Geoengineering characteristics modeling of Eocene limestone beds of the upper plateau of Mokattam area, Egypt using GIS techniques

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Abstract

This research paper is concerned with studying and evaluating the geoengineering characteristics and potential risks of the area under study with a view to safe urban expansion using GIS techniques. Different geotechnical laboratory tests such as Atterberg limits, free swelling test, swell potential and pressure tests, chemical analysis, unconfined compressive strength (UCS) and rock quality designation (RQD) were performed on 28 boreholes (95 samples). Furthermore, X-ray diffraction was used to examine clay minerals. The results indicate that the UCS values range from 47 to 72.2 kg/cm² and RQD from 21 to 45%. The free swell ratio ranges from 110 to 120%, and the plasticity index from 34 to 37%. In addition, GIS techniques have been utilized to produce the distribution layers of different geotechnical characteristics, then integrated to produce a geospatial urban model for delineating and defining safe and dangerous urban zones. This model is classified into four classes: low, moderate, high and very high hazard. Low and moderate hazards were detected in the major portion of the survey area. These portions are suitable for foundations at shallow depths. However, high to very high hazards were detected in the southeast portion of the study area. The reason for these areas is caused by the existence of heavily fractured limestone and highly swelling clay layers. This model would aid in the creation and discovery of the best areas of shallow base in the region under consideration.

Keywords Geospatial urban model · Geoengineering characteristics · GIS techniques · Unconfined compressive strength · Plasticity index

Introduction

In recent times, Egypt has witnessed a fast-growing population of over 90 million people. These numbers are below about 5% of Egypt's territory. To stay up with the rapid increase in population, in recent years, the Egyptian government has encouraged the development of projects in the desert zones outside the Delta and Nile Valley. Hundreds of new cities, industrial zones and tourist villages have been established in the last 2 decades. Utmost of these regions have not been rigorously investigated in determining their suitability for these developments or even for determining geological hazards. Thus, there is a dire need to assess these

zones for any development so as to bring down the numeral of risks as well as their catastrophic impact (Aly et al. 2005).

Limestone is a natural raw material of great importance as it is utilized in construction and decoration purposes, as well as in many industrial applications such as cement, chemical industries and fertilizers depending on its mechanical and physical properties (Harrison and Bloodworth 1994). From a geotechnical perspective, limestone has been studied in different regions of the world by several authors (e.g., Ben Salah et al. 2018; Dweirj et al. 2017; Pappalardo et al. 2016) and in Egypt (e.g., Roushdy et al. 2017; Ali and Yang 2014; Ahmed 2015; Abd El-Aal 2015; Abou Elmagd et al. 2020). Limestone fractures lead to serious damage to local infrastructure. Damage includes cracking and rupture of the paved main roads, the drinking water line, tipping of power and telephone lines, and cracking of adjacent buildings (Abdel Gowad et al. 2018). The Mokattam region has three plateaus: the upper plateau, the mid-plateau and the lower plateau. The current study focuses on the upper plateau, composed of successive layers of limestone, marl, and

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clay, having an average thickness of approximately 700 m, represented by Maadi Formation (Said 1962). The Mokattam plateau has serious problems, notably near the plateau's boundaries, where several landslides have occurred owing to the cracking of the limestone, producing landslides that have devastated many houses and hotels. In addition, the fractured limestone is covered with a layer of clay that causes most of the engineering issues due to volume variations in the swelling clays resulting from human activities (Velde 1995). Soil swelling has been treated with numerous chemical additives and industrial wastes such as the waste marble powder to improve strength, durability, and reduce construction risks (Sakr et al. 2021).

Several studies took place in the study area, among others (Moustafa and Abdel Twaab 1985; Moustafa et al. 1985, 1991; Eid et al., 2003; EL-Sohby et al. 2004; Geological Survey of Egypt (EGSMA) 2004). Helmy et al. (2007) focused on the effect of using the vertical concrete wall to improve the stability of fractured sedimentary rock slopes on the Mokattam Plateau. Park and Shin (2009) supplied a commercial chemical consolidation agent using (Wacker OH 100) to fill the porous space and reinforce the jointed rock. Pore filling was confirmed by the reduced permeability and porosity of the rock samples as a result of the application of the consolidation product. Sultan (2010) used the geophysical survey to identify the geotechnical problems on the upper plateau. The shallow portion of the upper plateau is composed of moderate velocity and high-resistivity fractured limestone with a thickness of 2–5 m, and the top layer of limestone contains caves of various dimensions that can cause damage to buildings. The limestone covers a layer of clay, which has a detrimental effect on the buildings due to high swelling property. Yousif (2000) the inclines of the Middle Eocene rocks that form the edges of the central Mokattam plateau are unsteady and probably regions of rock collapse in various spots. Saad et al. (2020a, b) estimated the sub-surface soil east of G. Mokattam using geoelectrical and sedimentological studies. The study demonstrated the existence of clay with high fracture limestone. The dominant mineral in the clay samples investigated is montmorillonite. The old building damage is due to the presence of caves in the limestone layers and the swelling of the mud layers.

Nowadays, people need a greater understanding of critical environmental systems in order to help resource managers in taking suitable actions to prepare for future sustainability. Engineers and planners in geotechnical engineering utilize Geographic information systems (GIS) to locate boreholes because it allows them to conduct fresh research, particularly in newly developed regions (Wan-Mohamad and Abdul-Ghani 2011; Dong et al. 2018). GIS technology is utilized in the initial stage to determine the site planning and locations of residential areas and public facilities such as production facilities and highway networks. This technology is also used

to interpolate values geographically and offer geoengineering data alongside the entire area rather than just boring points, where well data provide one-dimensional information on soil conditions along the depth that is subject to spatial ambiguity (Kim et al. 2020).

In this work, the integration approach of geoengineering characteristics and GIS is critical for building and providing digital maps and safety zones due to spatial correlation. GIS is an automated system for effectively storing, analyzing, and displaying geographic data (Dangermond 1984). The geospatial model is one of the important products of GIS uses in this study, and enables the representation or modeling of geographically referenced data graphically or geometrically, as the graphic form represents the location of the geographical phenomenon or its spatial distribution, while the geometric form describes its feature or characteristics. The map was considered a model in the 60s of the twentieth century, and then it was generally accepted by many cartographers later, considering that the map as a model reflects the actual surrounding world through personal understanding and awareness of the cartographer. Robinson et al. (1995) define the geospatial model in its simplest form as a composite map of a set of variables, derived from the aggregation of a number of one-variable maps. Geospatial models are especially suited to applications when time and cost constraints the necessary and predicted accuracy of the model (e.g., Risk assessments in areas lacking geotechnical testing). Therefore, there was an urgent need to integrate geotechnical data and GIS software efficiently by building a geospatial model by distinguishing spatial features (such as points and lines) from other non-spatial information.

These approaches have been utilized in a variety of research, including mineral exploration, environmental hazard, radiation hazard assessment, urbanization, and geotechnical modeling (Omar et al. 2016a, b, 2021; Arnous and Omar 2018; Saad et al. 2020a, b; Sakr et al. 2021; Omar 2021; Arnous et al. 2021; Aita and Omar 2021; Khan et al. 2021). All these recent publications demonstrated GIS's potential to simplify data interpretation and produce superior outcomes.

Thus, an appropriate study was performed to evaluate the geoengineering characteristics to check the suitability of the study area to the urban extension using GIS techniques. Construct the geospatial urban extension model to choose the most suitable locations for safe urban expansion. In addition, identify hazardous locations and how they can be treated before various construction activities.

Location and geological setting of study area

The investigation zone is located on Cairo's eastern outskirts, between northern latitude 29° 59' 20" and 30° 00' 50", and eastern longitude 31° 16' 30" and 31° 19' (Fig. 1).

The Mokattam area is a prominent plateau that borders Cairo from the southeast with its highest point at an altitude of 213 m a.s.l.

Geomorphologically, the investigated area has three plateaus. The high plateau is situated in the northern part, and its height ranges between 205 m in the southern part and 170 m in the northern part. A steep cliff separates it from the center plateau. As per NARSS (1997), the height of the central plateau reaches 110–150 m and the lower plateau reaches 50–80 m.

The geology of the examination region has been talked about by numerous authors (Said 1962, 1990; El-Shazly and Abdel-Hady 1976; Aboushok and Sherif 2000). Stratigraphically, this area is covered by a thick succession of carbonate rocks and less abundant argillaceous rocks ranging in age from Middle to Late Eocene, and they are distinguished into two main units, El Maadi and Gebel El Mokattam Formation (Fig. 2). El Maadi Formation is 45–60 m thick, and is composed of numerous yellowish brown dolomitic limestone that covers most of the surface of the Mokattam area. These incorporate shale and clayey marl layers alongside the essential limestone members. The El Mokattam Formation is essentially composed of white, medium-hard to hard limestone lying under El Maadi Formation. The upper member of the Mokattam Formation (Giushi) is 60 m long and made of thinly bedded white limestone. The structure of the investigation zone is principally determined by three main faults: NWN–SES, E–W and NW–SE trends (Fig. 2).

Fig. 2 Geological map of the study area (after NARSS 1997)

Materials and methods

The work was carried out in its different stages as described as the following (Fig. 3):

Field investigations

In the investigated region, 28 boreholes were drilled at depths ranging from 0 to 10 m below ground level. The scope of the field research was carried out using mechanical

Fig. 1 Location map and digital elevation model (DEM) with samples location of the study area

Fig. 3 Flowchart summarizing the methodological approach taken and defining the data used

rotary drilling rigs, and the field work was performed as per ASTM standards. A single core was used to obtain core samples from limestone rocks, and disturbed samples from backfill and loose soil from fractured limestone and clayey soil. After each core run, the retrieved sample was estimated to decide the total core recovery (Rec.%) and the RQD. All samples were first graded in situ by a geologist and records were prepared (Fig. 4A–D). Samples were taken at depths of 1.0 m, 3.0 m and 6.0 m below the soil surface at each borehole. The depths chosen account for the shallow depth of most foundations as well as the expected depth of the active zone in the research region. No groundwater or leaching appeared until the end of the borehole, and leaching may appear due to human use or climatic conditions, etc. The field samples were stored in plastic bags and taken to the lab for analysis and classification purposes.

Laboratory work

Several laboratory tests have been carried out on soil samples to investigate the physical and mechanical properties of the soil, including free swelling (FS), mineralogical identification, Atterberg limits, swell potential (S), swelling pressure (SP) and (UCS) on rock samples. Noting that the Atterberg limits comprise the plastic limit (PL) and liquid limit (LL) of fine-grained soils, which pass through sieve No.40, these limits were implemented in accordance with ASTM D-4318 (2010). The SP was implemented as per ASTM D-2435 (2011). Clay soil X-ray diffraction has been performed using a Philips diffractometer (9 type PW 3710) and a Ni-filter cake radiation. The samples were run from 2

to 50 at 40 mA and 40 kV. In addition, the testing program comprised the determination of the pH, chloride content (Cl^-), sulfate content (SO_4^{2-}) and the total dissolved salts (TDS). Cl^- and SO_4^{2-} were analyzed by ion chromatography. The instrument used was the Dionex IC model ICS 1100 equipped with high capacity columns (AS9) for anion (Cl and SO_3). Rock samples of almost cylindrical shape were tested using the UCS apparatus. The test was conducted as per the International Society of Rock Mechanics. (ISRM) and as per ASTM D-2938-95 (2002). These samples were tested in dry condition. Both diametral (D) and axial (A) test types were conducted on samples extracted from boreholes.

Spatial data analysis and geospatial modeling (GM) of the geoenvironmental properties

A geoenvironmental data integration approach and the development of a geospatial model for geoenvironmental hazards have been proposed in an attempt to help decision makers and the state in planning the safe urbanization of new urban areas. Geoenvironmental data collected must be entered into a database so as to model and evaluate the geoenvironmental properties of the studied region. The acquired data are then subjected to geospatial interpolation technology utilizing GIS for statistical analysis of the entire region and the integration of geoenvironmental data into a digital map with high spatial resolution. The goal of spatial interpolation is to identify and give soil information along the entire region instead of at a particular point that may be used for designing safe construction regions. Geospatial interpolation methods are broadly classified into two techniques: deterministic and geostatistical. The deterministic technique, which is based on basic empirical or preset mathematical equations, does not take into account the influence of spatial variation with distance forecasting values at unknown places (Kim et al. 2020). The geostatistical techniques, such as the kriging algorithm and its variants, are highly successful at interpolating spatial data over a large range of areas. The geostatistical techniques are considered more accurate than deterministic methods for geoenvironmental characteristic interpolation because of their better ambiguity integration (Arshid and Kamal 2020). In this work, this approach uses the kriging method to perform geostatistical analysis of geoenvironmental parameters. Spatial analyses contain a wide range of data, especially geoenvironmental measurement points. The geographic locations (X , Y) of these points are imported as geographical points in the grid into ArcGIS; however, the Z values can be defined using interpolation techniques. The kriging approach makes allowance for the influence of distance and direction.

The geospatial approach entails the creation of geodatabases, as well as the integration and analysis of geoenvironmental data. Using ArcGIS tools, a geospatial model

Fig. 4 Idealized soil profile of the upper plateau, El Mokattam area

of geotechnical hazards is created by creating geo-data sets and statistical weighting for each geoenvironmental indicator. The current work employs geospatial analysis to create a geo-database of several themed maps highlighting the most promising areas for safe urban development. The geotechnical data are integrated and assessed in this study using two ways; the first method is based on the weight

of the indicator, while the second method is based on collaboration experiences.

Several software tools were utilized to finish the modeling procedure, including ERDAS images 9.2, Arc map 10.5, and surfer v 12. Assessed loads appointed to these layers as demonstrated by the Egyptian code 2001. This model will be helpful in the development and discover

Table 1 Classification of expansive soil according to the plasticity index (after Chen 1988)

PI	Description
≤ 15	Low
15–30	Medium
30–50	High
< 50	Very high

the ideal areas of shallow foundation of the zone under examination.

Results and discussion

Geoengineering characteristics of clayey soil

PI is the basic parameter used for grading fine-grained soils. The following values from Table 1 were suggested by Chen (1988) to establish a relationship between soil expansion and

PI. The clay soils investigated are high-plastic soils, with PI values ranging from 37 to 39% (Table 2 and Fig. 5A). The geospatial distribution map values of PI show that the highest values occur in the northeastern and northwestern portions of the examined area represented by the red color. The low IP values are located in the southern area represented by the green color. The investigated soil's FS ratios vary from 110 to 120% Table 2 and Fig. 5B. The FS geospatial distribution map values show that the highest values are in the eastern portion represented by the red color, while the low values are situated in the south with the green color. This means that the soil may swell and problems with the building are expected, under the Egyptian Code 2001.

Seed et al. (1962) and Geraid (1974) presented an expansive soil classification based on S and SP values, as shown in Tables 3 and 4. Obviously, all soil classification methods are in agreement that the soil samples examined have a high degree of expansion, where S values range from 11.87 to 17.6% and SP from 692 to 816 kN/m² (Table 2 and Fig. 5C,

Table 2 Results of the studied clay samples

Sample no.	Initial water content (WC%)	Liquid limit (LL%)	Plastic limit (PL%)	Plasticity index (PI%)	Free swell (FS%)	Swelling pressure (SpkN/m ²)	Swelling potential (S%)
17-1	20.5	72	35	37	110	755	11.87
18-1	26.5	75	36	39	120	692	14.1
20-1	25.3	73	34	39	115	816	17.6

Fig. 5 Geospatial distribution map of PI (A), FS (B), SP (C) and S (D)

Table 3 Soil classification according to swelling potential (after Seed et al. 1962)

Degree of expansion	Swelling potential S (%)
Low	0–1.5
Medium	1.5–5
High	5–25
Very high	> 25

Table 4 Classification of expansive soil according to the swelling pressure (after Geraid 1974)

Degree of expansion	Swelling pressure SP (kPa)
Low	< 196
Medium	196–392
High	392–687
Very high	> 687

D). The geospatial distribution map values of SP (Fig. 5C) show that the highest values occur in the northeastern part with the red color, while the low values are in the western part with the green color. The geospatial distribution map values of S (Fig. 5D) indicate that the highest values are situated in the northeastern portion with the red color, while the low values are situated in the southern portion with the green color. The variation of swelling percent and applied pressure is illustrated in Fig. 6. The percent swell versus time of the studied sample no. 1 at boreholes 17, 18 and 20 (Fig. 7A–C).

Soil classification is an important factor in laboratory testing that indicates the properties of the soil in question. Laboratory determinations of LL and IP for the soil sample make it possible to assign fine grain soils to the appropriate group using the plasticity diagram. The plasticity diagram

showed that the clay specimens studied fall into high-grade plastic soil (Fig. 8).

The mineralogical and chemical composition of clay deposits varies considerably according to the type of relative proportions of their clay and non-clay minerals. As for the crystalline structure of clayey minerals, they are usually categorized in two groups; the type of two-layer structure, e.g., kaolinite group and the type of three-layer structure, (e.g., illite and montmorillonite groups). The network structure of these groups varies depending on the combination of tetrahedral silica layers $[\text{Si}_2\text{O}_5]^{2-}$ attached to the corners with octahedral layers of alumina $[\text{Al}_2(\text{OH})_4]^{2+}$. Mineralogical studies of the X-ray diffraction (XRD) analysis of the collected samples indicate that the sediments are comprised of montmorillonite and kaolinite (Fig. 9A–C). The important constituent of the clay minerals investigated was montmorillonite. Clay minerals such as montmorillonite in land clearly indicate the potential to expand. Thus, this kind of soil is not permitted to direct the foundation over them due to its high swelling property, which dangerously affects the constructions.

Geoengineering characteristics of limestone rock

The (RQD) is the relationship between the total length of rock samples 10 cm or greater and the length of the core. The RQD described as excellent, good, fair, poor and very poor as per the Egyptian code 2001 (Table 5). The RQD values of the examined rock samples are considered very poor to poor, with values ranging between 21 and 45% (Table 6). The geospatial distribution map values of RQD (Fig. 10A) showed that the highest values are distributed in some parts of the study area. These parts are distributed in the north-eastern, southwestern and central parts represented by the red color. The lower values are distributed in the southern and western parts represented by the green color. Table 6 and Fig. 10B show the UCS values of the studied rock samples

Fig. 6 Variations of swelling percent and applied pressure

Fig. 7 Percent swell versus time of the studied clay samples

Fig. 8 Plasticity chart of the studied clayey soil

which ranged from 47 to 72.2 kg/cm². This figure shows that the highest UCS values are concentrated in the western and southwestern parts represented by the red color. The lowest values are concentrated in the central part represented by the green color. These values refer to the limestone samples under study are highly fractured, as these values indicate low

Fig. 9 X-ray diffraction of the studied clay minerals

Table 5 Rock classification according to RQD in Egyptian code

RQD%	Rock quality
< 25	Very poor
25–50	Poor
50–75	Fair
75–90	Good
90–100	Excellent

strength and weak to medium weak based upon Egyptian code 2001, Deere and Miller (1966) (Tables 7 and 8). The limestone of the upper plateau contains caves which may cause some damage to construction.

Table 9 presents the chemistry of the limestone samples examined to detect the pH, Cl⁻, SO₃²⁻ and TDS salts. The

Table 6 Results of RQD and UCS of the studied rock samples

Sample no.	UCS (kg/cm ²)	Description	RQD (%)	Description
1-1	52.4	Medium weak	39	Poor
2-1	60.1	Medium weak	45	Poor
3-1	47	Weak	30	Poor
4-1	61	Medium weak	50	Poor
5-1	50	Medium weak	36	Poor
6-1	64.6	Medium weak	33	Poor
7-1	56	Medium weak	30	Poor
8-1	67	Medium weak	38	Poor
9-1	68.4	Medium weak	38	Poor
10-1	64.7	Medium weak	30	Poor
11-1	59	Medium weak	36	Poor
12-1	64.5	Medium weak	40	Poor
13-1	62.4	Medium weak	36	Poor
14-1	59.5	Medium weak	36	poor
15-1	64	Medium weak	35	Poor
16-1	68	Medium weak	40	Poor
17-2	55.8	Medium weak	21	Very poor
18-2	61.2	Medium weak	26	Poor
19-1	57.2	Medium weak	30	Poor
20-2	56.5	Medium weak	34	Poor
21-1	58	Medium weak	38	Poor
22-1	58.3	Medium weak	38	Poor
23-1	62.2	Medium weak	42	Poor
24-1	64.7	Medium weak	45	Poor
25-1	68.4	Medium weak	38	Poor
26-1	68.3	Medium weak	45	Poor
27-1	69.2	Medium weak	45	Poor
28-1	72.2	Medium weak	45	Poor

TDS values from 100 to 1050 (Fig. 11A), where higher values of TDS are distributed in the most of the examined area, which appear with the red color. The lower values are distributed in some localities represented by southwestern, eastern and northeastern areas, which appear with

the green color. The high estimations of TDS are coming about because of high filtering and/or dissipation of salts which solidified in soil, where the filtering may prompt a subsidence of soil under the structures. The Cl^- values from 320 ppm (moderately aggressive) to 480 ppm (moderately aggressive) (Fig. 11B). The high values of Cl^- salts are distributed in the southeastern part shown as red, while the low values are distributed in the southern part shown as green. The SO_3^{2-} ranges from 160 ppm (non aggressive) to 260 ppm (moderately aggressive) (Fig. 11C). Many localities have higher values of SO_3^{2-} salts distributed in some parts of the study area. These parts are distributed in the northeastern, southeastern and southwestern portions, which appear with the red color. The lower values are found in two northern and northeastern parts, which appear with the green color. The pH values range from 7 to 8.2 (Fig. 11D), where high pH values are distributed in the southeastern and southwestern portions depicted with the red color. Lower pH values are spread across the north of the study area represented by the green color. The pH is an important agent that is utilized to transform the SO_4 , Cl and TDS into ions. The high rates of these particles in the soil detrimentally affect the foundations, as per Egyptian code 2001. Components of chemical investigation could be utilized to estimate the kind of utilized concrete. The geospatial distribution maps of pH, Cl^- , SO_3^{2-} and TDS are illustrated in Fig. 11A–D, respectively.

Geospatial modeling of geoenvironmental characteristics

The construction, fitting to shallow establishments with the end goal of urbanization in the investigation area is resolved using GIS techniques in the modeling process. Where, this model will be helpful in the development and discovery of the ideal areas of shallow foundation of the zone under examination. In the current work, we incorporate all the parameters and properties that control and help secure construction, inhabitants, and norms that are utilized

Fig. 10 Geospatial distribution map of RQD (A) and UCS (B)

Table 7 Rock classification according to unconfined compressive strength in Egyptian Code

UCS (kg/cm ²)	Rock type
> 2000	Extremely hard
2000–1000	Very hard
1000–500	Hard
500–125	Medium hard
125–50	Medium weak
50–12.5	Weak
≤ 12.5	Very weak

Table 8 Rock classification according to unconfined compressive strength (after Deere and Miller 1966)

UCS (MPa)	Description
> 200	Very high strength
110–220	High strength
55–110	Medium strength
27.5–55	Low strength
< 27.5	Very low strength

Table 9 Chemical analysis of the studied rock samples

Sample no.	pH	SO ₃ (ppm)	Cl (ppm)	TDS	Type of soil
1-2	7.4	210	450	950	Limestone
2-2	7.5	190	435	1050	Limestone
3-2	7.2	200	360	100	Limestone
4-2	8.1	250	480	885	Limestone
5-2	7.2	176	380	890	Limestone
6-2	7.4	210	410	950	Limestone
7-2	7.2	190	435	1040	Limestone
8-2	8.2	260	360	100	Limestone
9-2	7.6	160	400	885	Limestone
10-2	7.5	190	380	990	Limestone
11-2	7.2	176	380	890	Limestone
12-2	7.6	210	410	950	Limestone
13-2	7.4	190	435	1040	Limestone
14-2	7.9	260	360	100	Limestone
15-2	7	160	400	885	Limestone
16-2	7.3	190	380	990	Limestone
19-2	7.8	200	320	990	Limestone
26-2	7.9	210	330	890	Limestone

to investigate the suitability of sites. The geospatial urban model in the examination area (Fig. 12) was constructed by integration of physical, mechanical, and chemical analysis of soil and rocks (Figs. 5, 10 and 11). The constructed geospatial urban model within the study area is broken down into four areas: low, moderate, high and very high, with mid blue, mid green, yellow and red colors, respectively. Most of the regions in the investigated zone were found to have low and moderate hazard zones. These areas are ideal for shallow foundations. The high and very high zones were

observed in some small areas in the southeast of the investigation area. Appropriate care must be taken in these areas (high and very high zones) before designing the foundations. Based on geotechnical rock and soil research results of the field region, appropriate caution should be needed in many locations, such as demands for using sulfate-resistant cement in all sub-surface concrete works.

Remediation and mitigation

From the results shown above, the Mokattam area suffers from the existence of any problems represented by high fractured limestone and clay layers that have high swelling properties. Another major problem is the infiltration of water. Water leakage and runoff into cavities and cracks are due to natural causes such as precipitation accumulation and as a result of human activities such as irrigation and breakdown of sanitation facilities. The accumulation of rain over time occurs in deeper strata in contact with limestone and shale. Later, urban development has increased water consumption without improvements to the sanitation system. Typically, ducts are subjected to joint opening, cracking, and increased leakage, leading piping and internal erosion of the surrounding soil. This is normally unattended. As a result, infiltration moves downhill or weak areas of shale and marl, causing softening, saturation, and deterioration of the geomechanical states of those clay layers. Consequently, the subsequent degradation of the bearing condition occurs and collapses due to bending and fracture of the overlying layers (EL-Sohby et al. 2004).

The limestone in the Mokattam area is mostly porous and sensitive to chemical reactions with water rich in sulfates and chlorides. The pores make it possible to store water in the rock formation, creating a good environment for chemical reactions. A portion of the soluble carbonate constituents dissolves in the stored water, which results in a continuous process of creating voids and expanding existing voids. This process goes on and eventually leads to the formation of large pores, pits, and cavities, finally reducing the rock to a low porous formation with remarkably low resistance. Therefore, subsidence, flexion and fracture occur in the overlying strata. Fractured parts of the bedrock are further separated from the parent rock. Near the cliff, instability erupts and rocks fall. In addition, down the cliff, the degradation of the geomechanical state of the clay strata caused by the seepage of water affects the limestone complex which covers it, in order for tensile and existing fractures to determine the conditions conducive to failure.

To solve these problems, it is preferable using a mat foundation rather than a spread foundation to repair subsidence or failure of buildings. Fractured limestone is, therefore, considered a suitable base layer for light engineering structures. In the case of heavy structures and

Fig. 11 Geospatial TDS, Cl^- , SO_4^{2-} and pH (A–D) values, respectively, distribution map of the study area

Fig. 12 Geospatial urban map of the upper plateau, El Mokattam area

construction, grout is essential to enhance the resistance of the bedrock to the desired level. Consolidation grout is accepted measure for sealing open joints and fractures and improving weak areas in foundation rock. The most commonly used materials for grouting are cement, asphalt, clay and hot bitumen. Grout mixes made from cement are commonly used in recent grout practices. Cement typically consists of > 95% of the grout mixture, and other components include bentonite, various chemical additives, polyurethane and artificial sponges. The stable clay-cement grout mixture utilizes clay as the base component along with cement and bentonite as additional components (Abd El-Aal and Masoud 2017). The other way around, to reduce soil swelling and prevent buildings from moving

upwards, it is recommended that they be replaced and/or stabilized with chemical additives.

Summary and conclusion

The current study succeeded in identifying the geoengineering characteristics of the upper plateau of the Mokattam region for its evaluation of the safe urban extension. The geoengineering investigation described in this article indicated the presence of several engineering problems confronting Mokattam civil engineers. According to the Egyptian Code, these problems are distinguished by badly fractured limestone and the presence of clay layers with substantial swelling, the value of which exceeds 100% and has an adverse influence over the building.

The current work demonstrates the efficacy of GIS approaches in the construction of geospatial urban models in the context of safe regional development. In this work, we integrate and exploit multivariate data by overlaying geoengineering layers to generate an integrated geoengineering hazard model that delineates safe and dangerous building regions for the study area. The produced model is categorized into four zones as low, moderate, high, and very high hazard zones to assess the suitability of the study area for the safe urban extension. The geospatial model shows the low and moderate hazard zones covers the majority of the study area. These regions are ideal for foundations with shallow

depths. The high hazard zone is represented by a tiny region in the research area's center, but the very high hazard zone was not detected in the study area. In addition, this model will be used as an information base in the future to reduce the risk impact of buildings.

Recommendations

The current study is recommended for geophysical studies, including shallow seismic refraction tomography and multi-channel analysis to detect subsoil condition and p-wave velocity distribution, which is important in the evaluation of fracture and geological units, and also to visualize the fractures extent in the underground strata. For heavy structures and buildings, it is necessary to inject cement, grout and mat foundations to prevent future engineering hazards.

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