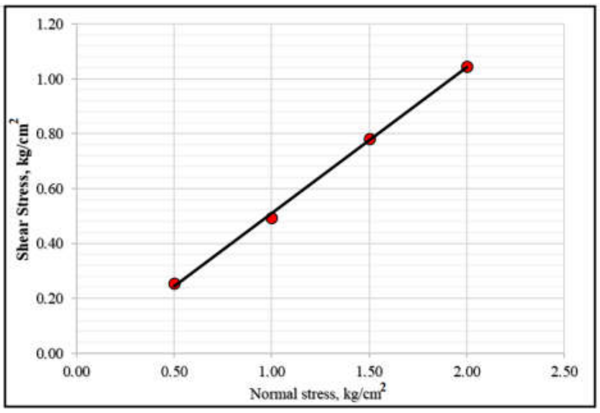

Figure (15) Direct shear at project of Alshawajrah site borehole.

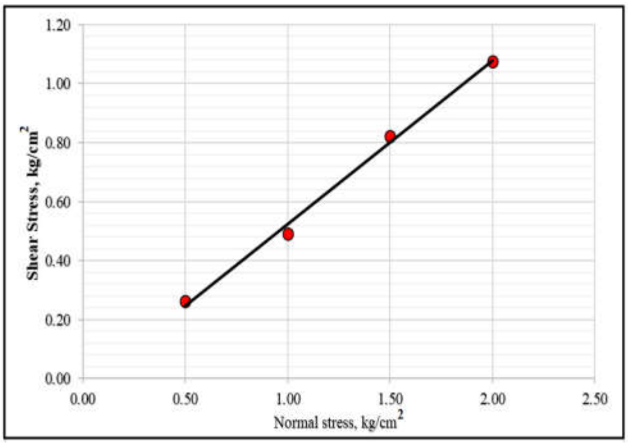

Figure (16). Direct shear at project of Almaaboj site borehole.

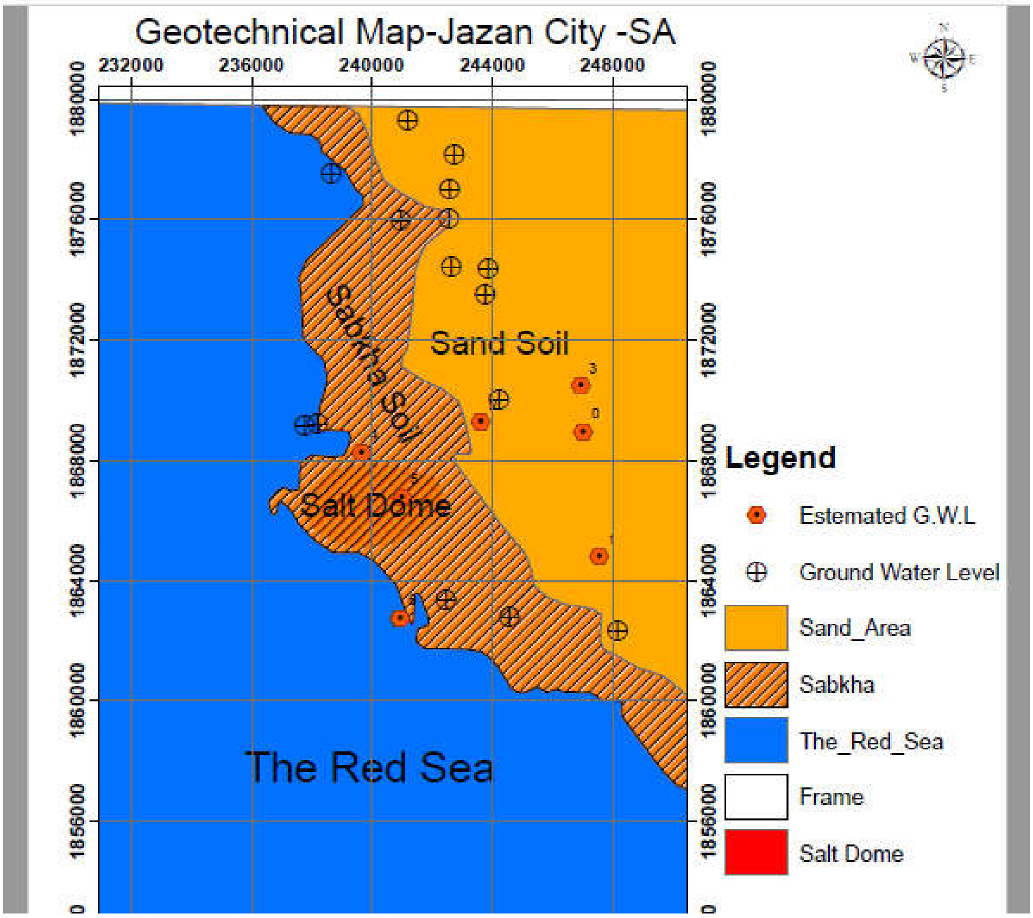

Figure (17): The actual borehole and estimated data by using ArcGIS 10.1 Software

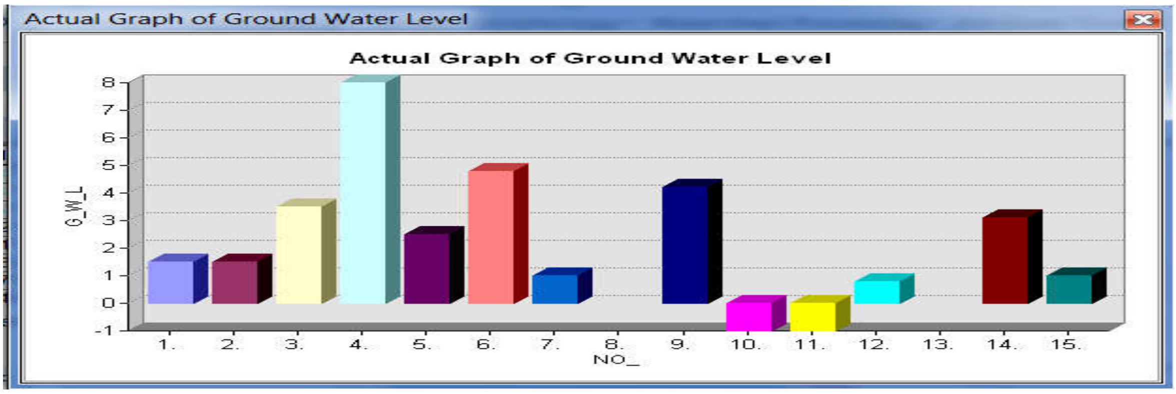

Figure (18): The graph of actual ground water data (is derived from ArcGIS10.1)

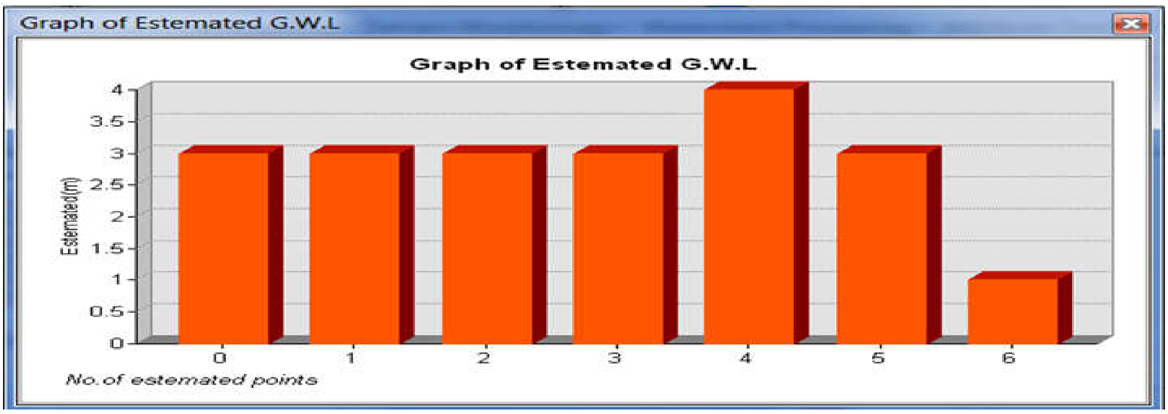

Figure (19): The graph of estimating groundwater data (is derived from ArcGIS10.1)

Table 1. Direct Shear data of Dehaigah site borehole

Description	Angle of shearing resistance Φ (°)	Conhesion(C) (Kg/cm^2)	Dry Density (gm/cm^2)
Crushed dolomite Stone	29	0	1.60

Table (2): Direct Shear data of Almagariah site borehole

Description	Angle of shearing resistance Φ (°)	Conhesion(C) (Kg/cm^2)	Dry Density (gm/cm^3)
Crushed dolomite Stone	28	0	1.70

Table (3): Direct Shear data of Alshwajrah site borehole

Description	Angle of shearing resistance Φ (°)	Conhesion(C) (Kg/cm^2)	Dry Density (gm/cm^3)
Crushed dolomite Stone	28	0	1.71

Table (4): Direct Shear data of Almaaboj site borehole

Description	Angle of shearing resistance Φ (°)	Conhesion(C) (Kg/cm^2)	Dry Density (gm/cm^3)
Crushed dolomite Stone	29	0	1.60

Conclusion

The study clearly revealed the potentiality of applying modern GIS methods for establishing the geotechnical map in the Jazan City application area and were measured the values of data are not available by using the ArcGIS 10.1 facilities. In general, we note that there are not enough geotechnical data in the study area, and is highly recommended to use GIS software to establish the geotechnical map in order to save time and cost. The role of the nature of the boreholes data also must be considered. In this study the source of data is an existing map and digitizing was carried out on screen using ArcGIS10.1 Software facilities. There is no doubt that the validity of the Geotechnical map would be increased and such difficulties would be encountered if data are obtained in digital form. Another conclusion of this study can be summarized in the following points:

- The terrain of Jazan city is close to the sea level is flat and extending from the north-west to the south. And groundwater level is almost at the ground surface near the western area of the city of Jazan and is relatively deep in the downtown of the city, gradually down from the north and south parts reaching right below the sea level;
- Chlorides in groundwater are present frequently as we turn to the south and southeast of the city of Jazan and note its decline in the western and northern regions, and in soil located in the eastern region and descending gradually as we move to the south-west and also decrease in areas in the north of the city of Jazan;
- Sulfates in groundwater not exist in the southwestern region and begin to spread as we head to the north of the city and are present in the northwest of Jazan, and the sulfates in Soil is located in the vicinity of the sea in the city of Jazan;
- PH in groundwater is absent in the southeastern region and is increasing as we move north and west of the city of Jazan, and in the soil is generally located in the northwestern and eastern regions and gradually disappears in the center and south of Jazan city;
- The cohesion of the soil of Jazan city as a whole, the cohesion is weak, but some areas near the sea are sandy with some of the soft soil, and we find some areas in the center of Jazan there is cohesion between the soil particles;
- Bearing Capacity of Jazan city as a whole, low bearing capacity due to low cohesion and angle of internal friction of the soil(sabkha soil) especially at locations of the areas near the sea is sandy with some of the soft soil, and we find some areas in the center of Jazan. the sabkha soil layer thickness of 8 m, when the small angle of internal friction equal(24°and 27°), as the foundation diameter increased from 5 m to 7.5 m, for all values of sabkha layer thickness;
- The results of investigation of direct shear stress in jazan city showed the average of Angle of shearing resistance Φ (°) and dry Density (gm/cm^2) equals 28.5° and 1.65 respectively; and
- Finally, the mechanical properties of the soil showed that the soil of Jizan reaches cohesion of(c = 0.2 kg/ cm^2) and the angle of internal friction of soil reaches (Φ=31°), and the unconfined compressive stress at failure (qu) is between 1.0 to 2.20 kg/cm.

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