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Soil Characteristics in Selected Landfill Sites in the Babylon Governorate, Iraq

Ali Chabuk[1], Nadhir Al-Ansari[1], Hussein Musa Hussein[2], Suhair Kamaleddin[3], Sven Knutsson[1], Roland Pusch[1] and Jan Laue[1]

1. Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, Lulea 971 87, Sweden;

2. Department of Geology, Faculty of Science, University of Kufa, Kufa 31003, Iraq;

3. Iraqi Ministry of Housing & Construction, National Center for Construction Laboratories and Research Babylon, Baghdad 1001, Iraq

Abstract: The Babylon Governorate is situated in the middle of Iraq. It covers an area of 5,315 km^2 and has 2,092,998 inhabitants distributed throughout its five major cities (Qadhaa). Presently, there is no landfill site in the governorate that meets the environmental criteria for the disposal of municipal and industrial waste. Consequently, GIS (geographic information system) and methods of multi-criteria decision making were used here to select the best sites in each city in the Babylon Governorate that would fulfil the environmental requirements. Two sites were chosen in each city. As the groundwater is very shallow in this area, the design should ensure against groundwater pollution by leachate from these sites. To avoid this problem, soil investigation was conducted at these sites so that the most suitable landfill design could be accomplished. The results of soil investigation in these sites include the soil profile, groundwater depth, chemical properties, allowable bearing capacity, Atterberg limits test results and material characteristics of the soil strata. From the research, it is believed that the best design is one that puts the landfill above ground.

Key words: Bearing capacity, Atterberg limit, landfill, Babylon, Iraq.

1. Introduction

The location of landfills and the methods of disposing of solid waste at a site can create serious environmental problems. The greatest concerns regarding landfill's impact on the environment are related to its effects on ground water, surface water, air, soil, as well as the odor produced and issues arising from the transportation of solid waste [1]. Landfills are still considered the most popular method of disposal for solid waste. The increasing rate of population growth, improving standards of living, industrial growth and increasing commercial activities are major factors behind the increase in the quantity of waste produced around the world [2-4]. About 95% of solid waste that is generated in the world is disposed of in landfills [3, 4]. In the past, landfill sites were not well managed, especially where there were limited restrictions upon the type of waste dumped in landfills. Different kinds of industrial, household and sometimes toxic wastes were mixed together in the same landfill [3, 5].

The site selection process for landfill is considered to be one of the most complex tasks related to solid waste management systems because many factors must be taken into consideration. Examples of such factors include government and municipal funding, government regulation, social and environmental factors, concerns for public health, growing environmental awareness, reduced land availability for landfills and increasing political and social opposition to the establishment of landfill sites [6-9]. In the 1930s, the United States was one of the countries that saw the earliest changes in the development of sanitary landfills through depositing the solid waste in layers, compacting it, and then covering it with soil on a daily basis. Many countries (such as Canada, the United

Corresponding author: Nadhir Al-Ansari, professor; research fields: water resources and environment. E-mail: nadhir.alansari@ltu.se.

States, Australia and Sweden) implemented stringent governmental regulations relating to the selection, design and monitoring of modern landfills in order to avoid negative social and environmental impacts [3].

GIS s (geographic information system) and MCDM (multi-criteria decision making) methods are recommended for siting landfills because they are powerful and integrated tools that are able to solve the problems that arise in landfill site selection. Decision makers often use MCDA (multi-criteria decision making analysis) to handle large quantities of complex information. In MCDM methods in this context, weightings for criteria maps are derived and used alongside GIS to identify a suitable landfill site. Many methods of multi-criteria decision making analysis can be used. GIS is one of these approaches, and it has a high ability to manage large volumes of spatial data and simulate the required effect factors from a variety of sources [10-12].

Babylon Governorate is situated in the Mesopotamia Basin, which is referred to historically as the area located between the Tigris and Euphrates Rivers. It is essentially a flat terrain, with a gentle slope from northwest to the southeast towards the Arabian Gulf. The Mesopotamia Basin is mainly covered by different types of Quaternary sediments. The Quaternary Period comprises different sediment types. Depending on their genesis, the sediments are classified as fluvial, lacustrine, aeolian, polygenic anthropogenic sediments, and gypcrete [13]. The area in this governorate is also characterized by its shallow groundwater. The water table varies in depth from 0.423 m to 15.97 m below the surface of the ground in most of the areas.

There are 11 types of soil distributed within the Babylon Governorate [14]. These types are: (1) gypsiferous gravel soils; (2) mixed gypsiferous desert land; (3) sand dune land; (4) active dune land; (5) river levee soils; (6) silted haur and marsh soils; (7) river basin soils, poorly drained phase; (8) river basin soils, poorly drained phase; (9) basin depression soils; (10) haur soils; and (11) periodically flooded soils. These soil types were used as categories to select landfill sites in each city in the Babylon Governorate, with each type given an appropriate weighting based on its importance in preventing groundwater contamination by leachate from waste.

In selecting a landfill site, the main purpose of conducting soil investigation is usually to acquire the necessary data to study the different strata of soil at the selected sites and to know the groundwater depth at the sites [15]. The soil investigations at each site include knowing the characteristics of the subsoil profile for distributed samples marked (D), undisturbed samples marked (U) and split spoon samples marked (S.S.). In addition, the Atterberg limits of fine grained soils, the thickness of each stratum, and the allowable bearing capacity of the soil are required in order to estimate both the quantities of solid waste that can be put at each site, and the groundwater depth for each site. The chemical properties for the soil are also measured. This involves assessing the percentage of sulphate, chloride, and gypsum, the TSS (total soluble salts) and the organic material content for the soil samples plus the sulphate content (mg/L) for the water samples.

Refs. [16-22] assess potential landfill sites using GIS and MCDA methods in the field. The main aim of this study was to conduct soil investigations on the selected landfill sites in the Babylon Governorate in order to determine the best landfill design for these sites.

2. Study Area

Babylon Governorate is located in the middle of Iraq, about 100 km to the south of the Iraqi capital, Baghdad [23]. It is situated between latitude 32°5'41" N and 33°7'36" N, and longitude 44°2'43" E and 45°12'11" E (Fig. 1). The Babylon Governorate includes one of the most famous cities of the ancient world, Babylon, which was considered the power centre of an influential empire. The Babylon Governorate covers an area of 5,315 km^2 [24]. It has a population of 2,092,998 inhabitants (2015 census figures), distributed throughout its main cities [25]. Administratively, the

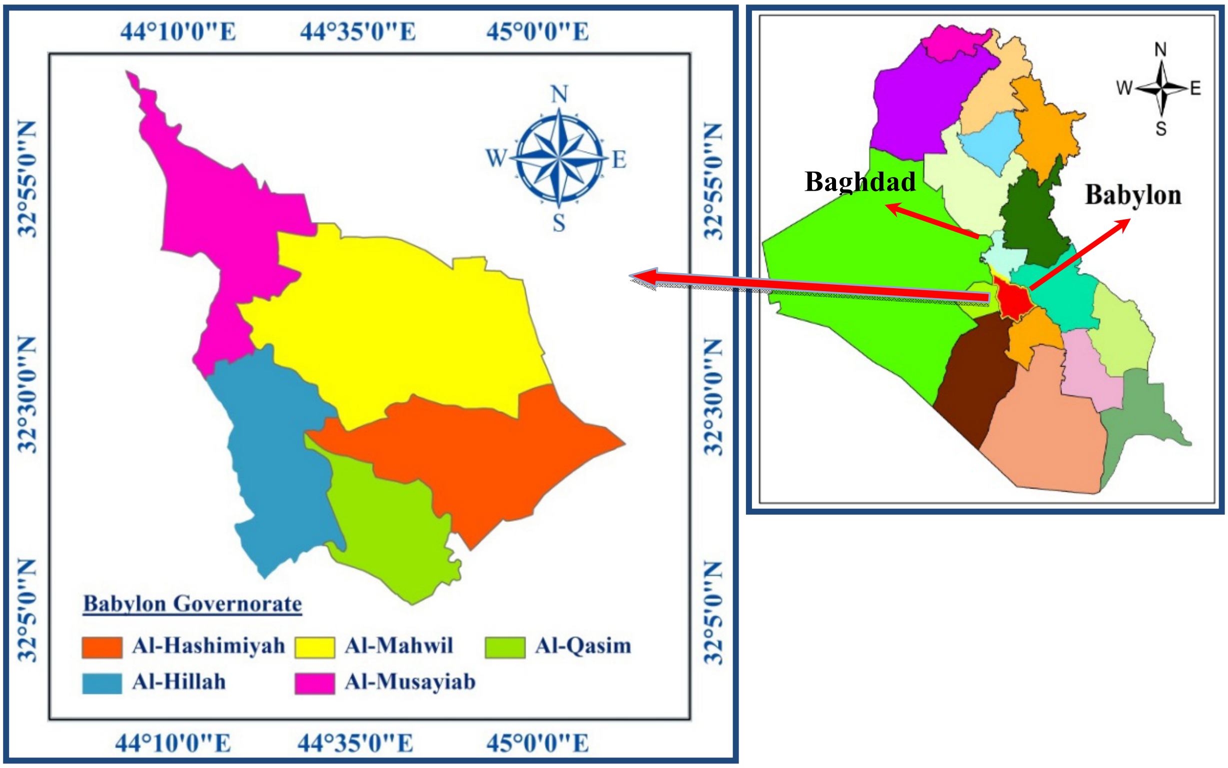

Fig. 1 The Babylon Governorate, Iraq.

Babylon Governorate consists of five major cities, referred to as Qadhaa. These Qadhaa are Al-Hillah, Al-Hashimiyah, Al-Musayiab, Al-Mahawil and Al-Qasim. Sixteen smaller cities are geographically and administratively connected to these major cities, and these are called Nahiah.

The governorate is characterized by comparatively flat and inclining land. The northern part of the Babylon Governorate rises to about 60 m above mean sea level, and the southern part falls to about 20 m above mean sea level. The lands of the Babylon Governorate are fertile, and the Shatt Al-Hillah River passes through most cities in the governorate. This river branches off from the Euphrates River at the city of Sadah in the north of the governorate in Al-Musayiab Qadhaa [24, 26].

3. Selected Candidate Landfill Sites

In order to select candidate sites for landfill in the five Qadhaas in the Babylon Governorate that would meet the environmental and scientific criteria, GIS software and multi-criteria decision making methods were used. Fifteen of the most important criteria were selected and incorporated into GIS for the analysis process with the intention of producing a map with which to select the best sites for landfill in each Qadhaa in the governorate. These criteria are groundwater depth, urban centers, rivers, villages, soil types, elevation, agriculture, roads, land slope, land use, archaeological sites, power lines, gas pipelines, oil pipelines and railways.

The required maps for this study were prepared using multiple sources. The first source was already available digital maps (shape files), and the second source was drawn from published maps, with the relevant information from each map converted to a digital map format. The third source was already available data, which were entered in a GIS to produce a digital map after generating the interpolation between these data. For the current study, the literature review, the opinions of experts in this field, various requirements, regulations and available data about the study area were all used to classify each criterion into categories (sub-criteria). Subsequently, each category was assigned a suitability score. To prepare each criterion and sub-criteria for analysis, many steps were performed in a GIS environment using special analysis tools.

Each candidate site was selected from within the category of the most suitable area in the final map for landfill siting (Fig. 2) based on the estimated quantity of cumulative solid waste which will be generated from 2020 to 2030, as calculated by Chabuk et al. [26]. Based on this condition, the final map of selected sites for landfill in the Babylon Governorate shows the location and the area required for each site (Table 1).

4. Soil Investigations

The selected candidate sites for landfill in Babylon Governorate were checked against the satellite images (2011) of the Babylon Governorate [27] to make sure that these sites were suitable for landfill in the Qadhaas of the Babylon Governorate.

To check the soil characteristics in the selected sites for landfill in the field, soil investigations were conducted for the prime candidate sites in 2016 by the Iraqi Ministry of Housing & Construction—National Center for Construction Laboratories and Research Babylon, Iraq (Fig. 3) [28]. Details of the soil investigations in these selected sites are as follows.

4.1 Field Exploration in the Selected Sites

4.1.1 Drilling and Sampling

Drilling was done using flight augers. The diameter of the drilled bore holes was 15.0 cm. The distributed samples (D) were collected from the auger cuttings at different depths. The undisturbed samples, marked (U), were obtained using Shelby tubes. Split spoon samples (S.S.) were obtained from a standard split spoon used in the S.P.T (Standard Penetration Test) which was performed for every test boring at different intervals depending on the stratification of the soil.

4.1.2 Number of Bore Holes and Their Depth

Two borehole locations were assigned for each site by the local authority concerned, and the boreholes were drilled to a specific depth below ground surface (N.G.S).

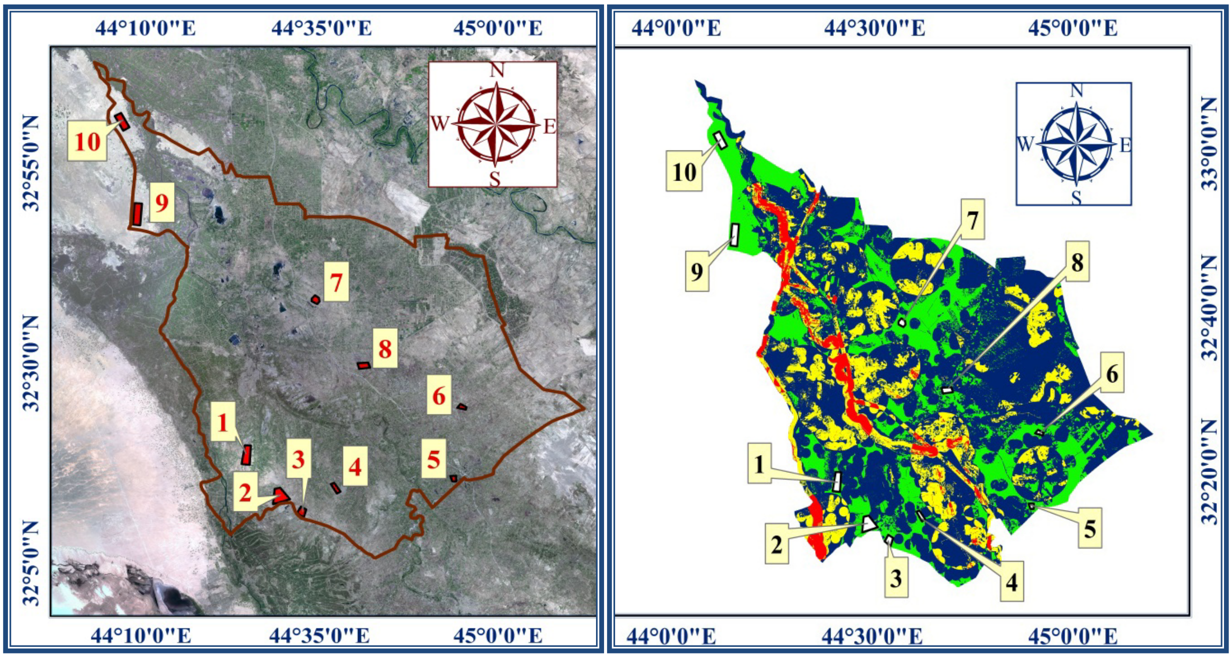

Fig. 2 Candidate sites for landfill in the Babylon Governorate.

Table 1 Landfill in the Qadhaas of the Babylon Governorate.

Qadhaa (city)	Required area (km^2)	Area of candidate sites		Location	No. of site in Fig. 2
		Site	Area (km^2)		
Al-Hillah	Method 1 4.175	No. 1	6.768	Latitude 32°18'45" N Longitude 44°24'40" E	1
	Method 2 4.778	No. 2	8.204	Latitude 32°13'43" N Longitude 44°29'15" E	2
Al-Qasim	Method 1 0.577	No. 1	2.766	Latitude 32°11'43" N Longitude 44°32'26" E	3
	Method 2 0.772	No. 2	2.055	Latitude 32°14'38" N Longitude 44°37'10" E	4
Al-Hashimiyah	Method 1 0.844	No. 1	1.374	Latitude 32°24'51" N Longitude 44°54'41" E	6
	Method 2 1.013	No. 2	1.288	Latitude 32°15'54" N Longitude 44°53'38" E	5
Al-Mahawil	Method 1 0.738	No. 1	2.218	Latitude 32°38'12" N Longitude 44°34'9" E	7
	Method 2 0.975	No. 2	2.950	Latitude 32°29'59" N Longitude 44°41'2" E	8
Al-Musayiab	Method 1 1.674	No. 1	7.965	Latitude 32°48'39" N Longitude 44°8'59" E	9
	Method 2 2.080	No. 2	5.952	Latitude 33°0'14" N Longitude 44°6'46" E	10

Fig. 3 Soil investigations works at candidate sites in the Babylon Governorate.

5. Results

5.1 Subsoil Stratification

The subsoil profile for the selected sites in each Qadhaa in the Babylon Governorate was analyzed according to the USCS (Unified Soil Classification System) (ASTM 2487), which is generally used in assessing the engineering properties of soils and is based on grain size and plasticity characteristics (Atterberg limits).

5.1.1 Soil Profile for Al-Hillah City, Al-Hillah Qadhaa

The subsoil profile for Al-Hillah City, Al-Hillah Qadhaa (borehole site No. 1) can be summarized as follows:

The first layer is fill material to a thickness of about 0.5 m.

The second layer is about 2.0 m thick, consisting of red brown, medium to very stiff, silty clay with gypsum and organic material, and containing a thin layer of brown, medium clayey, sandy silt and organic material of about 0.5 m in thickness.

Then, there is a layer of brown, red, stiff to very stiff, silty clay with gypsum and organic material of about 6.0 m in thickness, and containing a thin layer of brown, medium clayey, sandy silt and organic material that is about 0.5 m thick.

The last layer is yellow, grey, medium silty sand to the end of the bore.

The underground water level was encountered at a depth of 2 m below the ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the overall soil stratification are shown in the borehole log and soil profile (Fig. 4).

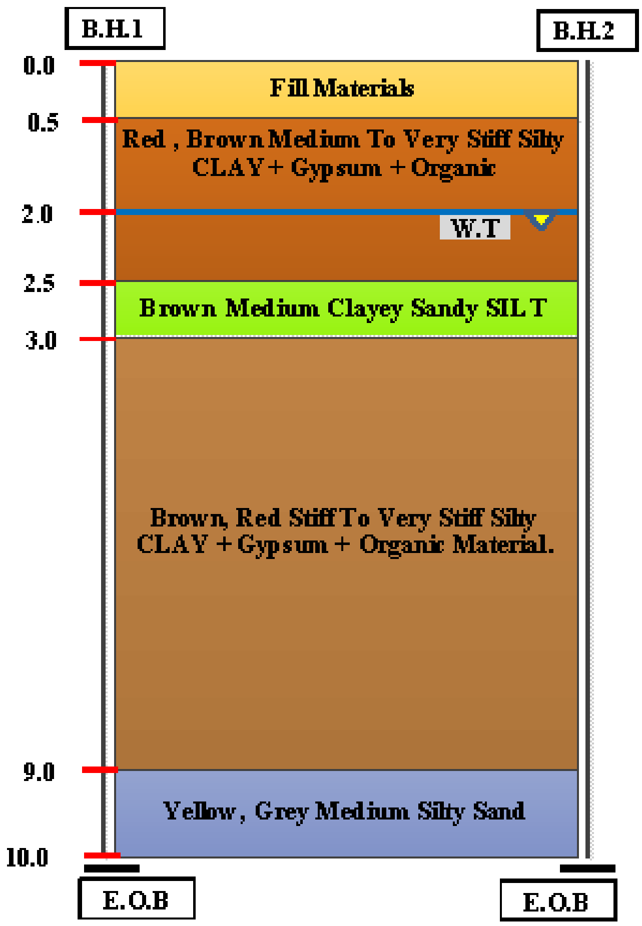

Fig. 4 Soil profile for Al-Hillah City, Al-Hillah Qadhaa.

5.1.2 Soil Profile for Al-Kifil City, Al-Hillah Qadhaa

The subsoil profile for Al-Kifil City, Al-Hillah Qadhaa (site No. 2) can be summarized as follows:

The first layer is about 7.5 m thick, consisting of brown, stiff to hard, sandy silty clay (CL, MH-OH) with organic material. It also contains a thin layer of brown, clayey, silty sand of about 0.5 m in thickness.

Then, there is a layer of brown, medium to very dense, clayey, silty sand (river sand) which extends down to the end of the bore below N.G.S.

The underground water level was encountered at a depth of 2 m below the ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification are shown in the borehole log and soil profile (Fig. 5).

In Al-Qasim City, Al-Qasim Qadhaa (site No. 2), the subsoil profile can be summarized according to the unified classification system as follows:

The upper layer is fill material of about (0.5-1.0) m in thickness.

Then, there is a layer of brown, stiff, silty clay of about (0.5) m in thickness.

The following layer is brown, medium clayey silty sand.

The main layer is brown, grey medium to very stiff, sandy silty clay and silty clay (CH-CL) with organic material, iron oxide, roots, shells and gypsum which extends down to the end of the bore. This layer also contains a thin layer of brown black, medium clayey, silty sand (river sand).

5.1.3 Soil Profile for Al-Qasim city, Al-Qasim Qadhaa

The underground water level was encountered at a depth of 2.2 m below the ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification for the hole are shown in the borehole log and soil profile (Fig. 6).

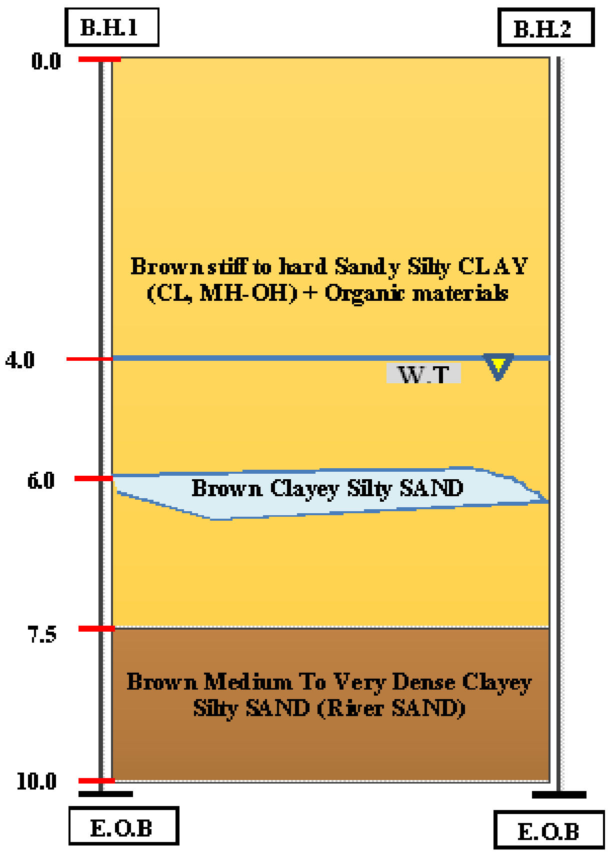

Fig. 5 Soil profile for Al-Kifil City, Al-Hillah Qadhaa.

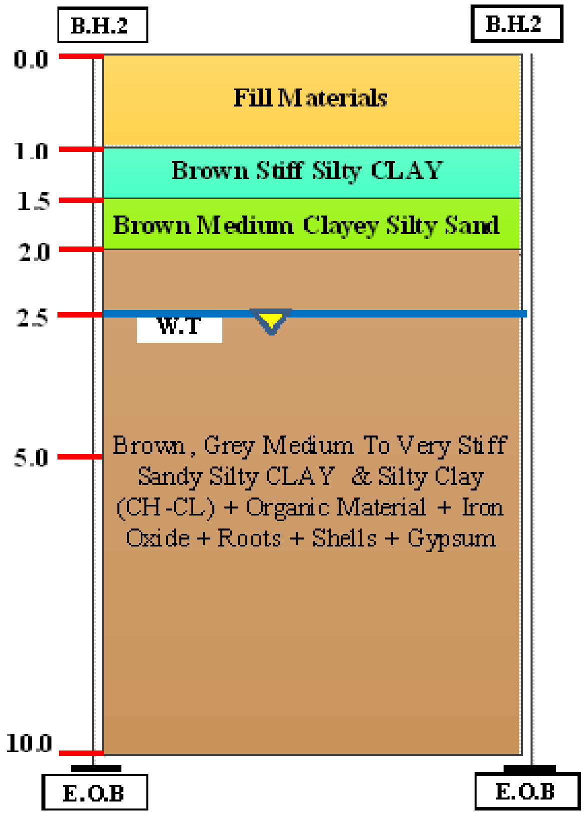

Fig. 6 Soil profile for Al-Qasim City, Al-Qasim Qadhaa.

5.1.4 Soil Profile for Al-Talyaah City, Al-Qasim Qadhaa

The subsoil profile for Al-Talyaah City, Al-Qasim Qadhaa (borehole site No. 1) is similar to the subsoil profile from Al- Kifil City, Al-Hillah Qadhaa (borehole site No. 2). These sites are located in the same area and have similar properties, and the distance between these sites is about 4 km.

Here, however, the underground water level was encountered at a depth of 4.7 m below ground surface (G.S.), measured 24 hours after drilling terminated.

5.1.5 Soil Profile for Al-Medhatyah City, Al-Hashimiyah Qadhaa

The classification and description for the subsoil profile for Al-Medhatyah City-Al-Hashimiyah Qadhaa (borehole site No.1) according to the unified classification system can be summarized as follows:

The first layer is fill material of about 1.2 m in thickness.

Then, there is a brown, soft sandy silty clay (CL) with roots to a thickness of about 0.5 m.

The following layer is brown, loose to medium sandy clayey silt with roots, and extending down to a depth of about 8 m below the ground water surface. This layer includes a lense of brown, medium sandy, silty clay (CL).

Next is a layer of brown, medium to stiff, sandy silty clay (CL-CH) that extends down to 10 m below the ground surface.

The underground water level was encountered at a depth of 3.8 m below the ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification for the hole are shown in the borehole log and soil profile (Fig. 7).

5.1.6 Soil Profile for Al-Shomaly City, Al-Hashimiyah Qadhaa

According to the unified classification system, the subsoil profile for Al-Shomaly City, Al-Hashimiyah Qadhaa (borehole site No. 2) can be summarized as follows:

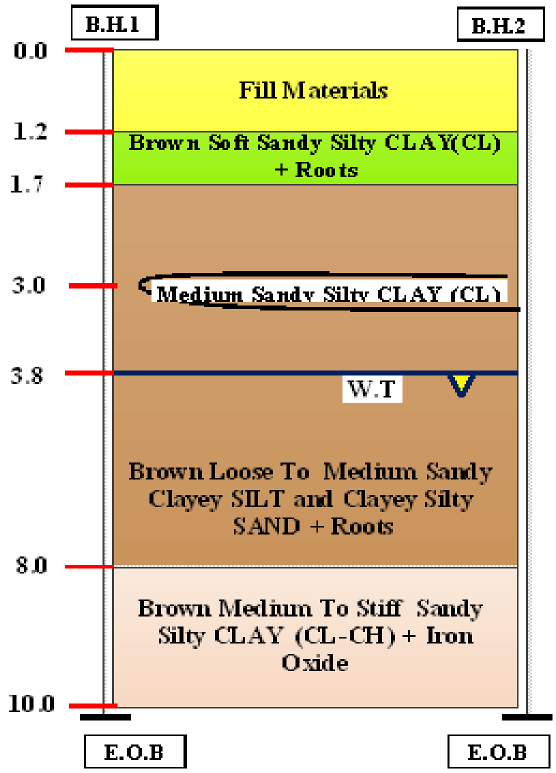

Fig. 7 Soil profile for Al-Medhatyah City, Al-Hashimiyah Qadhaa.

The first layer is fill material of about 0.7 m in thickness.

The next layer is brown and grey, soft to very stiff, silty clay with organic material and iron oxide of about 6 m in thickness. This layer also contains a lense of brown, medium clayey silt of about 0.75 m in thickness.

Then, there is a layer of brown, medium sandy, clayey silt of about 1 m in thickness.

The following layer is brown and black, medium silty clayey sand (river sand) down to a depth of 9 m below N.G.S.

The last layer is brown, very stiff to hard clay down to the end of the bore.

The underground water level was encountered at a depth of 4 m below ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification for the hole are shown in the borehole log and soil profile (Fig. 8).

5.1.7 Soil Profile for Al-Imam City, Al-Mahawil Qadhaa

The subsoil profile for Al-Imam City, Al-Mahawil Qadhaa (borehole site No. 1) can be summarized according to the unified classification system as follows:

The first layer is fill material of about 0.5 m in thickness.

The main layer is brown, black medium to very stiff, silty clay with gypsum and organic material down to about 9.5 m below G.S.

The last layer is brown, medium sandy, clayey silt with iron oxide and is about 0.5 m thick.

The underground water level was encountered at a depth of 2.7 m below ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification for the hole are shown in the borehole log and soil profile (Fig. 9).

5.1.8 Soil Profile for Al-Neel City, Al-Mahawil Qadhaa

The Al-Neel city, Al-Mahawil Qadhaa (borehole site No. 2) subsoil profile can be summarized according to the unified classification system as follows:

The main layer is brown, medium to very stiff, silty

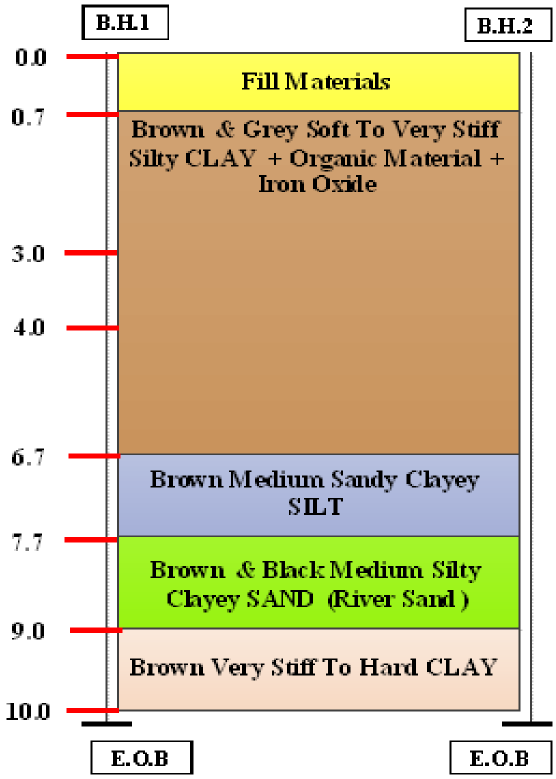

Fig. 8 Soil profile for Al-Shomaly City, Al-Hashimiyah Qadhaa.

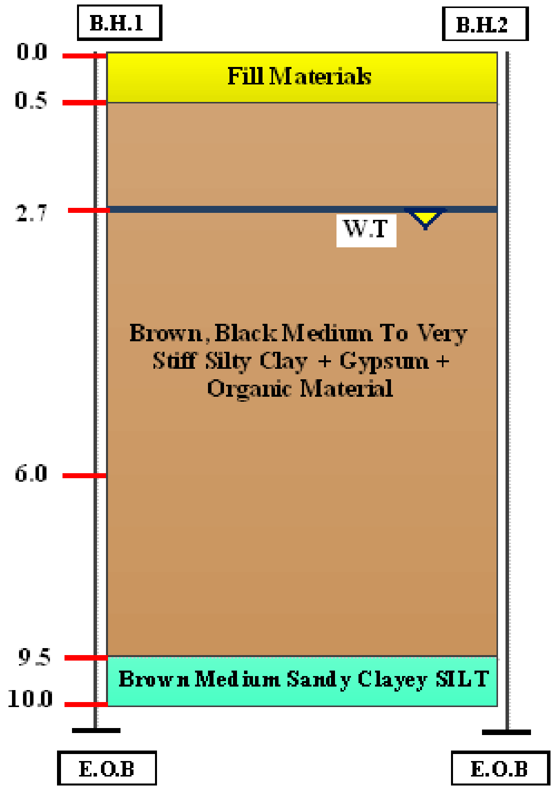

Fig. 9 Soil profile for Al-Imam City, Al-Mahawil Qadhaa.

clay and sandy silty clay (CH- CL- OL) with organic material and iron oxide.

The underground water level was encountered at a depth of 2.1 m below ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification for the hole are shown in the borehole log and soil profile (Fig. 10).

5.1.9 Soil Profile for JurfAl-Sakhar City, Al-Musayiab Qadhaa

Due to the security situation in this area, where people are not allowed to visit this area, the work was based on previous data available at governmental departments. According to the unified classification system, the subsoil profile for Jurf Al-Sakhar City-Al-Musayiab Qadhaa can be summarized as follows:

The upper layer is brown, medium dense, highly gypsums, silty sand extending down to 2 m below N.G.S.

Then, there is a layer of brown, stiff, highly gypsum, sandy silty clay extending down to about 9 m below N.G.S.

Finally, there is a layer of dense to very dense, silty sand extending down to the end of the bore.

The underground water level was encountered at a depth of 10 m below ground surface (G.S.), measured 24 hours after drilling terminated.

Details of the soil stratification for the hole are shown in the borehole log and soil profile (Fig. 11).

5.2 Chemical Properties

The results of the chemical tests for the soil and water samples are shown in Table 2. These results show the percentage of sulphate, chloride, and gypsum content, the TSS content and the organic material content for the soil samples. For the water samples, only the sulphate content (mg/L) was measured.

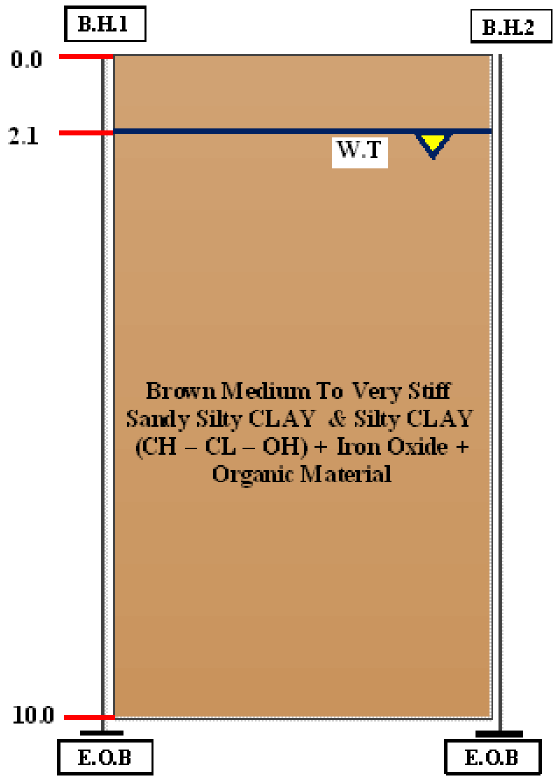

Fig. 10 Soil profile for Al-Neel City, Al-Mahawil Qadhaa.

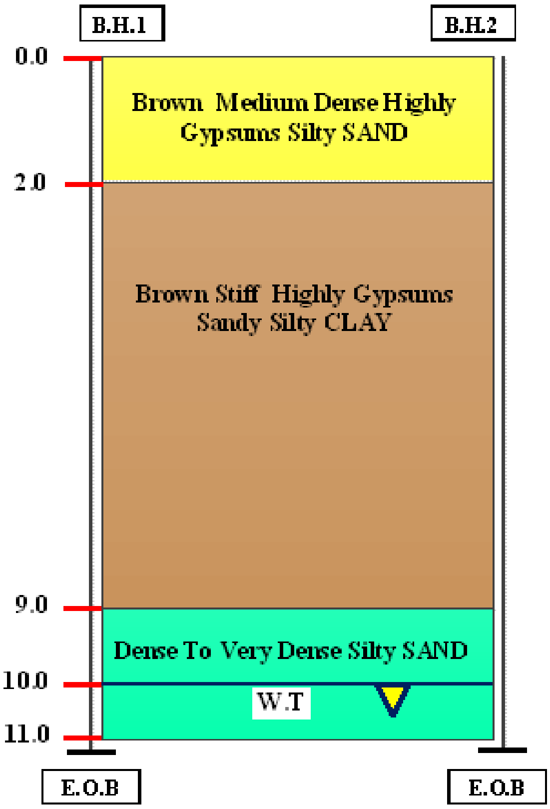

Fig. 11 Soil profile for JurfAl-Sakhar City, Al-Musayiab Qadhaa.

Table 2 Results of the chemical tests for soil and water samples.

Qadhaa	City	Borehole site No.	Sulphate content (%)	Chloride content (%)	Gypsum content (%)	TSS (%)	Organic material content (%)	Sulphate content in water (mg/L)
Al-Hillah	Hillah	1	0.21-3.13	0.018-0.213	0.45-6.73	0.94-8.92	1.06	276.1
Al-Hillah	Kifil	2	0.05-0.59	0.01775-0.01778	0.11-0.59	0.23-0.82	0.54-1.89	389.6
Al-Qasim	Talyaah	1	0.05-0.59	0.01775-0.01778	0.11-0.59	0.23-0.82	0.54-1.89	389.6
Al-Qasim	Qasim	2	0.32-4.75	0.018-0.378	0.69-10.22	1.21-11.81	0.11-0.95	384.5
Al-Hashimiyah	Medhatyah	1	0.04-0.14	0.018-0.036	0.162-0.29	0.52-0.97	-	61.9
Al-Hashimiyah	Shomaly	2	0.121-0.66	0.124-0.568	0.26-1.42	0.58-1.77	1.40	290.5
Al-Mahawil	Imam	1	0.195-2.978	0.0177-0.0178	0.42-6.4	0.79-9.21	0.39	266.1
Al-Mahawil	Neel	2	0.161-0.823	0.0177-0.0355	0.35-1.77	1.2-2.5	0.84-1.76	97.21
Al-Musayiab	JurfAl-Sakhar	1+2	0.62-22.5	0.07-0.11	1.33-48.46	2.4-51.4	4.0-4.71	178.4

5.3 Allowable Bearing Capacity

The allowable bearing capacity at different depths in meters below the G.S. profile in each Qadhaa in the Babylon Governorate differs from one site to another based on the soil profile for each selected site, as shown in Table 3.

5.4 Atterberg Limits Test Results

Generally, the values of the liquid limit (L.L), plasticity index (P.I) and moisture content (M.C) at different depths indicate the natural moisture content of each soil profile based on the test results in each site. These are shown in Table 4.

5.5 Soil Classification and Material Characteristics

The soil texture types are classified according to two general methods of soil classification: the USDA (US Department of Agriculture) texture classification system and the USCS (Unified Soil Classification System) (ASTM 2487). The USDA system, used by soil scientists and agronomists, is based principally on texture (grain size distribution). The USCS system is generally used in assessing the engineering properties of soils and is based on grain size and plasticity characteristics (Atterberg limits). The characteristics of materials in each stratum of soil were estimated in the laboratory (Table 5).

Table 3 Allowable bearing capacity at different depths below G.S. for each site.

Qadhaa	City	Site No.	Depth (m) Below G.S.	Allowable bearing capacity (t/m^2)	Allowable bearing capacity (kN/m^2)
Al-Hillah	Hillah	1	1-1.5	5	50
			1.5-2.5	10	100
	Kifil	2	1	7.5	75
			2-3	10	100
Al-Qasim	Talyaah	1	1	7.5	75
			2-3	10	100
	Qasim	2	1-2	6	60
			2-3	10	100
			3-4	13	130
Al-Hashimiyah	Medhatyah	1	1-2.5	4	40
			3-3.5	6	60
			4-5	8	80
	Shomaly	2	1.5-2.5	6	60
Al-Mahawil	Imam	1	1-1.5	5	50
			1.5-2	6	60
			3.5-3	10	100
	Neel	2	1-2	7	70
			2-3	12	120
Al-Musayiab	JurfAl-Sakhar	1+2	1-1.5	7	70
			2-3	10	100

Table 4 Natural moisture content and the cohesive layer at each site.

Qadhaa	City	Borehole site No.	Natural moisture content	Cohesive layer
Al-Hillah	Hillah	1	Closer to the plastic limit than to the liquid limit	Tends to be over consolidated and with a medium to very stiff consistency
	Kifil	2	Closer to the plastic limit than to the liquid limit	Tends to be over consolidated and with a stiff to hard consistency
Al-Qasim	Talyaah	1	Closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a stiff to hard consistency
	Qasim	2	Closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a medium to hard consistency
Al-Hashimiyah	Medhatyah	1	Closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a soft to stiff consistency
	Shomaly	2	It is closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a soft to hard consistency
Al-Mahawil	Imam	1	It is closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a medium to very stiff consistency
	Neel	2	It is closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a medium to very stiff consistency
Al-Musayiab	JurfAl-Sakhar	1+2	It is closer to the plastic limit than to the liquid limit	Tends to be over consolidated, with a stiff to hard consistency

Table 5 Summary of the soil compositions of sites and their material characteristics.

No.	Layers	Classification		Total porosity	Field capacity	Permanent wilting point	Saturated hydraulic conductivity	Thick (m)	GWT (m)
		USDA	USCS						
Al-Hillah City-Al-Hillah Qadhaa									
1	Fill material	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	0.5	2
2	Silty clay + gypsum	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	2	
3	Clayey sandy silt	CL	CL	0.464	0.310	0.187	6.4×10^{-5}	0.5	
4	Silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	6	
5	Silty SAND	LS	SM	0.437	0.105	0.047	1.7×10^{-3}	1	
Al-Kifil City-Al-Hillah Qadhaa & Al-Talyaahcity-Al-Qasim Qadhaa									
1	Sandy silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	7.5	4
2	Clayey silty sand	SL	SM	0.453	0.190	0.085	7.2×10^{-4}	0.5	
3	Silty clayey sand	LS	SM	0.447	0.118	0.065	1.4×10^{-3}	2.5	
Al-Qasim City-Al-Qasim Qadhaa									
1	Fill material	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	1	2.5
2	Silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	0.5	
3	Clayey silty sand	SL	SM	0.453	0.190	0.085	7.2×10^{-4}	0.5	
4	Sandy silty clay & silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	8	
Al-Imamcity-Al-Mahawil Qadhaa									
1	Fill material	L	ML	0.419	0.307	0.180	1.9×10^{-3}	0.5	2.7
2	Clay	C	CH	0.378	0.371	0.265	1.7×10^{-5}	9	
3	Sandy clayey silt	SiCL	SC	0.471	0.342	0.210	4.2×10^{-5}	0.5	
Al-Neel city-Al-Mahawil Qadhaa									
1	Silty clay + sandy silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	10	2.1
		SiC	CH	0.479	0.371	0.251	2.5×10^{-5}		
Al-Medhatyah City-Al-Hashimiyah Qadhaa									
1	Fill material	SC	SC	0.430	0.321	0.221	3.3×10^{-5}	1.2	3.8
2	Sandy silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	0.5	
3	Sandy clayey silt	SiCL	SC	0.471	0.342	0.210	4.2×10^{-5}	6.3	
4	Sandy silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	2	
Al-Shomaly City-Al-Hashimiyah Qadhaa									
1	Fill material	SiL	ML	0.501	0.284	0.135	1.9×10^{-4}	0.7	4
2	Silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	6	
3	Sandy clayey silt	SiCL	SC	0.471	0.342	0.210	4.2×10^{-5}	1	
4	Silty clayey sand	LS	SM	0.447	0.118	0.065	1.4×10^{-3}	1.3	
5	Clay	C	CH	0.378	0.371	0.265	1.7×10^{-5}	1	
Jurf Al-Sakhar City-Al-Musayiab Qadhaa									
1	Silty sand	SL	SM	0.453	0.190	0.085	7.2×10^{-4}	2	10
2	Sandy silty clay	SiC	CH	0.479	0.371	0.251	2.5×10^{-5}	7	
3	Dense silty sand	LS	SM	0.437	0.105	0.047	1.7×10^{-3}	1	

6. Conclusions

The present study aimed to conduct soil investigations as part of the selection process for the best sites for landfill in each Qadhaa in the Babylon Governorate. GIS software and multi-criteria decision making methods were used to determine suitable sites for landfill from within the final output maps of suitability index for landfills and which had been implemented in previous studies. Each site was subjected to field soil tests to find the composition of the soil strata at each site to a depth of 10 m, and these results were compared with the soil properties that were adopted for final site selection. The Iraqi Ministry of Housing & Construction, National Centre for Construction Laboratories and Research Babylon, Iraq, carried out the analytical work on the soil in 2016.

The results of the soil investigation at these sites include a determination of the soil profile for each site, the chemical properties, the allowable bearing capacity; Atterberg limits test results and the material characteristics of the strata. In addition, the level of groundwater depth at each site was ascertained.

In Al-Hillah City, Al-Hillah Qadhaa, there are five layers that include fill material (0.5 m), silty clay (2 m), clayey sandy silt (0.5 m), silty clay (6 m) and silty sand (1 m). There are four soil layers at both Al-Kifil City, Al-Hillah Qadhaa and Al-Talyaah City, Al-Qasim Qadhaa, and these layers consist of fill material (1 m), sandy silty clay (6 m), clayey silty sand (0.5 m) and silty clayey sand (2.5 m). The composition of the four soil layers from Al-Qasim City, Al-Qasim Qadhaa are fill material (1 m), Silty clay (0.5 m), clayey silty sand (0.5 m), and sandy silty clay & silty clay (8 m). In Al-Imam City, Al-Mahawil Qadhaa, the three soil layers include fill material (0.5 m), clay (9 m) and sandy clayey silt (0.5 m), whilst at Al-Neel City, Al-Mahawil Qadhaa, the soil consists of silty clay and sandy silty clay (10 m). The soil composition in Al-Medhatyah City, Al-Hashimiyah Qadhaa, includes fill material (1.2 m), sandy silty clay (0.5 m), sandy clayey silt and clayey silty sand (6.3 m), and sandy silty clay (2 m). For Al-Shomaly City, Al-Hashimiyah Qadhaa, the five soil strata are fill material (0.7 m), silty clay (6 m), sandy clayey silt (1 m), silty clayey sand (1.3 m), and clay (1 m). The soil compositions in Jurf Al-Sakhar City, Al-Musayiab Qadhaa, are silty sand (2 m), sandy silty clay (7 m) and dense silty sand (1 m).

The results of the chemical tests for the soil and water samples, at all sites, showed that the maximum contents of sulphate, chloride, gypsum total soluble salts and organic materials were 22.5%, 0.57%, 0.568%, 51.4% and 4.71%, respectively, whilst the minimum contents were 0.04%, 0.0177%, 0.11%, 0.21% and 0.11%, respectively. For water samples, the maximum sulphate content was 389.6 mg/L, while the minimum sulphate content was 61.9 mg/L.

The allowable bearing capacity at different depths below G.S. for all sites varied from 5 to 13 t/m^2 or (50-130) kN/m^2. For all sites, the natural moisture content was closer to the plastic limit than to the liquid limit, whereas the cohesive layers generally were tending to be over consolidated. The cohesive layer was medium to very stiff consistency in Al-Hillah Al-Imam, and Al-Neel; stiff to hard consistency in Al-Kifil Al-Talyaah andJurfAl-Sakhar; stiff to hard consistency in Al-Qasim; medium to hard consistency in Al-Medhatyah; soft to hard consistency in Al-Shomaly.

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