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Geotechnical site investigations for possible urban extensions at Suez City, Egypt using GIS

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Abstract With the development of economic activities in the world, the construction activities have also increased. A proper surface and subsurface investigation is made to assess the general suitability of the site and to prepare an adequate and economic safe design for the proposed work. The main purpose of the current study is to create a spatial model of the geotechnical conditions and considerations by using geographic information systems (GIS) techniques to develop and analyze a site model and to plan site activities at the new extension of Suez City (SC). In the geotechnical site evaluations, GIS can be used in four ways, data integration, data visualization and analysis, planning and summarizing site activities, and data presentation. The integrated data can be displayed; manipulated and analyzed using tools build into the GIS programs, thus creating the geotechnical site model of the study area. Decisions can be made for further site activities and the results of the site activities can be integrated into the GIS site model. Interpretation of geotechnical data frequently involves assimilating information from many sites each with a unique geographical location. Interpretation of these data requires the spatial location to incorporate into the analysis. Weights are assigned to different of mechanical, physical soil properties, geological, hydrogeological, and other ancillary data. Finally, the weighted maps are integrated using a GIS based on the construction purposes for the new extension of SC for significant cost savings in design, construction and longevity. The ideal and good zones' highest regime has been observed towards central and western regions with sporadic pockets. The marginal zones to average zones are moderately suited for shallow foundation.

Keywords Geospatial analysis · Urban planning · Geo-environmental · Foundations

Introduction

Over the last century, the world has witnessed rapid urbanization. Urbanization can be explained to be the process that involves an increasing number of a nation's population living in cities or suburbs. The growth is becoming so rapid; it is becoming a major problem to states across the world. In 2005, it was estimated that around 3.2 billion people on the earth are urban dwellers and it was projected that by 2008 half of the entire world's population will be living in urban areas (United Nations 2005). Urban expansion has been a hot topic not only in the management of sustainable development but also in the fields of remote sensing (RS) and geographic information systems (GIS). Urban development is a complicated dynamic process involving various actors with different patterns of behavior. Modeling an urban development pattern is the prerequisite to understand the process. Today, the spatial planning and decision support methods are used to make the process of planning and decision making more transparent with the new development and advance geospatial technologies (Collins et al. 2001; Malczewski 2004; 2006). The construction sites and site selection are an extremely busy place where working environment is ever changing that becomes difficult to predict before or during construction. Poor safety planning and ever-changing environment of construction sites often lead to accidents

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which affect people, project economics, and social life and bring additional legal liabilities. Poor safety on site keeps workers and their relatives always in physical and psychological troubles which economically affect the project by increasing direct and indirect costs (Bansal 2010). With the sustainable development of the economic activities in the world, the construction activities have also increased manifold to assess the general suitability of the site and to prepare an adequate and economic safe design for the proposed work, in addition to the proper sub-surface investigation is made. Site investigations are necessary to assess the suitability of the site for proposed structure, enable a safe and cost-effective design and to advise on the changes that may arise in the ground and environmental conditions of the site due to construction and operation of the project (Player 2000 and Rajesh et al. 2003). Throughout the world, urban geology occupies a key place in planning and mapping the geological environment of the cities. It is also defined as the study of land resources and geologic hazards related to the development and expansion of urban areas (Baker 1975; Fuchu et al. 1994). Urban geology provides information of urban geologic environments as a scientific basis for planners and engineers for rational land use planning and urban development. Such mapping can be classified in terms of purpose, content and scale (El May, et al. 2010). Within the frame of urban geology, the geotechnical mapping consider as an important tool providing geotechnical parameters to establish a suitable map for construction, which help to establish a safe urban extension. Furthermore, the data collection, geological analysis and the establishment of the map, one other purpose of urban geology is to provide geological knowledge to planners and politicians for the establishment of rational development planning. Several urban geological studies of some cities are good examples for this approach (Baker 1975; Akpokodje 1979; Bowles 1984; Edbrooke et al. 2003; Haworth 2003; Nott 2003; Willey 2003; Woodward 2005; Chowdhury and Flentje 2007; Ozsan et al. 2007; El May et al. 2009, El May, et al. 2010).

Globally, over the last two decades, many studies have attempted to map, integrate, and assess hazards and have produced vulnerability maps portraying their spatial distribution, particularly by using RS/GIS and performing zonation hazards; in order to prepare geotechnical zonation maps and cross-sections of a chosen sub-section. A GIS tool has been used to prepare the zonation maps and also to determine the suitability of the foundation soils in residential areas regarding the geotechnical suitability of the foundations of residential areas. Also, in geotechnical investigations, the engineering, in other words the geo-engineering properties of soil layers must be known down for a required depth. In this respect, a GIS tool has been used to prepare the zonation maps in order to determine the

suitability of the foundation soils in residential areas (Orhan and Tosun 2010). Furthermore, GIS has been frequently used for spatial data management and manipulation. A geo-environmental evaluation for urban land-use planning often requires a large amount of spatial information. It could be argued that a GIS is a powerful tool as it evaluate a huge numbers of data for the geo-environmental assessment to perform analyses of very large areas in a reasonable time. In addition to that, an important feature of a GIS is the ability to generate new information by integrating the existing diverse datasets sharing a compatible spatial referencing system. Today, GIS technology has been widely used to assess natural geo-hazards, groundwater vulnerability assessment and site selection for waste disposal studies, which are related to the geo-environmental assessment for urban land-use planning (Jones 2001; Dai et al. 2001a; Arnous 2004; Hasan et al. 2004; Chacon et al. 2006; Pandey et al. 2008; Arnous and Green 2010; Farrokhnia et al. 2010; Pradhan and Youssef 2010; Youssef et al. 2010; 2011 and Arnous, et al. 2011). Multiple approaches and methodologies have been implemented into the GIS to produce most accurate data, such as multi-criteria decision analysis, fuzzy logic and artificial neural networks. In the last decades, the GIS technique is mostly used by geoscientists for determining the landslides and landslide susceptibility zonation studies for over last decades by creating of engineering geological maps by means of landslide susceptibility (Pradhan 2010, 2011; Arnous 2010; Pradhan et al. 2010a, b). Moreover, seismic zonation maps can also be created by GIS (Nath 2004, 2005; Orhan et al. 2007; Tosun et al. 2007; Orhan and Tosun 2010 and Safari et al. 2010). In addition to, liquefaction potential of an area could be achieved by multi geo-data handling by means of multi-criteria decision analysis (Kolat et al. 2006). Furthermore, previous studies have demonstrated the capability of GIS as a method of analysis in civil engineering projects (Jankowski and Richard 1994; Collins et al. 2001; Jones and Barron 2002), and the GIS models can manipulate, compile, and process spatial data above or below the earth's surface. Also, the GIS in conjunction with RS, geophysical data, and other governmental records can be used to determine the preliminary hazard/suitability during a site investigation (Kasani 2005). The purpose of integrating different data types in a GIS environment is to identify different potential hazards that will affect the development, especially if the area is promising for urban development, tourism, and/or industrial activities.

The aim of present study is to develop a GIS model, that evaluates the geotechnical conditions and considerations for safe construction purposes and apply this model at new Suez City (SC) extensions to elucidate its applicability.

Problem statement

Geotechnical engineering has generally been regarded as a part of civil engineering. The fundamental principles of mechanics and hydraulics have underpinned its development. Recognition of the articulate nature of soils and rocks, their geological origin, and their variability has led to the birth, nurturing, and development of the disciplines of soil mechanics and rock mechanics (Chowdhury and Flentje 2007). Physical such as particle size, structure composition, and engineering properties include strength, angle of internal friction, cohesion, stress–strain modulus, poison's ratio, fluid and environmental affect on soil and rocks (climate, rainfall, gravitational, and chemical). Thus, soil mechanics is a subset of geotechnical engineering that is used on the predication of the behavior and performance of soil and rocks as construction materials or as support to engineering works (Bowles 1984; Woodward 2005).

Most of the clay soils found in arid or semi-arid environment exhibit some swelling potential. Swelling clay may be considered as one of the most destructive phenomena offered by Mother Nature in many countries, where the cost of damages caused by swellings clays more than twice the damages caused by floods, hurricanes, tornadoes and earthquakes (Haliburton 1984). The soil of the SC area suffers from swelling problems. The clay has a potential swelling and swelling pressure ranging between 0.5 and 10.3 kg/cm^2 (Mahfouz 1999). On the surface, deposits of disgorging material is clear, consisting of some silty clay intercalated with sand and gravel and in some localities it was interbedded with a thin layer of gypsum crystals at or near the surface. According to Abdel Tawab and Shendi (1993) and Mahfouz 1999, there is a thin lenses of silty clay appear at El-Sahab in the upper layers, which might go unnoticed if fixed interval sampling adopted. Gypsum crystals cause an increase in soil strength because the strength of the gypsum layer is higher than the clay itself. In addition, one of El-Sahab sector's buildings has suffered from a serious tilting (i. e., about 30 ° from the vertical) and a subsidence of about 2 m. Accordingly, the local authorities have decided some quick arrangements to control the problem and to decrease its bad effects. A few months later, most of the other buildings in the El-Sahab sector have suffered the same conditions which pushed the local authorities to move all the residents to a safe place (Shendi 2000).

Therefore, before construction work, site geotechnical investigation should be carried out which depends upon the nature of building works. To design a foundation that will support adequate structure load, it is essential to determine the nature and properties of soil that will support the foundation. This process requires geological, geotechnical, and other relevant information that affect the construction or performance of civil engineering project so that a safe and economical structure can be designed (Terzaghi and Peck 1967; Player 2000). The geological, geomorphological, hydrogeological environmental impacts and geotechnical hazards existing in the study area create a multi-criteria problem. A GIS is very efficient in modeling and analyzing various types of spatial data and provides options to assess site hazard for developmental purposes. Eastman et al. (1995) and El-Ghawaby (2006) mentioned that there are two common approaches for multi-criteria evaluation, the concordance–discordance and the weighted linear combination. In the former approach, each pair of alternatives can be analyzed for the degree that one outranks the other on specific criteria. In addition to weighting procedures of factors controlling land-use activities, based on statistical analysis of quantitative data and/or experience-driven approach of qualitative data, are standardized and normalized to pursuit by all planners. Both modeling approaches are applied in estimating rank scores of all influencing factors and their impact degree percentage.

This study was carried out for a small region in SC, Egypt by using available maps and ancillary data, followed by digitization, building topology, verification and analysis to develop a spatial framework. The aim of this work is to develop a GIS-based model, which evaluates the geotechnical conditions and considerations for safe construction purposes and apply this model at new extensions of SC to reveal its applicability.

Study area characteristics

SC is located at the northern part of the Red Sea where the Suez Canal enters the Gulf of Suez, Egypt. It is located between 29° 50′30″, 30° 02′50″N latitudes and 32° 26′00″, 32° 35′40″E longitudes. The area is covered by subset from Enhanced Thematic Mapper (ETM^{+7}) satellite image that has path 176/row 39 number and it extends for approximately area about 150 km^2 (Fig. 1). The area boundaries comprise the uneven high ground adjoining Gabal Ataqa to the west, Suez Canal to the east. The Cairo gap, the area between Gabal Ataqa and Gabal Geneifa, lies to the west. SC is situated in the south. The proposed urban development topography was to be on gently sloping and slightly dissected ground rising to the west and northwest towards the base of the precipitous Gabal Ataqa. The average elevation above mean sea level is about 12 m. The upland area is located at the up faulted limestone plateau of Gabal Ataqa (871 m), it exerts a profound influence upon its geomorphology. Whereas the low land areas are determined as the isthmus stretches eastward. The area is mainly drained by the drainage from the northern part of Gabal Ataqa and has given rise to wadis and streams that turn eastward. The main
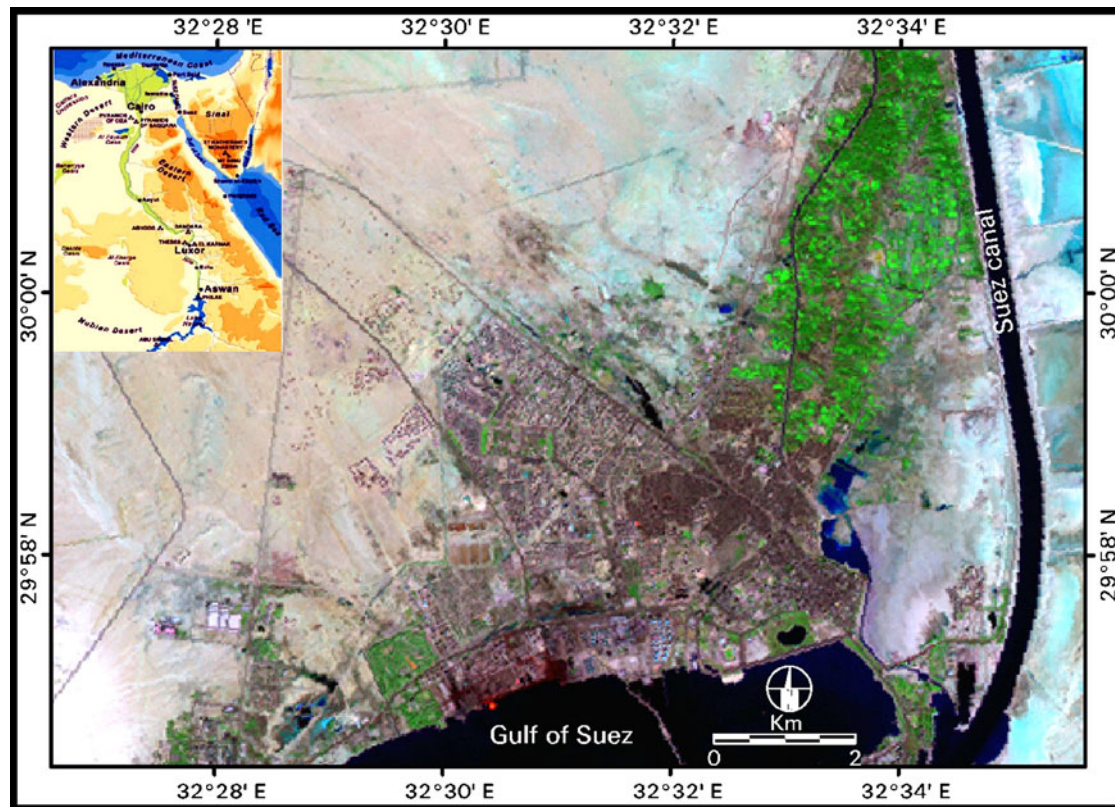
Fig. 1 Location map of SC area and its ETM image

landforms units of the Suez area are represented in beach and raised marine deposits, offshore bar and fringes, other coastal deposits, fluvial deposits, Miocene bedrock, and build-up areas (Bush et al. 1980; Mahfouz 1999; Jones 2001 and Arnous 2004) (Fig. 2).

Climatologically, the area under investigation is characterized by arid climatic conditions, dominated by a long hot rainless summer and a mild winter. The average annual rainfall 23.6 mm but it is extremely variable and average temperature of 22.5°C. Wind predominately blows from N, NE, or NW directions and the mean annual wind speed is 4.6 knots. The study area is highly evaporated and has an annual daily mean of 9.4 mm, the clouds and fogs are common at night time and early morning and give rise to regular fall (Egyptian Metrological Authority 1996).

The main feature that characterizes the geological setting and tectonics of the study area is attributed to the regional tectonic framework of the Gulf of Suez and Red Sea rift (Steckler et al. 1988). The extensive previous geological studies led to important models for the formation of this and other rifts around the world (Moustafa 1976; Moustafa and Abdellah 1991; Colletta et al. 1988; Martinez and Cochran 1988; Moustafa 1993, and Bosworth 1995).

Structurally, the area under investigation is located along the western side of the Gulf of Suez region which is situated within the stable belt of Egypt (Smith 1984). The

tectonic disturbance of the study area is slightly where the western marginal fault of the rift with a throw of several thousand meters and a NNE–SSW trend runs along the base of Gabal Ataqa. The Miocene sediments are either horizontal or gently folded and throw of the faults is at a maximum only a few tens of meters. The main fold axes trend WNW–ESE and such folds can be observed adjacent to the Suez–Ismailia road at El-Kubri and in the neighboring sandstones outcrops. The olds are in the form of elongated basins and domes. In addition, there are two sets of faults represents in Suez area as the major set WNW–ESE is parallel to the trend of the folds and to faults elsewhere in the Suez graben and a secondary sets between N–S and NNE–SSW (Robson 1971) are sub-parallel to the major rift faulting and probably show later movement on faults associated with the original rift block (Bush et al. 1980).

Materials and methods

Modern satellite imagery, together with traditional aerial photos provides rich multi-resolution and scale of data sources for monitoring and assessment urban development process. By using GIS, it is technically possible to integrate large quantities of data for further spatial analysis related to

Fig. 2 Main landform units of the Suez area (modified after Bush et al. 1980)
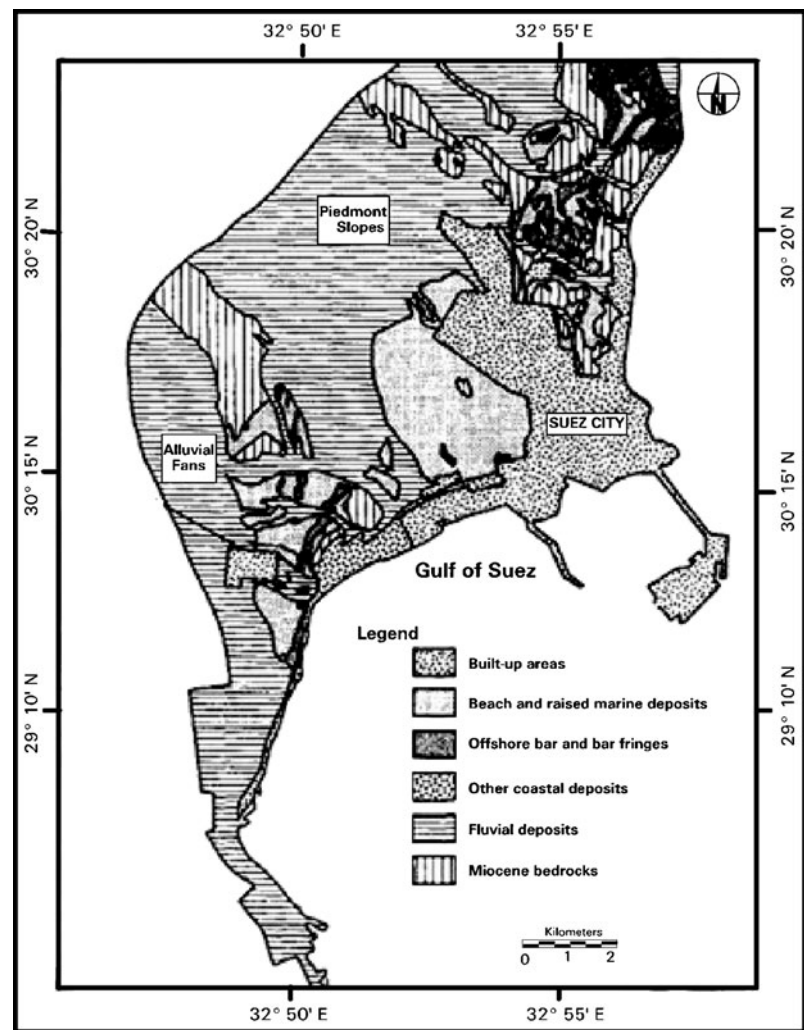
urban development. However, it has become common knowledge that urban development is a complicated dynamic process, which involves various physical, social, and economic factors. The complexity lies in the unknown amount of factors, multi-scale interactions among factors and its unpredictable dynamics, which are beyond the capacities of current GIS theory and method. Pattern and process are reciprocally related like "egg and chicken", and both of them and their relation are also scale-dependent. The seeking of determinant factors on a varied scale is the first step to understand the dynamic process. Towards this purpose, it is required to integrate remote sensing, GIS, geo-statistics and other modeling techniques for understanding the interaction between urban development patterns and processes (Jianquan and Masser 2001)

In the current study, mainly ERDAS IMAGINE 9.2, ARC GIS 9.2 and ARC INFO 7.2 software have been used. The digital elevation model (DEM) image constructed from topographic map (Scale 1:50,000), and geo-reference data represent in topographic and geological published maps and other ancillary geological data. In addition to tabular data,

which are including physical and mechanical properties of soil from Mahfouz 1999, the tabular data contains geographical location, geotechnical properties of soils, groundwater observations, and aggressive of soil bearing salts. Moreover, groundwater is associated with high salt content and precautions for it, lithology, and geomorphology.

Geological mapping is done using enhanced and rectified ETM + 7 images. The rectified image is then enhanced through histogram equalization, principal components, image inversion, and rationing techniques using image-processing software ERDAS for better exposition of primarily geotechnical features. GIS is used for mapping features by activity; a line-link facility between image processing software ERDAS and GIS package of ARC/INFO and ARC GIS.

Generally, the better interpretation of different geological, hydrological, geophysical, geotechnical, and other related data often requires that their spatial location be incorporated into the analysis. GIS can be used for storing geotechnical data as well as their spatial locations in a relational database. It also provides the facility to analyze

the spatial data objectively using various logical conditions. The designed spatial model is continually refined as more information is gathered and integrated into existing model. GIS is used for design spatial modeling of the geotechnical conditions of the soft rocks at new SC, Egypt through the integration of geological, geomorphological, hydrogeological, and geotechnical data and thematic maps that were prepared and extracted from enhanced satellite images and analysis of geotechnical properties of soil.

The digital and thematic maps are classified into different factors that is related to the geotechnical site and urban extension of the study area as geotechnical (physical properties and mechanical properties of soil), hydrogeological (depth to water, water table and chemical properties of groundwater), geological, and geomorphological factors. The extracted are integrated to generate the spatial model of geotechnical site of the study area (Fig. 3). The thematic maps are classified and scored into different factors that are controlled in the urban extension then integrated to generate the spatial model of the geotechnical sites prospect of the study area.

A different range of values or features should have a different score in a scale according to its importance in potentiality of the geotechnical properties. An overlay operation would then evaluate the intersected region by a sum of the score, so that each resulting region is characterized by a score measuring its potential. Based on this method, the capability of geotechnical properties condition of the present study area is estimated. Features of an individual geotechnical parameters

theme have been scored in the 1–5 scale in the ascending order of urban extension significance.

The raw score for each feature is then normalized using the following relation to ensure that no layer exerts an influence over the other.

$$X_j = R_J - R_{min}/R_{max} - R_{min} \qquad (1)$$

(Shahid and Nath 2002)

Where; X_j is the normalized score R_J is the raw score, R_{max} is the minimum score, and R_{min} is the maximum score of a layer.

To evaluate the different sites of an area to represent the new effects in quantitative and qualitative, and develop new interpolations each time, the decision makers represents the different scenarios according to the qualification and quantification parameters. The following formula is used:

$$E = \sum Xi \times f(Xi) \qquad (2)$$

(Neves and Condessa 1994)

E	Topic quality
X	Factor weight
$f(Xi)$	Category weight
n	Number of factors

In the present study, different geospatial software programs were used to build the GIS system. They
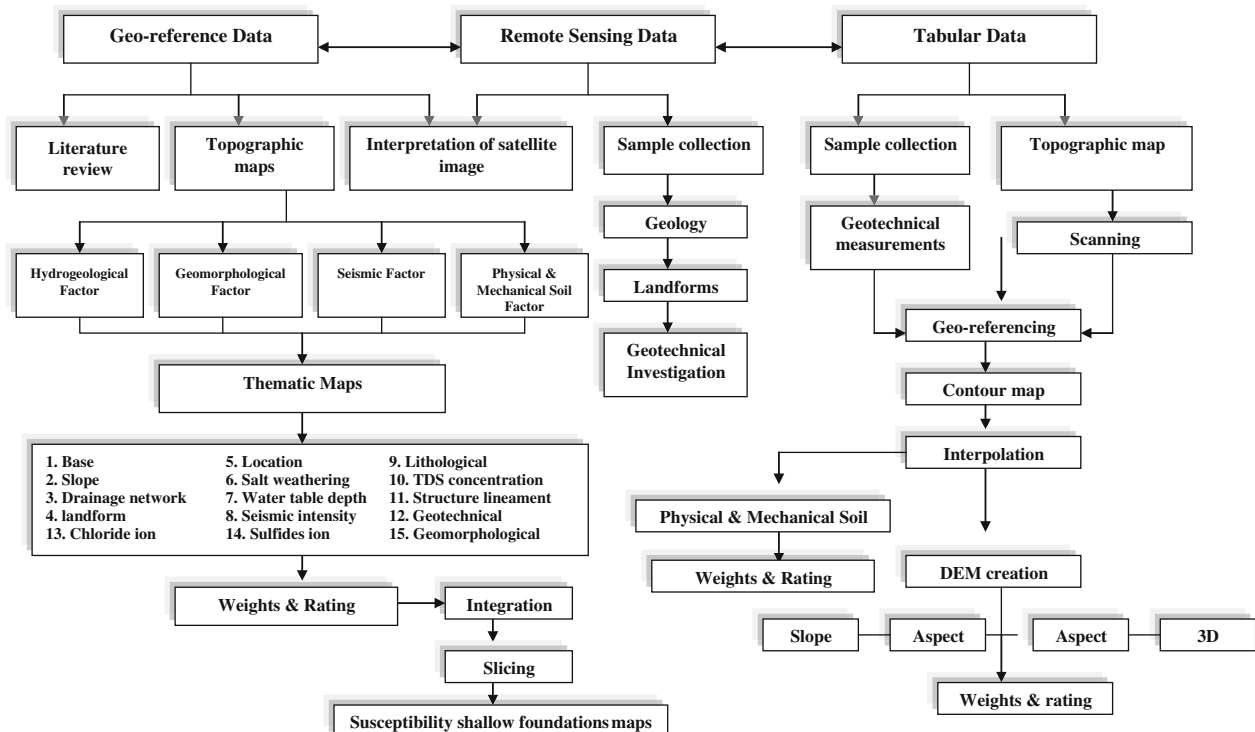

Fig. 3 Flow chart illustrating the methodology steps followed in the present study

introduced a new approach on data organization based on the non-statically property of information for design GIS system for construction proposes. Therefore, these systems are usually conceived for storing information in a structured perspective and providing "Query-Display" functions, as well as the available analysis functions are dependent from each software. Consequently, the equation for determine site selection quality is applied to different factors for construction purposes then the arithmetic overlay is applied and integrated by using GIS programs. Where, the quantitative elements of evaluation, in reference to objects and phenomena that are not easily quantifiable, will improve the ability to define rules and procedures that will support decision making in the planning process. By selecting easily with a mouse the characteristics in terms of factors and categories, we can find the sites on the general scenario that are adequate to locate the new urban site. Table 1 illustrates the factors and categories of the arithmetic weights that must be considered on the selection of new urban sites. The selection and definition of the characteristics of the new site will interact with the data from the already evaluated scenarios. The new characteristics introduced will modify the values of the sites defined according the proposed controlling factors for construction purposes. This process of interaction is the basis for the construction of simulation tools as the introduction of a new classified and evaluated element or site will affect the values of near sites making possible to estimate the effects of each modification of land use/land cover. Finally, the decision support model for construction purposes will enclose a set of rules defined according to qualitative and quantitative information in the GIS system and represent the different scenarios according to the statistical and expert transformation of the qualification and quantification topics. These rules represent both the strategic goals of the municipality and the legal normative on local planning and land use management.

Results and discussion

Mapping with various geotechnical information systems data were collected, compiled and assembled. In the present study, the geotechnical site investigation deal mostly with surface and abundant subsurface information. This part of results deals with application of GIS technique for construction and geotechnical site investigation model that is continually refined as more information is gathered and integrated into existing model. These purposes have been achieved by processing the mechanical, physical soil properties and chemical ground water properties raw data through digitization ad data layers. These layers were treated through the different GIS software to produce the

univariant and multivariant GIS maps. Univariant GIS maps are constructed using only one variable for its values such as sulfide ions (SO_3^{-2}), chloride ions (Cl^{-1}), total dissolved solid (TDS), pH, and water table maps for groundwater chemical properties. Multivariant GIS maps constructed using more variables have to be considered to get the final decision map such as hydrogeological, mechanical, and physical soil factors. These factor maps will be preformed to make the final decision map for the new extensions of SC. Now, the variables parameters are registered to influence suitability of every surface unit in the SC area to be developed for urban expansion and safe construction purposes of the study area under investigation to be developed. These controlling parameters include hydrogeological, morphopedological, climatological, geological, geomorphological, environmental hazards, socio-economic impacts, and geotechnical factors were considered the most important in assessing suitability of the study area. The distribution and suitability zonation maps for different geotechnical parameters were established using GIS. These parameters are grouped to seven major factors. Table 1 presents the rates of each parameter for every specific objective.

Hydrogeological factor

Groundwater is one of the main factors affecting the stability of foundation excavations as well as the implementation of the excavation works. This factor is represented in the present study by integrated multivariate digital map for groundwater level, TDS, Cl^{-1}, SO_3^{-2}, and pH values univariant digital maps. Mahfouz 1999 mentioned that the groundwater chemical analysis of the study area have shown that many sites need to use sulfate-resisting cement in all subsurface concrete works. In addition, to analyze the ground water at any site prior to construction to investigate, determine its chemical properties and act accordingly. Groundwater table map (Fig. 4) represents the distribution of groundwater level, where there is a harmony between topographic map and groundwater level map; and also the depth of water table map is prepared based on the static level given from the available geotechnical boreholes. Areas with shallow static level (0–5 m) are considered as the least favorable, and between 5–10 m as favorable. Deeper than 10 m are the most favorable areas. These are related to the environment where there are four principal recharge sources of water in the area of study. The higher TDS values are related to high evaporation and/or leaching of salts that crystallized in soils (Fig. 5). It is very dangerous because leaching may cause a settlement of soil under building that has been erected. Jones 2001 stated that the rapid investigation of the groundwater–salt system yield maps of the depth to water,

Table 1 Score assigned to different features of geotechnical site thematic maps

Factor	Parameter	Attribute	Raw score	Normalized score	Relative value
Groundwater	Depth to water (Meters)	<1	1	0.00	Poor
		1–3	2	0.25	Marginal
		3–6	3	0.5	Average
		6–12	4	0.75	Good
		>12	5	1	Ideal
	pH value	<4	1	0.00	Poor
		4–6.9	2	0.25	Marginal
		7	5	1	Ideal
		7.1–11	2	0.25	Marginal
		>11	1	0.00	Poor
	Total dissolved salts (ppm)	>2,000	5	1	Ideal
		2,000–5,000	4	0.75	Good
		5,000–8,000	3	0.50	Average
		8,000–11,000	2	0.25	Marginal
		<11,000	1	0.00	Poor
	Chloride ion (ppm)	<1,000	5	1	Ideal
		1,000–2,000	4	0.75	Good
		2,000–3,000	3	0.50	Average
		3,000–4,000	2	0.25	Marginal
		>4,000	1	0.00	Poor
	Sulfides ion (ppm)	<10,000	5	1	Poor
		10,000–20,000	4	0.75	Marginal
		20,000–30,000	3	0.50	Ideal
		30,000–40,000	2	0.25	Marginal
		>40,000	1	0.00	Poor
Geological	Soil type	Sand & gravel	5	1	Ideal
		Sand, gravel & clay	3	0.5	Average
		Lime stone	2	0.25	Marginal
		Clay & silt	1	0.00	Poor
	Fracture intensity (qualitative)	Very low	5	1	Ideal
		Low	4	0.75	Good
		Moderate	3	0.50	Average
		High	2	0.25	Marginal
		Very high	1	0.00	Poor
Climate	Precipitation (mm/year)	<5	5	1	Ideal
		5–10	4	0.75	Good
		10–15	3	0.50	Average
		15–20	2	0.25	Marginal
		>25	1	0.00	Poor
	Wind erosion potential (qualitative)	Very low	5	1	Ideal
		Low	4	0.75	Good
		Moderate	3	0.50	Average
		High	2	0.25	Marginal
		Very high	1	0.00	Poor
	Evaporation rate (qualitative)	Very low	1	0.00	Poor
		Low	2	0.25	Marginal
		Moderate	3	0.50	Average
		High	2	0.25	Marginal
		Very high	1	0.00	Poor

Table 1 (continued)

Factor	Parameter	Attribute	Raw score	Normalized score	Relative value
	Temperature (qualitative)	Very low	1	0.00	Poor
		Low	2	0.25	Marginal
		Moderate	3	0.50	Average
		High	2	0.25	Marginal
		Very high	1	0.00	Poor
Geological Hazards	Epicenter intensity (Mb)	<1	5	1	Ideal
		1–2	4	0.75	Good
		2–4	3	0.50	Average
		4–5	2	0.25	Marginal
		>5	1	0.00	Poor
	Seismic intensity (qualitative)	Background	5	1	Ideal
		Low	4	0.75	Good
		Moderate	3	0.50	Average
		High	2	0.25	Marginal
		Very high	1	0.00	Poor
	Flooding potential (qualitative)	Background	5	1	Ideal
		Low probability	4	0.75	Good
		Moderate probability	3	0.50	Average
		High probability	2	0.25	Marginal
		Risky	1	0.00	Poor
	Sand dunes (qualitative)	Background	5	1	Ideal
		Buffer 250–500 m	4	0.75	Good
		Buffer 100–250 m	3	0.50	Average
		Buffer 100 m	2	0.25	Marginal
		Inside	1	0.00	Poor
Geomorphology	Slope (degree)	0–2	5	1	Ideal
		2–5	4	0.75	Good
		5–8	3	0.50	Average
		8–15	2	0.25	Marginal
		>15	1	0.00	Poor
	Drainage density (qualitative)	Very low	5	1	Ideal
		Low	4	0.75	Good
		Moderate	3	0.50	Average
		High	2	0.25	Marginal
		Very high	1	0.00	Poor
	Geomorphic stability (qualitative)	Stable	5	1	Ideal
		Nearly stable	4	0.75	Good
		Moderate stable	3	0.50	Average
		Marginally stable	2	0.25	Marginal
		Unstable	1	0.00	Poor
Physical Properties of soil	Depth (meters)	<2.5	1	0.00	Poor
		2.5–7.5	2	0.25	Marginal
		7.5–12.5	3	0.5	Average
		12.5–17.5	4	0.75	Good
		>17.5	5	1	Ideal
	Plastic limit (%)	<25	5	1	Ideal
		25–30	4	0.75	Good
		30–35	3	0.50	Average
		35–40	2	0.25	Marginal

Table 1 (continued)

Factor	Parameter	Attribute	Raw score	Normalized score	Relative value
		>40	1	0.00	Poor
	Liquid limit (%)	<30	5	1	Ideal
		30–40	4	0.75	Good
		40– 50	3	0.50	Average
		50–60	2	0.25	Marginal
		>60	1	0.00	Poor
	Nature water content (%)	<15	5	1	Ideal
		15–33	4	0.75	Good
		33–50	3	0.50	Average
		50–67	2	0.25	Marginal
		>67	1	0.00	Poor
	Compression index (%)	<0.1	1	0.00	Poor
		0.1–5.2	2	0.25	Marginal
		5.2–10.4	3	0.5	Average
		10.4–20.8	4	0.75	Good
		>20.8	5	1	Ideal
Mechanical Properties of soil	Unconfined compression strength (kg/cm^2)	<0.5	1	0.00	Poor
		0.5–1.4	2	0.25	Marginal
		1.4–2.3	3	0.5	Average
		2.3–3.1	4	0.75	Good
		<3.1	5	1	Ideal
	Pre-consolidated pressure (kg/cm^2)	<1	1	0.00	Poor
		1.0– 1.7	2	0.25	Marginal
		1.7–2.3	3	0.5	Average
		2.3–3.0	4	0.75	Good
		>3.0	5	1	Ideal
	Swelling pressure (kg/cm^2)	<0.5	5	1	Ideal
		0.5–2.5	4	0.75	Good
		2.5–5	3	0.50	Average
		5.0–7.5	2	0.25	Marginal
		>7.5	1	0.00	Poor

groundwater contours and conductivity values, which were combined to yield a groundwater intensity map using a fourfold zonal division based on the relationship between the topographic surface, the capillary fringe and the water table (Fig. 6). Cl^{-1} distribution in soil of the study area (Fig. 7) is a wide valley with the trued low chloride ion content and consequently TDS. Sulfides ion (SO_3^{-2}) distribution in the Suez area, higher values due to the presence of crystals of gypsum that have been leached under pressure and concentrated in groundwater as a result of increase sulfide ion in groundwater and its effect in construction (Fig. 8). pH values play important role in transformation the TDS, CL and SO4 into ions. The higher values are related to TDS, Cl^{-1}, and SO_3^{-2}. Jones 2001 mentioned and concluded that the important

points to emerge in the SC area were the extremely shallow depth of the water table along the coastal belt and associated potential for capillary rise in buildings; the huge range of conductivity values recorded and the high values in strongly evaporating zones; in addition, the extensive areas of relatively low conductivity located in the west near the fertilizer factory, in the center of the Suez area focusing on the sewage works and in the east beneath SC, adjacent to the fresh water canal and the north western extension of SC particularly under Feisal sector (Fig. 6). An integrated to TDS, Cl^{-1}, and SO_3^{-2} univariant digital map after being weighted by using GIS into hydrogeological factor dynamic map (Fig. 9) shows that there is a correlation between these elements of groundwater in the Suez area. Increasing values of TDS, Cl^{-1},

Fig. 4 Susceptibility of water table depth distribution map of the study area
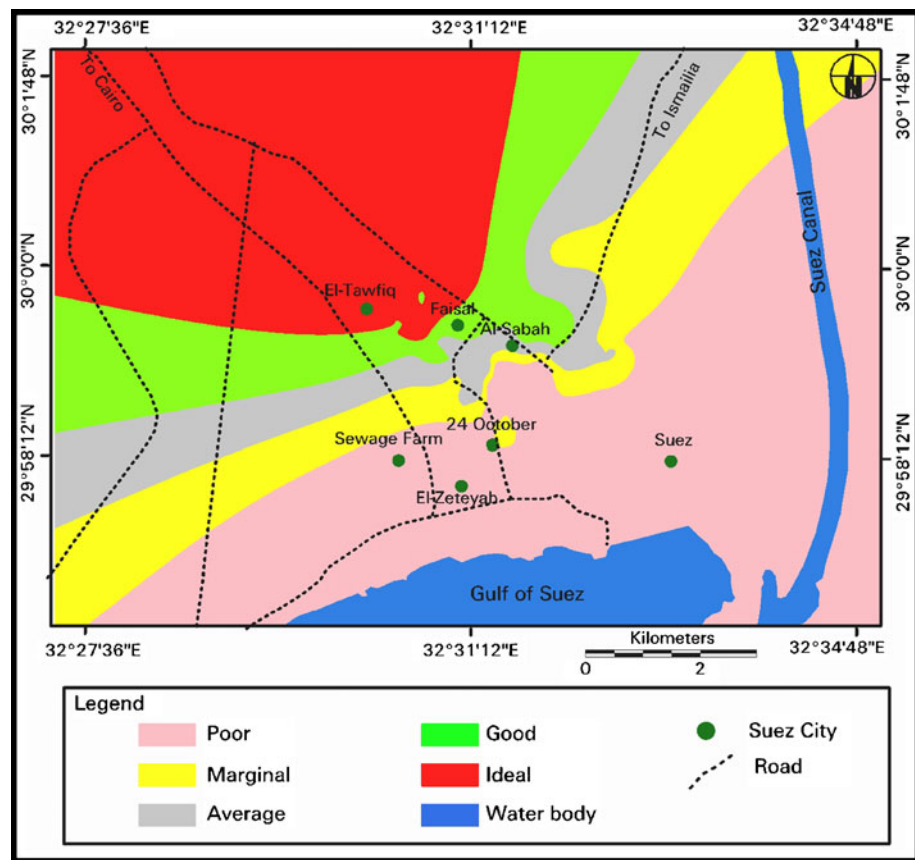

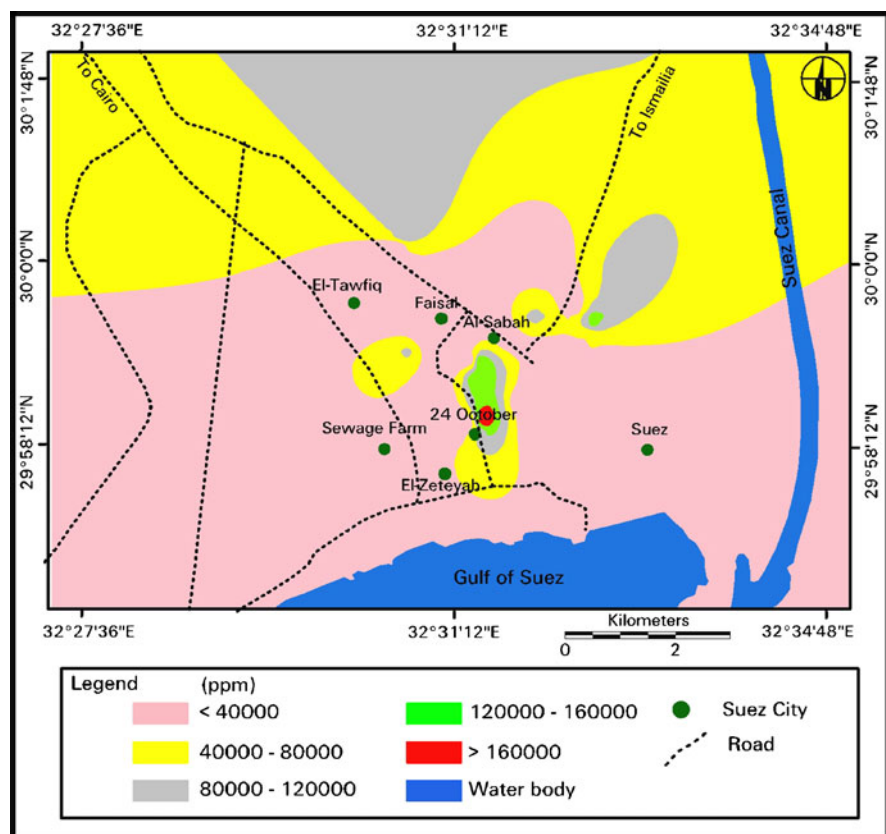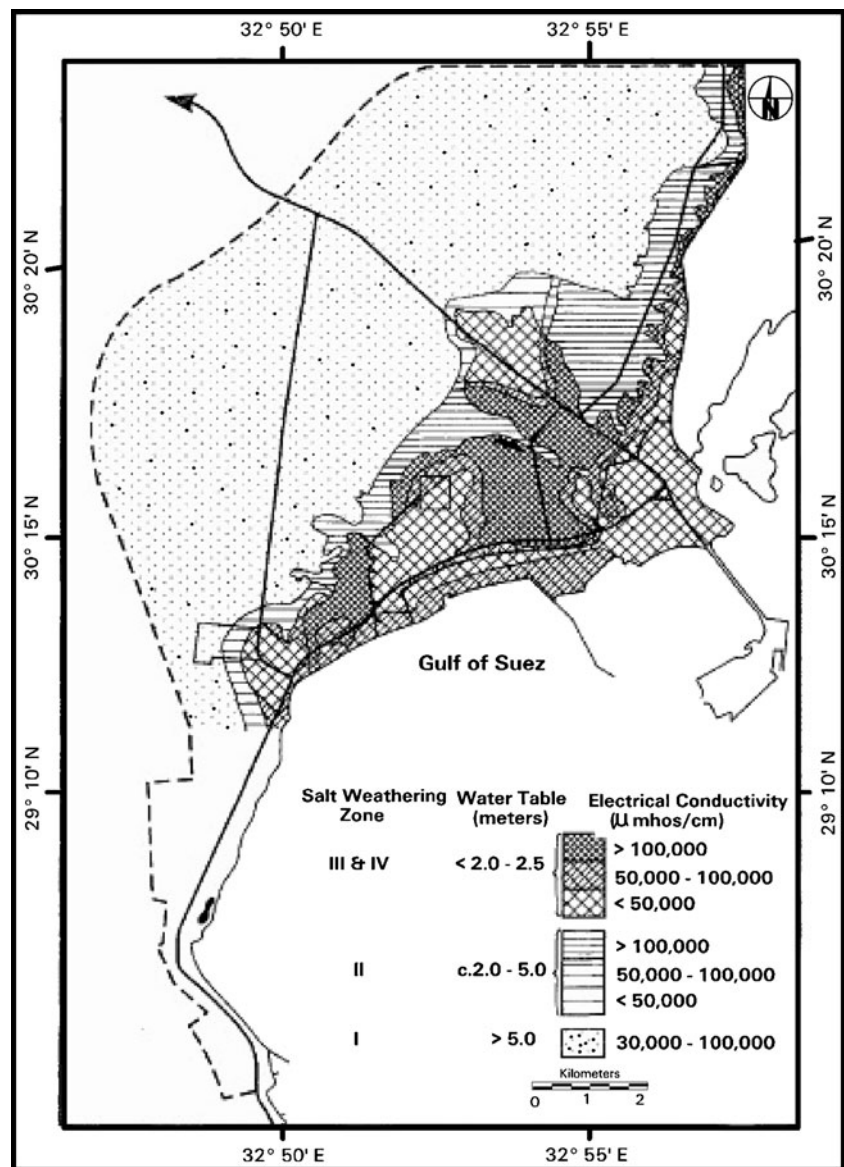**Fig. 5** TDS concentration distribution map of the study area

Fig. 6 Salt weathering (aggressive ground) hazard map of Suez area (modified after Jones 2001)

and SO_3^{-2} will be increased; consequently, precaution must be considered to adverse effect of high proportion of salts bearing groundwater during foundations.

Geomorphological factor

Rapid engineering geological/geomorphological surveys are sometimes required for extensive urban and industrial developments on tracts of land for which little or background topographic or geotechnical information is available (Jones 2001). Slope is an important factor while considering the help of engineering construction and susceptibility to landsliding (Dai et al. 2001a; Süzen and Doyuran 2004). Therefore, the slope layer will only contribute to the microzonation map to help engineering constructions (El May et al. 2009). In addition to the geomorphological surveys, ground conditions are helpful in explaining the

recent history of development of the landscape and the active processes in the landscape at the present time. Thus, it is an essential part of geotechnical mapping and is often a decisive factor in the planning of an investigation (Kleinhans 2002). The terrain analysis of the DEM of the study area showed that the slope is ranging from flat to gently undulating degrees. The average elevation above sea level is 12 m. Hence, from the geomorphological point of view, the investigated area is suitable for construction shallow foundations and the scoring weight value is recorded in Table 1 for producing final suitability map for new urban extension of the study area. From the geological and geomorphological point of view, SC has the relatively uniform surface coloration and insignificant topography were typically deceptive, concealing variations in ground conditions that only began to emerge with the commencement of exploratory subsurface investigations (Figs. 10 and 11).

Fig. 7 Susceptibility of chloride ion distribution map of the study area
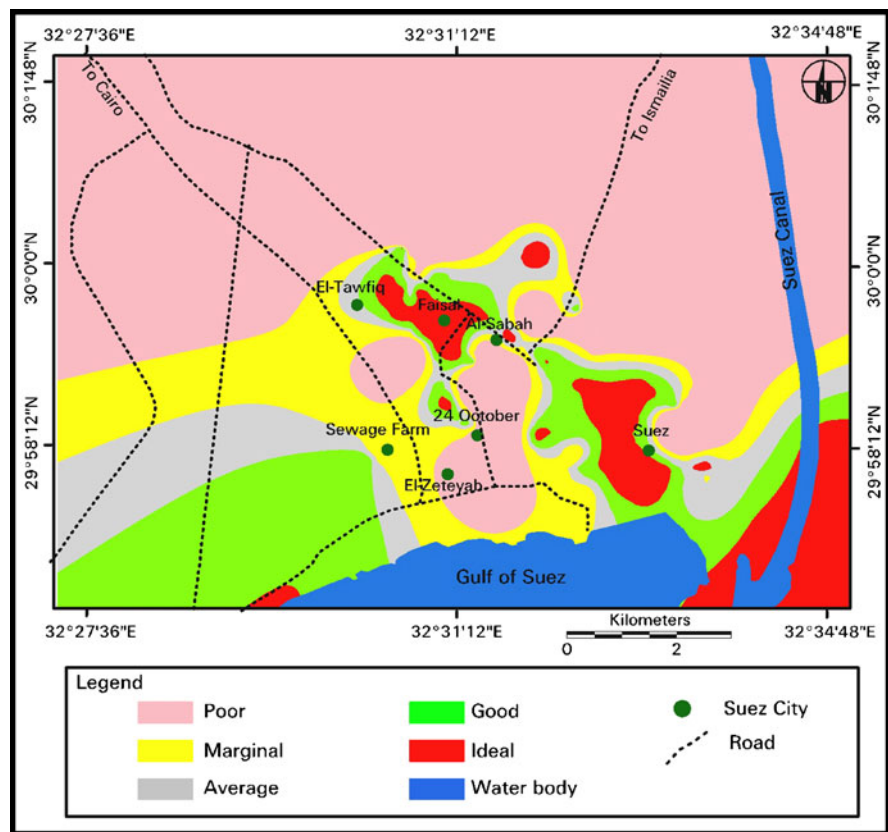

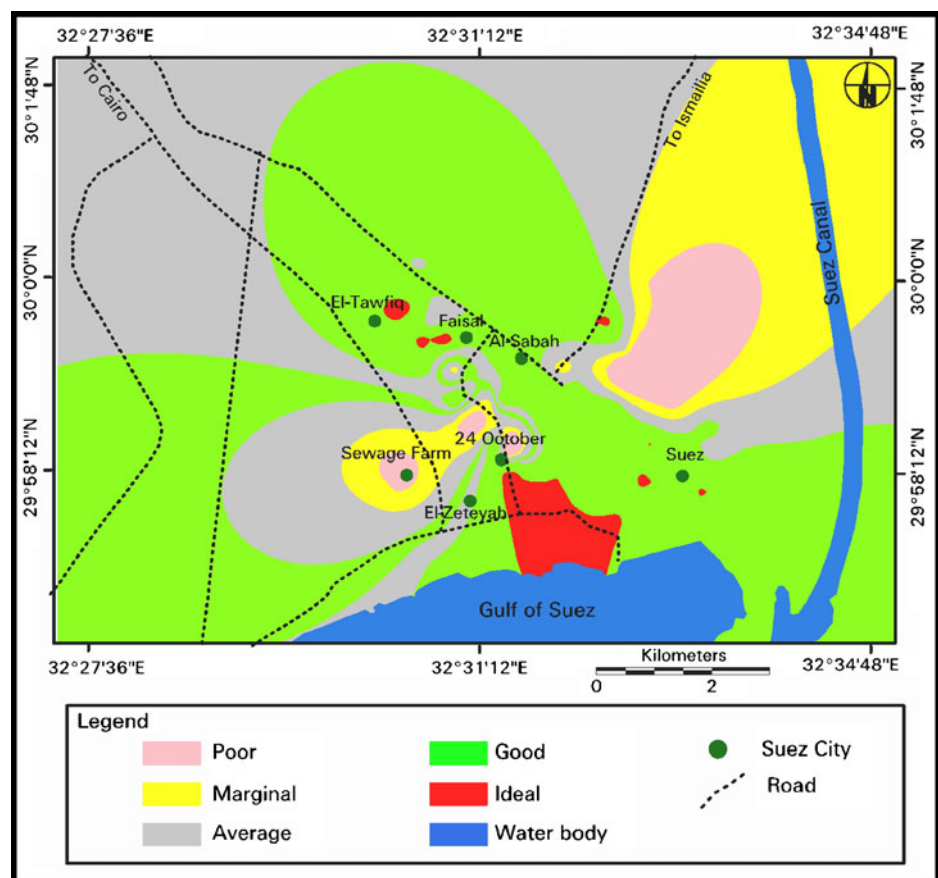**Fig. 8** Susceptibility of sulfides ion distribution map of the study area

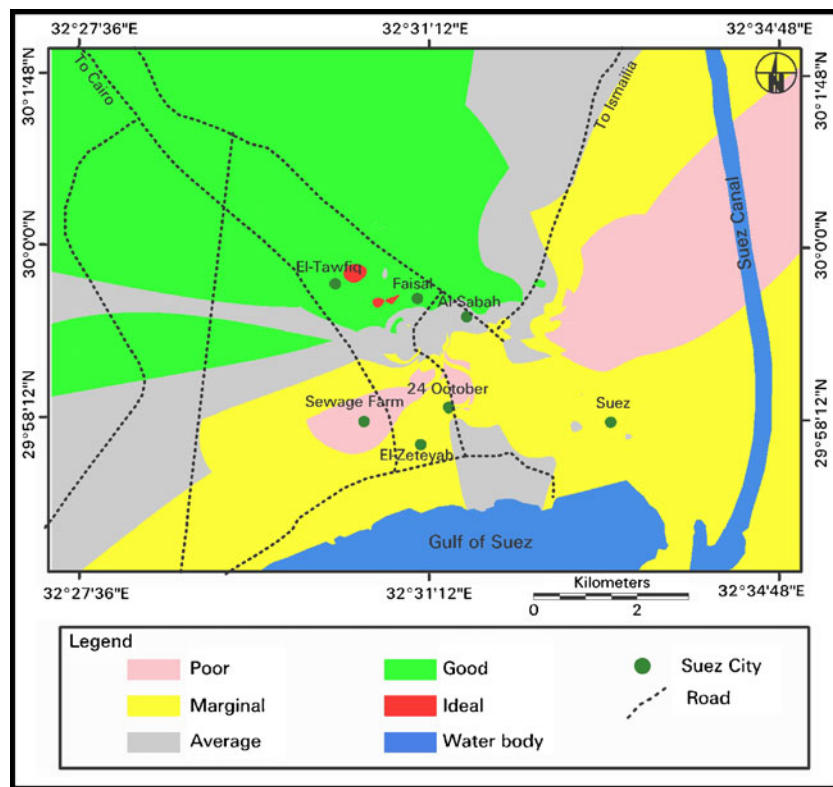Fig. 9 An integrated susceptibility hydrogeological factor map of SC area

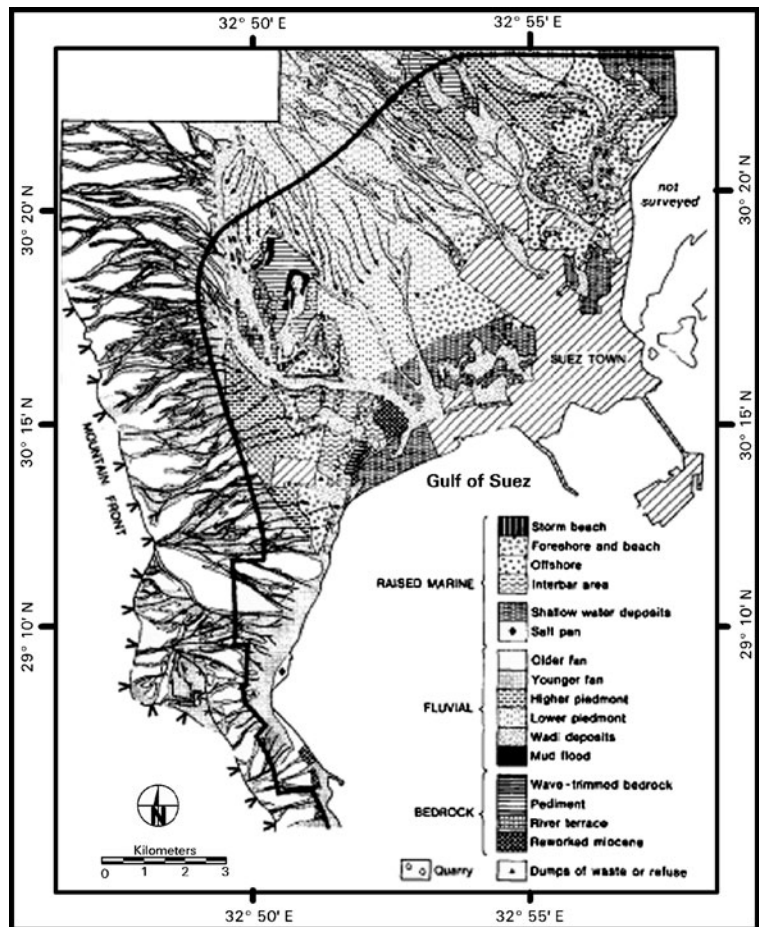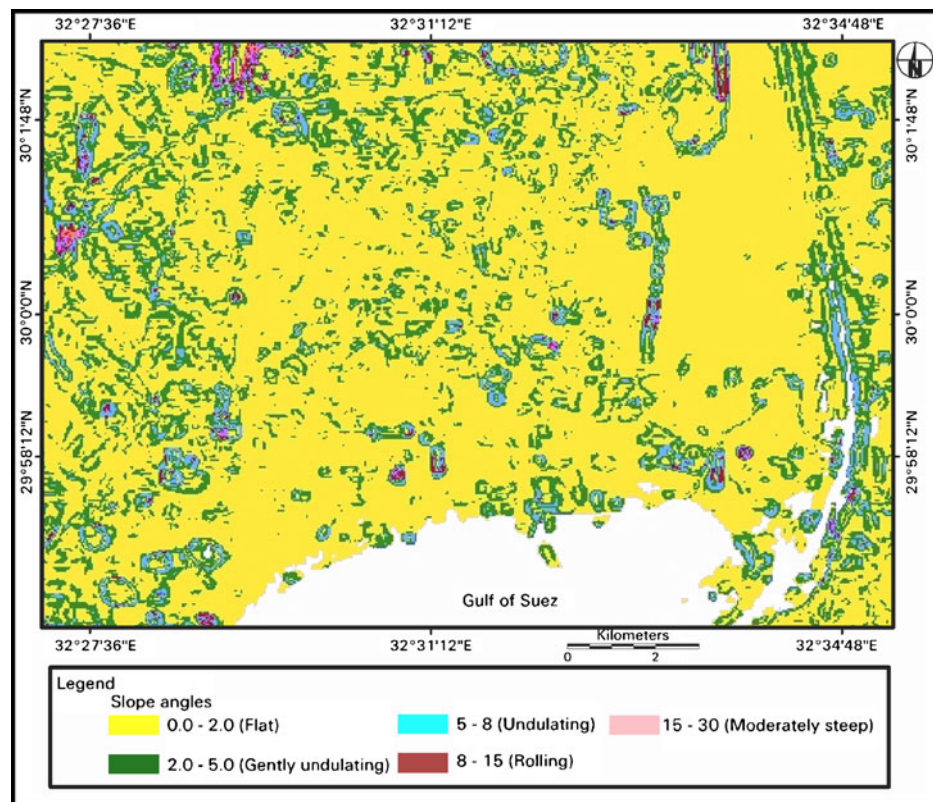Fig. 10 Geomorphological map of the Suez area (modified after Jones 2001)

Fig. 11 Slope map of SC area based on the DEM analysis

Legend
Slope angles

- 0.0 - 2.0 (Flat)
- 2.0 - 5.0 (Gently undulating)
- 5 - 8 (Undulating)
- 8 - 15 (Rolling)
- 15 - 30 (Moderately steep)

Seismic factor

Recent cracks confirm the importance of actual seismic activity that markedly increases from north to south and affects the recent and most shallow deposits. The distribution of the seismic activity pattern and data analysis for the study area clearly exhibits the urgent need for an assessment and rehabilitation program to mitigate geohazards along the existing structures (Arnous, et al. 2011). The seismic activity in the study area is conformable and related to wide active major faults and structure lineaments overall the study area and the surroundings, which have NW–SE trends that parallel and normal to the Gulf of Suez. Seismological data from 1900 to 2005 has been collected and analyzed to conduct seismic hazard assessment at the study area. SC and the surrounding areas are influenced by intense seismic activities ranging from high to low hazard degrees. Generally, fractures represent another source of risk in the study area. Integration between the intensity hazards maps (Fig. 12) and (Table 1) are carried out to define the relation between earthquakes activities and geological structures of the study area.

Physical and mechanical properties of soil factor

The soft clay formations are appearing in the northern and central parts of SC area. These formations exhibit low bearing capacity and high compressibility. Furthermore,

hard clay appears in most or near the surface of the SC which is characterized by a large thickness, high bearing capacity and low compressibility which requires a special attention from the geotechnical engineer. In addition, there is linear regression between swelling pressure and moisture content, dry density and plasticity index with good correlation coefficient (Mahfouz 1999). According to Abdel Tawab and Shendi (1993) and Mahfouz 1999, thin lenses of silty clay appear at El-Sahab in the upper layers, which might go unnoticed if fixed interval sampling is adopted. This undetected existence might cause several damages, particularly if some foundations are located above these lenses and others on the alluvial deposits. More damages can happen if the pile foundations are used. Shendi 2000 stated that the claystone in the study area has highly swelling potentialities, which may be responsible for the subsidence and tilting of the concerned building and recommended that any clay lenses must be delineated carefully and the sewage system in the study area must be under control and regular maintenance to prevent any future seepage. In the present research, the final stage of the geotechnical mapping factor is broken into two sub-factors as mechanical and physical properties of the soil that are play important role for urban constructions. Mechanical sub-factor represents integrated multivariate digital maps for swelling pressure, pre-consolidated pressure, and un-confined compressive length coverage (Fig. 13). On the

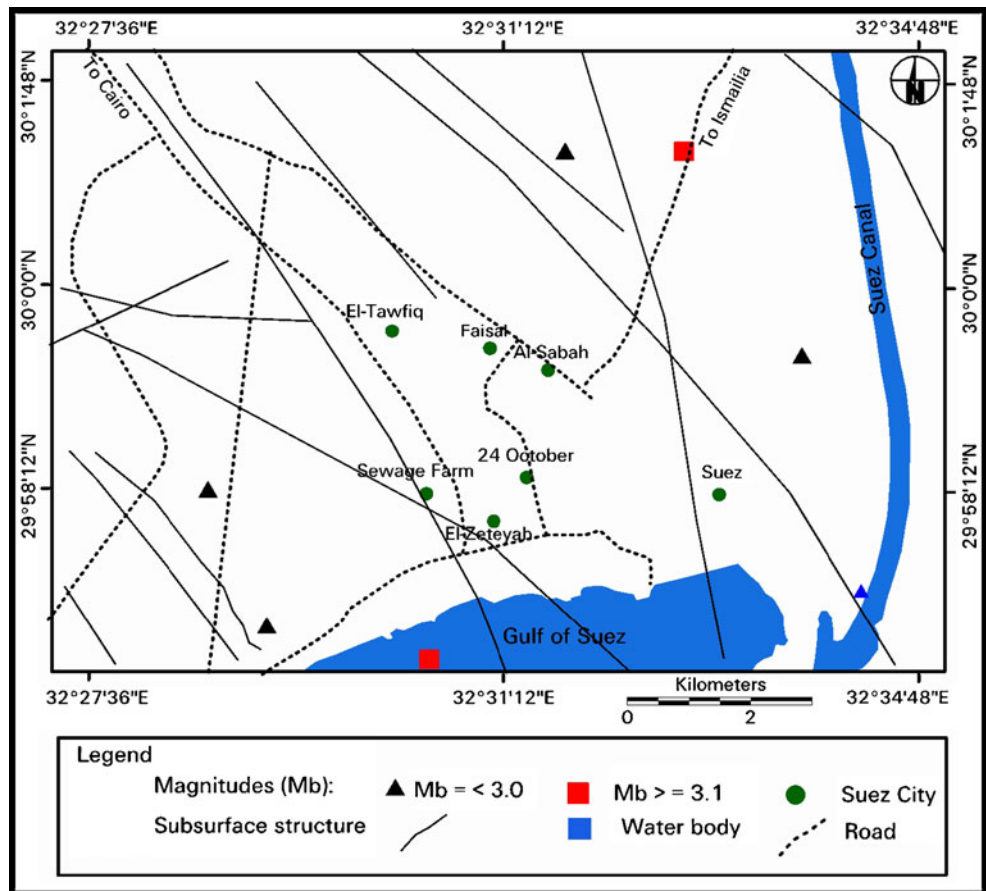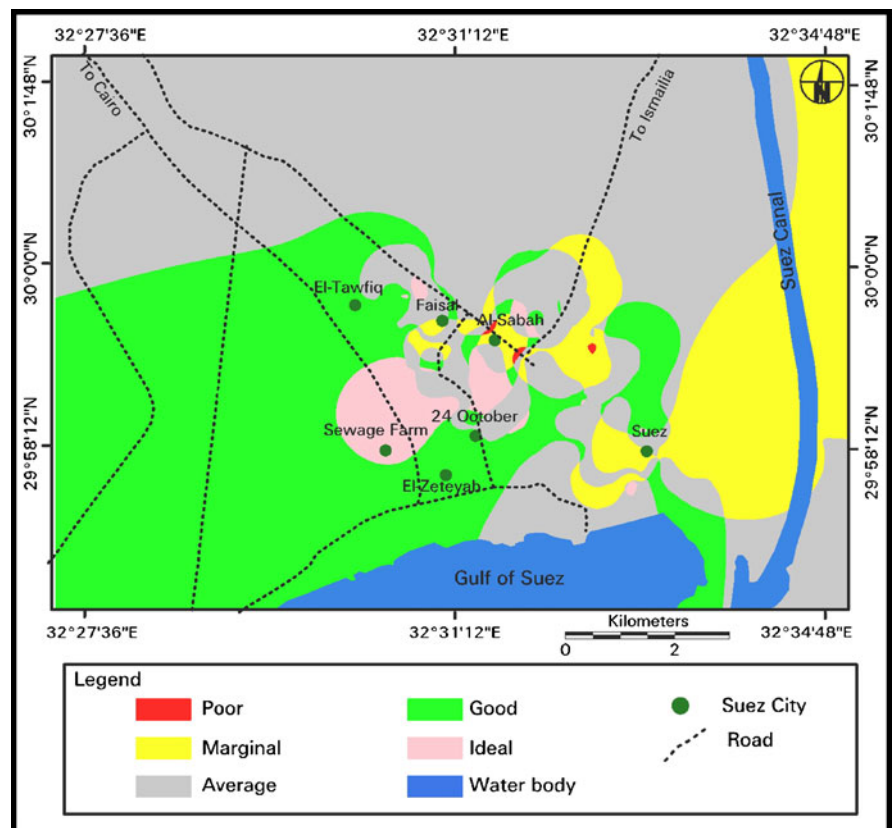**Fig. 12** An integrated seismo-tectonic map of SC area

Fig. 13 An integrated geotechnical mechanical factor map of SC area

other hand, the physical properties of the soil sub-factor contains some parameters such as liquid limit, plasticity index, nature water content, dry density, and consistency index coverages in the investigated area to finalize the zonation maps in the SC area (Fig. 14).

Suitability map for shallow foundation of the SC area

The area of interest is especially a good example for complex geology area with important urban extension where planners and decision makers need a useful map showing a geotechnical zoning for a safe urban extension. The available geotechnical data from boreholes and geotechnical tests are presented in geo-referenced map to show the most important factor, which is the bearing capacity.

To create a suitability map to construction in the SC area, the geotechnical zoning was carried out based on the previous presented factor maps. The approach presented for urban geological mapping is based on GIS utility. The process applied consists in a multi-criterion analysis and superposition and combination of parametric maps. The analysis is based on the impact of each factor on soil stability.

The suitability construction of the shallow foundation is decided by the integrated and arithmetic overlay previously

mentioned; important concerning factors had been performed using GIS system, which is a powerful tool for management of such a lot of data to construct the final decision map which helps in the selecting of the best area for construction shallow foundations of SC. The prepared zoning map is refined while superposing the zoning map to the depth of bearing capacity map to produce the final geotechnical mapping. Similar examples use other factors such as SPT results of Mahfouz 1999; Papadimitriou et al. 2007; Goh and Goh 2007; and El May et al. 2010; but in this work, we integrate all factors that control the building protection and the parameters that were used for the suitability sites analysis are physical, mechanical soil properties, terrain of the ground, groundwater, soil types and environmental hazards. The GIS system will take the values of input coverage's that are coding in the layers (Table 1).

For these input layers, the final susceptibility geotechnical map is divided into five zones and these zones are demarcated with suitability to a safe urban extension and construction (Fig. 15). The ideal and good zones' highest regime has been observed towards central and western regions with sporadic north Feisal or northeastern Al-Sabah pockets. This zone is well suitable for shallow foundations. The marginal zones to average zones are moderately suited

Fig. 14 An integrated geotechnical physical factor map of SC area
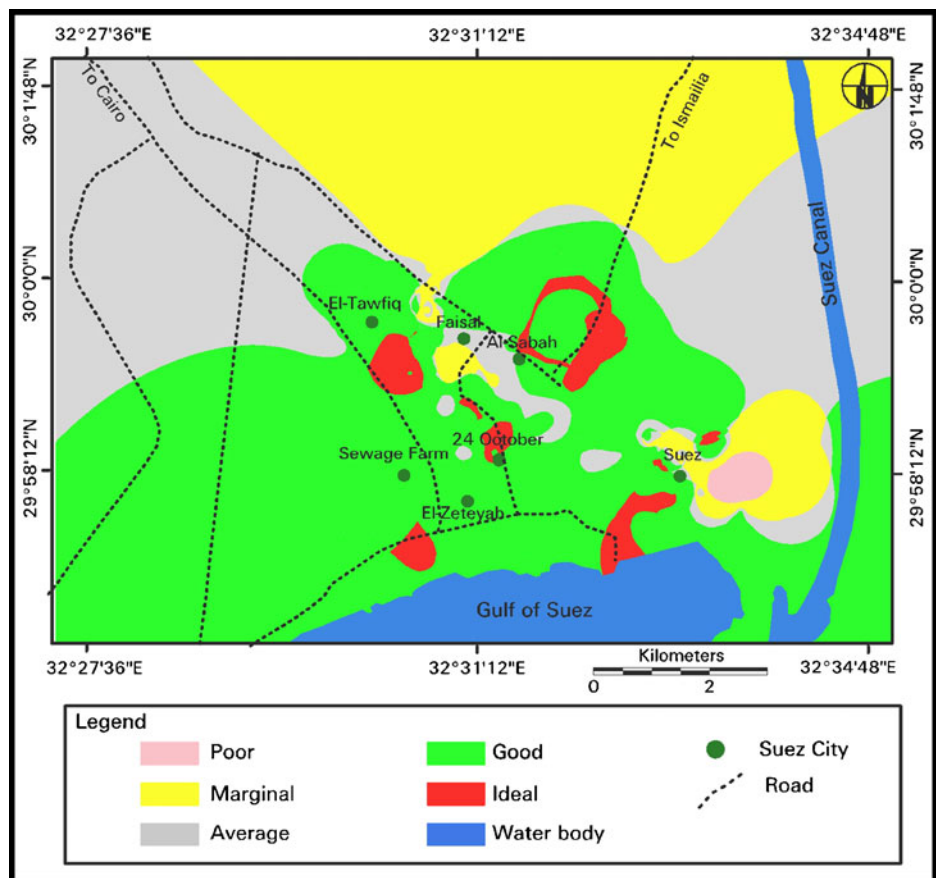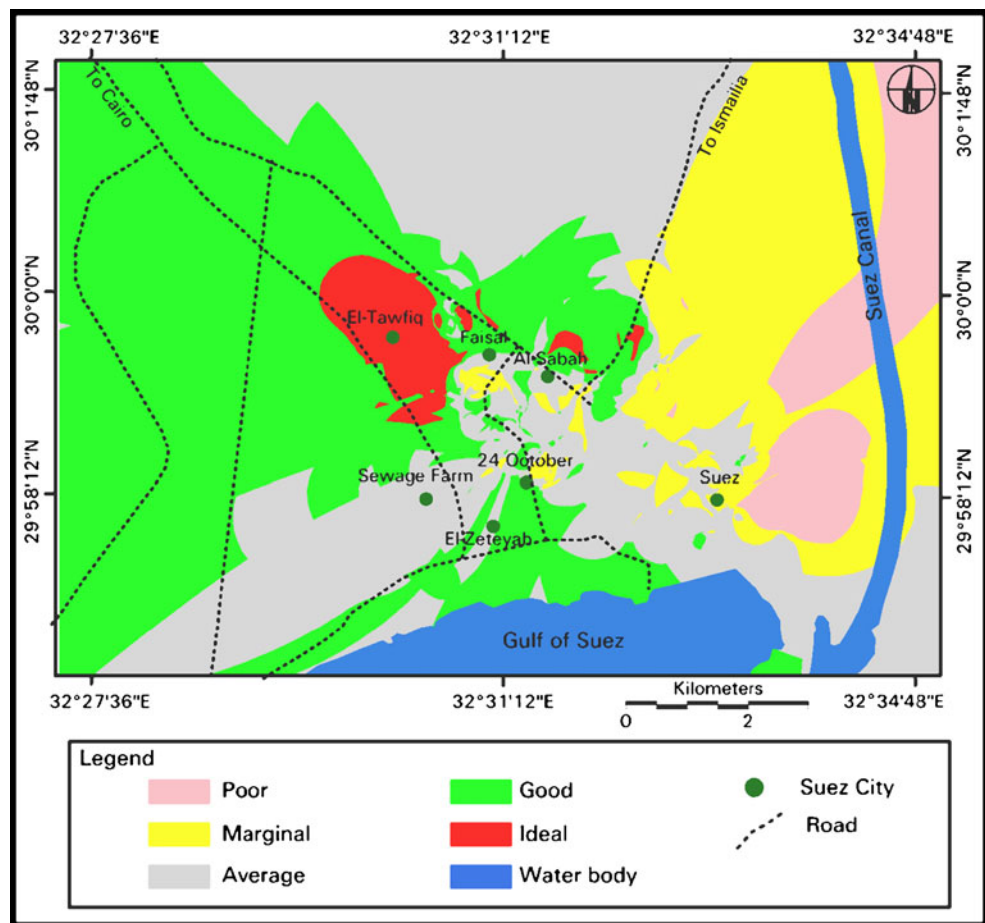
Fig. 15 An integrated susceptibility shallow foundations map, SC area

for shallow foundation. Proper care has been taken in the marginal zone before designing the foundations. The poor zone, unsuitable for the construction purposes of the shallow foundations except under more investigation as the type of structure, the expected loads, the allowable settlement, hydrogeochemical, and geophysical investigations. According to the result of the study area, proper care should be taken in many sites like the requirement of the use of sulfate-resisting cement in all subsurface concrete works. In addition, it is necessary to analyze the groundwater at any place prior to construction to determine its chemical properties and act accordingly (Mahfouz 1999). Particularly, if the rock formation, surface, subsurface structural geology elements and seismic activity are encountered, the geophysical investigation must be done to ensure their soundness and to avoid any foundations that are located above any silty clay lenses and other alluvial deposits in order to avoid more damage that may occur if pile foundations are used.

In this study, it was found that the prepared illustrations were useful in terms of generalizing the new urban extensions purposes of SC area. The validated confirmation of integrated GIS results in the present study were established by comparing the integrated results of geolog-

ical, hydrogeological, seismological, geotechnical factors, etc. of the present study and the previous studies results that were carried out on the small and limited local sites to investigate the surface and subsurface geotechnical studies such as Abdel Tawab and Shendi 1993; Mahfouz 1999 and Shendi 2000. The results of comparison processes show that there is a high similarity and more compatibility between present and previous results works. Although the final integrated GIS results of the new selected areas may need a geophysical investigation in order to test the subsurface bedrock and subsurface geological structures and make sure these structures are not active at this time. A final point is that the geotechnical zoning scale maps used in this study and in similar cases are important to avoid big practical errors in planning for the future urban extension of SC area. However, the results of this study do not lead to any loss of geotechnical mapping utility in safe urban extension. Before any local building project, a punctual specific study is inevitable. The role of such a detailed geotechnical investigation is either to provide some practice for safety urban project and to amplify the building security. In addition, the accurate geotechnical testing data can be used for the geotechnical micro zoning of the study area where amount of such data are available. The

suitability construction of the shallow foundation is decided by the integrated and arithmetic overlay; the ground conditions factors had been performed using GIS system, which is a powerful tool for management of such a lot of data to construct the final decision map which help in the decision makers to select of the best area for construction shallow foundations of the SC area, Egypt.

Conclusion

This study demonstrates the capacity of GIS techniques usage for the preparation of the geotechnical zoning maps regarding the suitability of a safe construction. Advantages of using these tools are easy data management, rapid and effective manipulation and analysis of data, data update and possibility to produce various maps. In this study, all data are processed by using the multi-criteria analysis by superposing geo-referenced information layers. As a result, the study area was categorized into five different zones and the soil formation are generally suitable for shallow foundations which are depending on other factors like the type of structure, the expected loads, the allowable settlement, hydrogeochemical and geophysical investigations must be done for the foundation bedrock before deciding the construction of the new settlement or development project in the study area. In addition, any clay lenses in the foundation bedrock must be delineated carefully and replaced by sand sediments, and also the sewage system in the Suez living areas must be under control and regular maintenance to prevent any future seepage due to damages and disasters and any other related factors.

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