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Geotechnical assessment of El-Qantarah Gharb area, Northwestern Ismailia District, Egypt: Land Stability and Sustainable Construction

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Abstract

This study offers a geotechnical assessment of El-Qantarah Gharb, northwest Ismailia District, focusing on evaluating the subsurface soil characteristics and identifying the related geotechnical issues that affect both constructions and urban planning. The results draw attention to some important problems like waterlogging, high soil compressibility, and existence of soft and weak clay layers, which pose serious risks to local urban planning and construction projects. To assess the soil's geotechnical properties, resolve these geotechnical problems, and provide a rational recommendation, a comprehensive laboratory and field geotechnical testing program was carried out. This program included the Standard Penetration Test (SPT), Atterberg limits, and consolidation tests. Three different layers make up the subsurface soil profile, which is associated with a number of stiff and soft clay lenses that have special geotechnical properties that necessitate specialized engineering solutions. Several stabilization and foundation techniques are suggested to improve structural stability and guarantee the safety of construction projects within the study area.

Keywords: ElQantarah Gharb area, geotechnical challenges, engineering solutions

1. Introduction

The current study area is situated to the northwestern district of Ismailia on the western bank of the Suez Canal. It is bordered by latitudes 30° 42' 30" N and 30° 49' 31"N and longitudes 32° 07' 00" E and 32° 19' 31"E (Fig.1). As a part of Egypt's 2030 Sustainable Development Strategy (ADS 2030), this area has been identified for significant national projects aimed at fostering economic, societal, and environmental development. The Suez Canal corridor project, which is one of these national projects, encompassing agricultural, industrial, and urban developments, highlights the urgent need for comprehensive geotechnical investigations to support sustainable infrastructure expansion.

Reconnaissance investigation during the present study, revealed the presence of critical land degradation issues such as salinization, alkalization, soil compaction, and waterlogging, which exacerbating the risks to construction projects. Hence, accurate and up-to-date geotechnical evaluations are essential to prevent potential engineering problems, and to suggest suitable solution.

Previous study carried out by [1] revealed the presence of weak hydraulic properties and high salt concentrations in west Ismailia soils due to the presence of evaporitic layers and ongoing seepage from the surrounding irrigated lands. According to [2] the soil types at the Suez Canal University, El-Qantarah Sharq, and Al-Mostaqbal localities are coarse-grained sand with good to excellent subgrade. With the exception of a few high-performing samples in El-Qantarah Sharq, the majority of sam-

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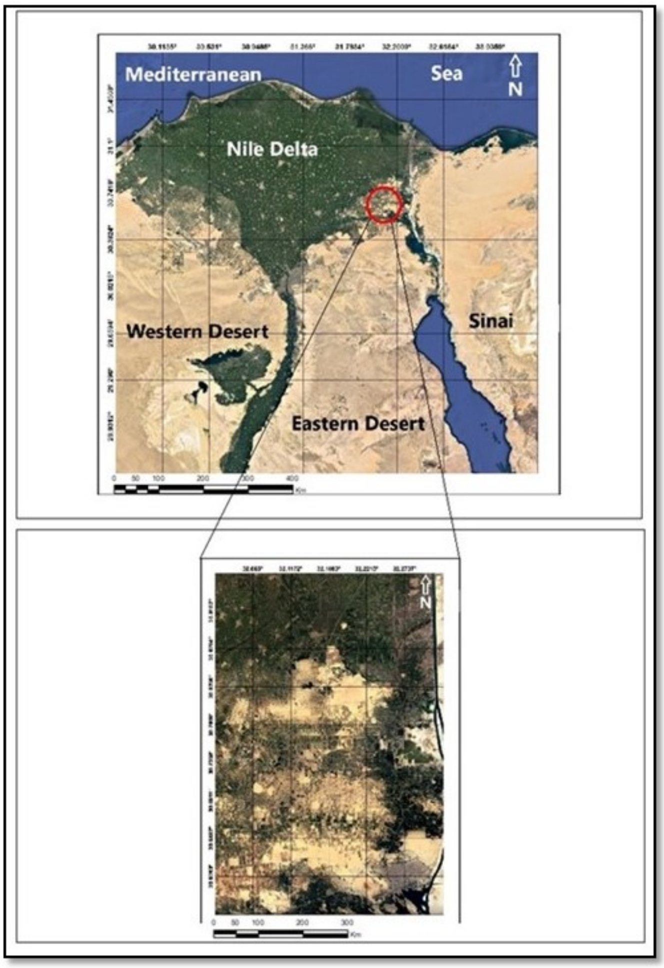

Figure 1: Location map of the study area

ples are only appropriate for sub-base layers because of their low California Bearing Ratio (CBR) values.

In Ismailia area, due to the presence of high plasticity clay (CH) clay lenses, [3] recommended the removal of the topmost part of the soil section down to a depth of about 3.5 m for shallow foundations, replacing it with non-cohesive soils. Continuous Flight Augering (CFA) piles with a diameter of 50 cm are advised for stabilizing flexible clayey layers. Optimal compaction should be achieved with a maximum dry density of 1.894 g/cm^3 at a water content of 7.8%.

There are very few studies that use sophisticated techniques to evaluate ground instability in the Ismailia District. Significant research was carried out by [4], who identified seven areas that were susceptible to ground instability. Among these, the Al-Mostaqbal and Al-Ferdan urbanization zones, which are parts of Ismailia district, had average rates of subsidence of -2.7 mm/year and -2.6 mm/year, respectively. The current research involved the attention to the fundamental relationship between factors such as groundwater levels, clay layer depth, and swelling potential on one side, and ground instability on the other side.

2. Geologic Setting

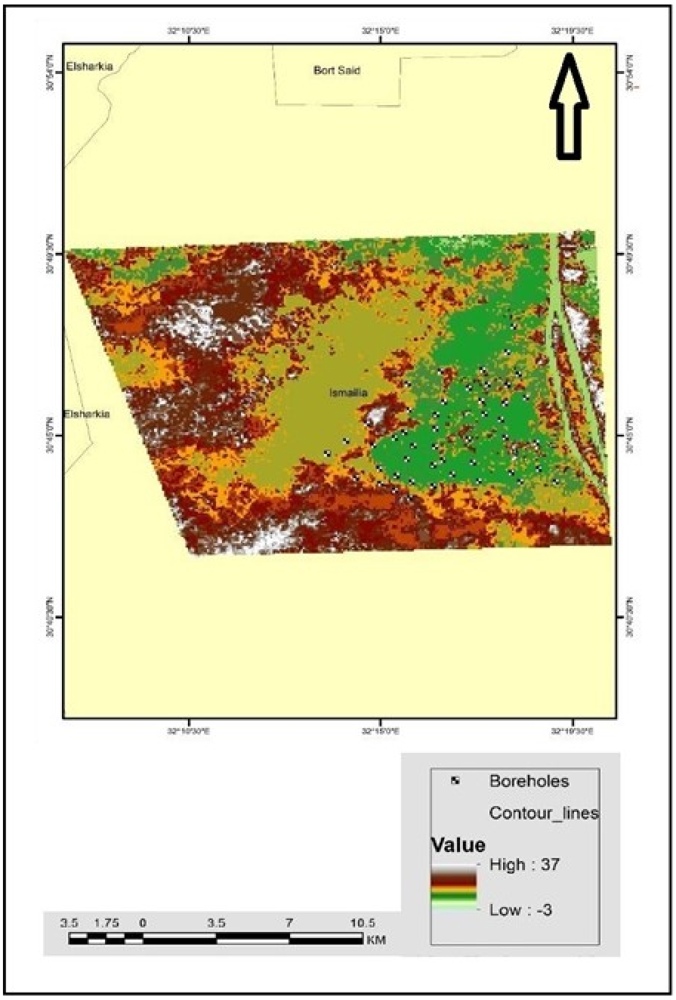

Figure 2: Digital Elevation Model (DEM) of the study area.

Based on the Digital Elevation Model (DEM) (Fig. 2), the study area exhibits elevations ranging from -3 m below sea level (b.s.l.) to 37 m above the sea level (a.s.l.). Generally, the low-lying regions are located near the Suez Canal, while the relatively highland is situated in the southern and northwestern parts. Areas of intermediate elevations are found in the central part.

El-Qantarah Gharb area is mainly covered by Quaternary deposits, which are extensively distributed in the northern region. These deposits are composed of undifferentiated Quaternary sediments, Pleistocene, and Holocene formations [5]; [6], [7] (Fig. 3). The Pleistocene deposits consist of gravel and sand interbedded with clay, while the Holocene deposits are categorized into three units. The first unit comprises Wadi deposits, the second consists of young deltaic sediments (Neonile period) made up of Nile silt, fine sands, and clays, and the third is Aeolian deposits, characterized by loose fine to coarse sands.

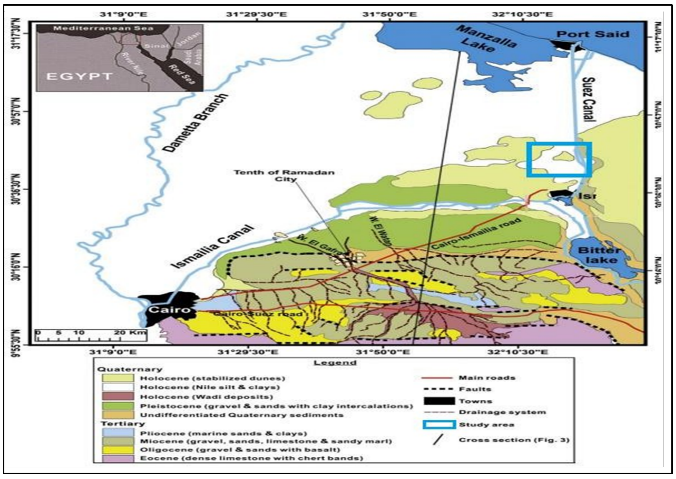

Figure 3: Geological map of the eastern Nile Delta including the study area [5]; [6], [7].

Quaternary sediments, particularly sabkha deposits, negatively impact construction and agriculture, causing subsidence in various areas and degrading soil geotechnical properties. These effects intensify toward the southern regions of the Ismailia District and along the Ismailia-Suez Road [1]; [8]. Waterlogging further exacerbates ground instability by promoting evaporation, leading to increased subsidence potential. Additionally, the formation of saline salts has severe destructive impacts on buildings and infrastructure in new development projects [9], [10]; [11].

3. MATERIALS AND METHODS

The geotechnical investigation carried out during the current study incorporated detailed field and laboratory tests to evaluate the subsurface soil condition. Field tests included drilling 47 boreholes (Fig. 4) which are distributed all over the study area and reach to a depth ranging from 10 to 26 meters using a rotary drilling rig. The Standard Penetration Test (SPT) has been performed according to [12] to assess soil bearing capacity. Soil samples were carefully collected using disturbed and undisturbed sampling techniques, cohesive soil coring, and stockpile sampling. Laboratory tests include moisture content determination [13], Atterberg limits [14], particle size distribution [15], consolidation test [16], and finally direct shear test [17]. Chemical analyses of groundwater and soil samples have been performed to evaluate their aggressiveness toward foundations. These analyses include pH measurement [18], total dissolved solids (TDS) determination [19], sulfate content [20], and chloride ion concentration [21].

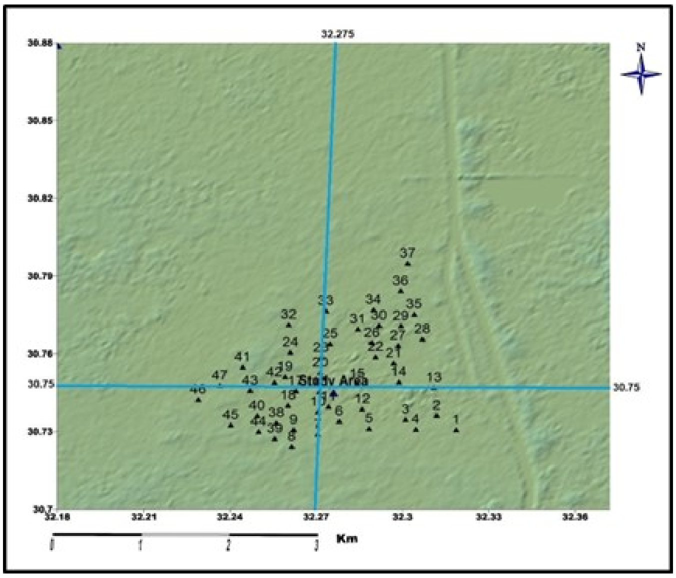

Figure 4: Map showing the locations of boreholes and the N-S and E-W-trending subsurface soil sections.

4. Results

4.1. Subsurface Soil Section

The geotechnical investigation of the study area revealed the presence of three distinct subsurface soil layers, each with unique characteristics (Figs. 5 & 6). As an example, the subsurface soil section of borehole no.1 is shown in (Fig. 7), and the description of these layers is as follows:

a- Layer A (Fill soil)

Layer A is the topmost layer which has a thickness of 1-2 m., and is composed of fine- to medium-grained sand, with traces of silt, gravel, and lime materials. The layer has a brown color and contains salty materials, which may influence its engineering behavior.

b- Layer B (Silt with fine- to medium-grained sand)

Layer B is primarily consists of silt with varying amounts of fine- to medium-grained sand, shell fragments, and lime materials. It has a thickness ranging from 2 to 8 m., and a greenish-gray or dark-gray color. It contains soft clay lenses which are encountered at depth ranging from 2 to 5 m., and has a thickness ranging from 1.5 to 2.5 m.

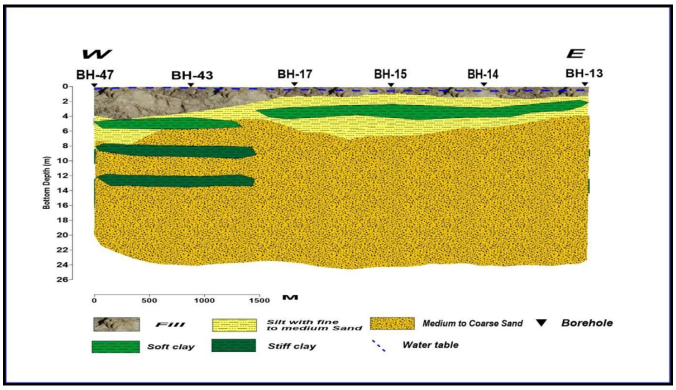

Figure 5: An East-west-trending subsurface soil section along the study area

The clay lenses exhibit notably high-water content, reaching up to 83%, alongside a liquid limit of 88% and a plastic limit of 33%, resulting in a plasticity index (PI) of 55%. Unconfined compressive strength (q_u) values for these lenses range between 0.1 and 0.5 kg/cm^2, reflecting a consistency that varies from very soft to soft.

Consolidation testing of specimens from Layer B reveals moderate consolidation characteristics. The coefficient of consolidation (Cv) is observed to range between 0.32 and 0.38 m^2/year, while the compression index (Cc) values, spanning 0.42 to 0.46, emphasize the soil's high compressibility. Furthermore, the over-consolidation ratio (OCR), ranging from 4.03 to 5.57, indicates that this layer has experienced significant historical loading, which enhances its resistance to further compression.

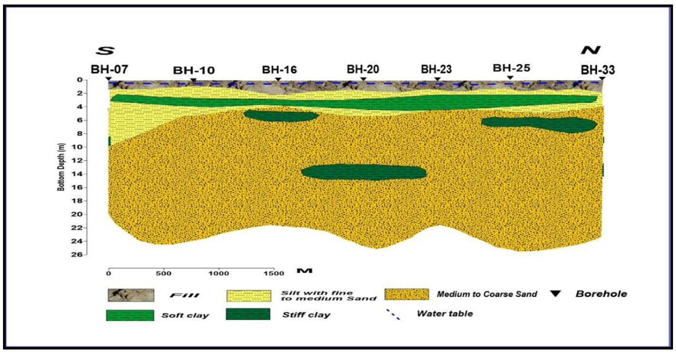

Figure 6: A north-south-trending subsurface soil section along the study area.

Despite these observations, the geotechnical properties of this layer present notable challenges for foundation design. Effective mitigation strategies, such as soil stabilization, drainage enhancement, or, where necessary, soil replacement, are essential to ensure the stability and performance of structures founded on this layer.

c- Layer C (Sandy soil)

Layer C is the lowermost layer, which consists of medium- to coarse-grained sand, with varying proportions of clay, silt, gravel, mica, and lime materials, and has a thickness ranging from 10 to 21 m. It exhibits densities ranging from medium dense to very dense, with standard penetration test (SPT) values ranging from 25 to 50 blows/cm. The relative density varies between 50% and 85%, and the internal friction angle ranges from 31° to 34°, reflecting its high shear strength. Additionally, stiff clay lenses within this layer are identified at depths of 4 to 15 meters, with thicknesses of 1 to 2.5 meters. These lenses have water content up to 36% and unconfined compressive strength values ranging from 1 to 3.5 kg/cm^2, indicating stiff to very stiff consistency.

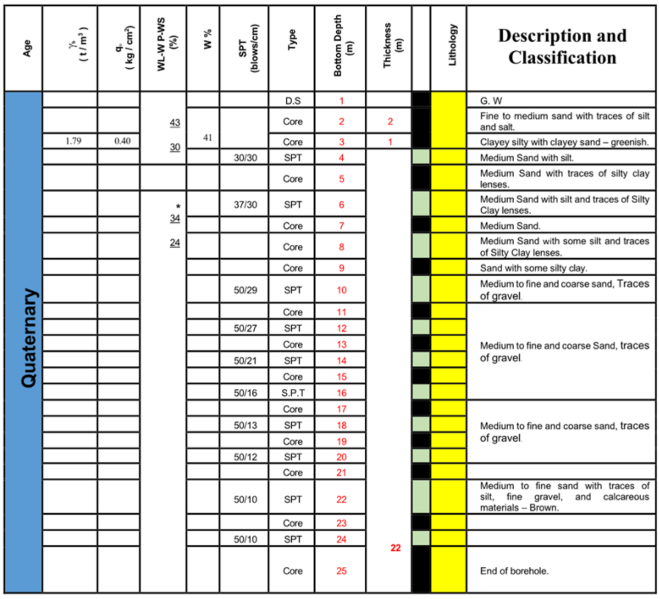

Figure 7: Subsurface soil sequence and results of tests carried out in borehole no.1, El-Qantarah Gharb area.

4.2. *Geotechnical Parameters*

4.2.1. *Standard Penetration Test (SPT)*

The values of the SPT display an increasing resistance with depth as shown in (Fig. 8). The SPT values of layer "C", exceeded 50 blows/ft at depths greater than 10 meters, highlighting its dense to very dense nature. Excellent load-bearing capacity and low settlement risks are displayed by the layer, where SPT values can reach high levels (30–50 blows/ft).

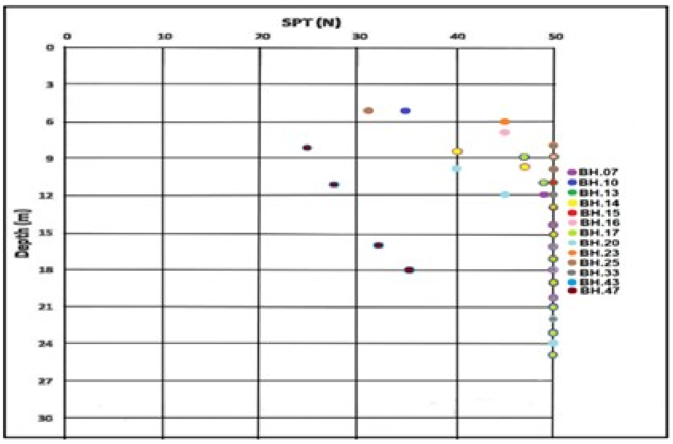

Figure 8: The relationship between SPT values and the depth of the sandy soil layer (C) of the study area.

4.2.2. *Atterberg Limits*

To examine the lateral variations of various values more quickly and accurately, distribution contour maps of the various parameters have been created using GIS technique.

a- Liquid Limit (LL)

According to the liquid limit (LL) distribution contour map which is shown in (Fig. 9), the values are ranging from 30 to 88%. The majority of the study area is characterized by very low to moderate values. However, the high values are encountered mainly in the southeastern part of the study area as well as some spots in the northeastern, central, and southwestern parts.

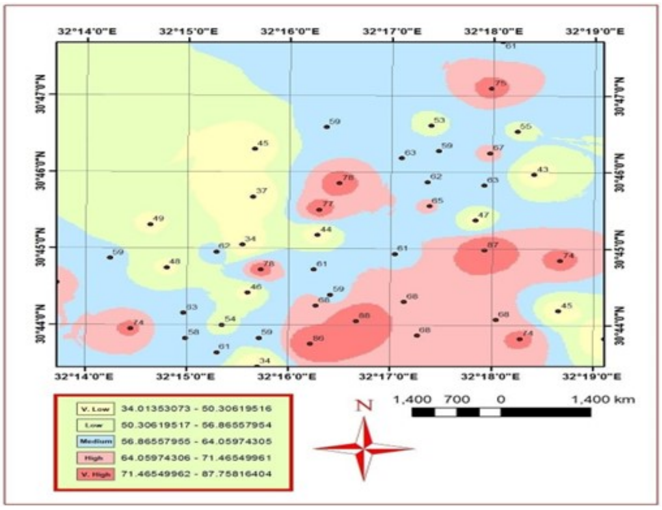

Figure 9: Contour map of liquid limit distribution of the study area.

b- Plastic Limit (PL)

The results of plastic limit (PL) of clayey samples are presented in the distribution contour map which is shown in (Fig. 10). This map shows the plastic limit values are ranging from 23% to 37%. The lower values are distributed in the eastern and western parts of the study area, whereas the higher values are concentrated in the central part.

c- Plasticity Index (PI)

The distribution contour map (Fig.11) shows that the plasticity index (PI) values are ranging from 12% to 55%. Careful inspection of the map shows that most of the study area exhibits low to moderate PI values, while high and very high PI values are encountered in the southeastern part, in

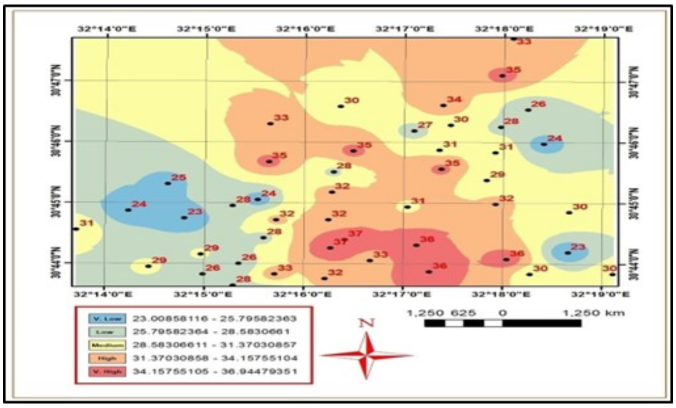

Figure 10: Contour map of plastic limit distribution of the study area.

addition to few isolated anomalies scattered in the northeastern, central, and southwestern parts.

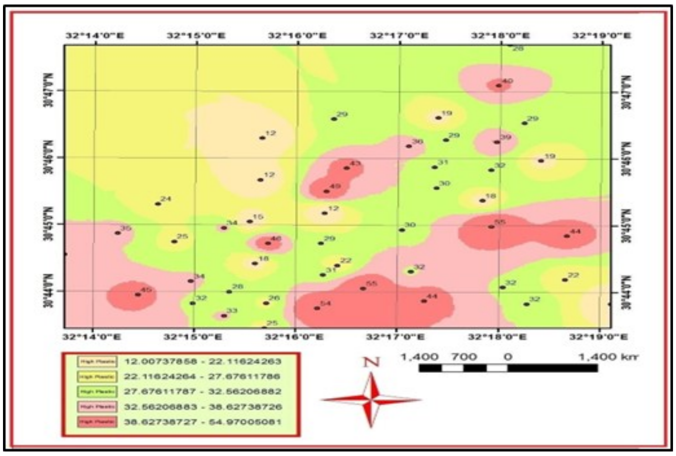

Figure 11: Contour map of plasticity index distribution of the study area.

d- Shrinkage Limit (SL)

The shrinkage limit (SL) results are illustrated in the distribution contour map shown in (Fig. 12). The SL values are ranging from 10% to 20%. The northwestern and southeastern parts of the study area are characterized by very low to moderate values, while high to very high values are situated in the northeastern and southwestern parts.

e- Liquidity Index (LI)

The liquidity index (LI) distribution contour map (Fig.13) shows that the values are ranging from -0.08 to 1.74%, indicating soils are varying from medium stiff to very soft. Higher values, indicative of liquid states, are predominantly concentrated in the eastern region, exceeding 1.03.

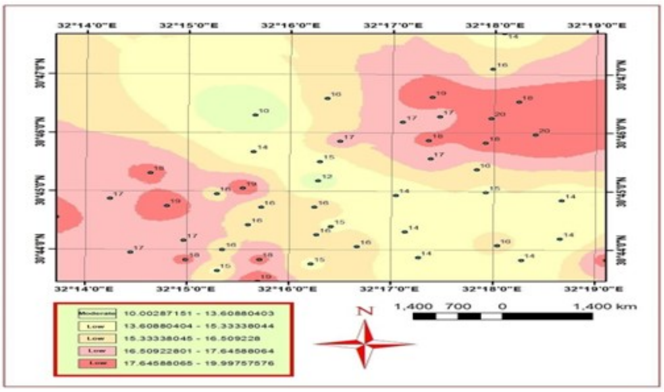

Figure 12: Contour map of shrinkage limit distribution at the study area.

These areas present significant engineering challenges due to their weak or water-saturated nature. Moderate values, reflecting plastic states, are primarily distributed in the central regions, suggesting relatively stable but still compressible soil conditions requiring further assessment for construction purposes. Lower values, associated with semi-plastic states, are mainly observed in some of the western and southwestern parts of the map. These zones of low liquidity index are more stable and may be more suitable for construction. The overall distribution shows a gradient of increasing values from west to east, which could correspond to natural variations in soil properties or groundwater levels across the study area.

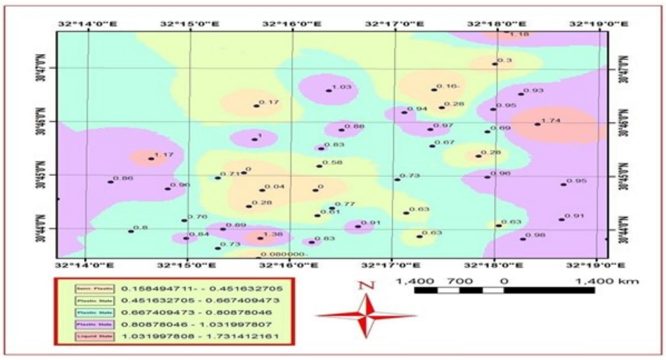

Figure 13: Liquidity index values distribution contour map of the study area.

f- Consistency Index (CI)

The consistency index distribution contour map indicates that the values range from -0.06 to 1.15 (Fig. 14). The lower values are located in the western and eastern parts, whereas the high values are encountered at the central sector of the study area. Generally, the consistency index of studied samples represents medium stiff to very soft soils.

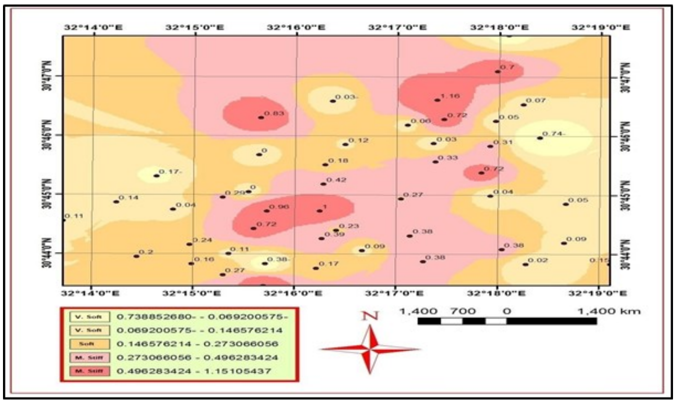

Figure 14: Consistency index values distribution contour map of the study area.

g- Unified Soil Classification System (USCS)

The laboratory determination of liquid limit and plasticity index of soil samples are essential requirements for applying Unified Soil Classification System (USCS). The plasticity charts (Figs. 15 & 16) exhibit that the soft clay soil samples are classified as inorganic clay with high and very high plasticity (CH), which constitutes 41.6% of the total clayey samples, whereas the stiff clay is classified as inorganic clay with high and very high plasticity (CL) soils that represent 26.6% of the total clayey samples. Meanwhile, the coarse-grained soils, composed predominantly of sand-sized particles and larger, are classified according to USCS and The Massachusetts Institute of Technology (MIT) systems as medium to coarse and fine sand, with traces of gravel.

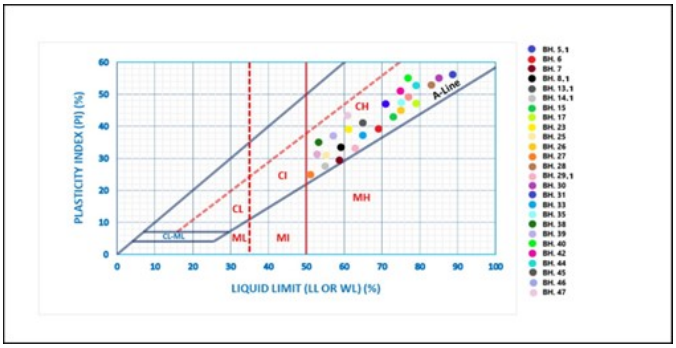

Figure 15: Plasticity chart of soft clay lenses samples of layer (B), of the study area.

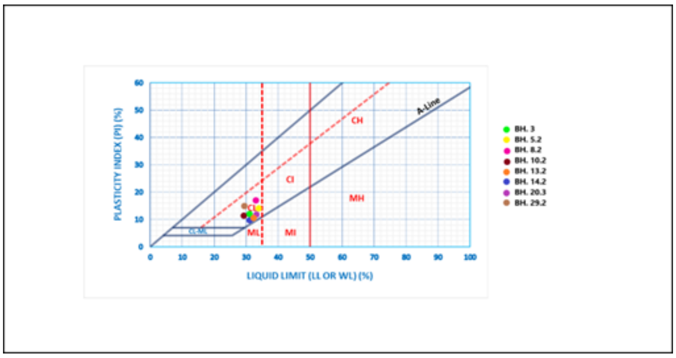

Figure 16: Plasticity chart of stiff clay lenses samples of layer (C), in the study area.

4.3. *Chemical Analysis*

The aim of chemical analysis is to assess the aggressiveness of soil and groundwater samples and testify their suitability for construction purposes. This analysis helps determine the potential impact of chemical compounds on construction materials such as concrete and steel, ensuring the long-term stability and durability of the structures. It also identifies corrosive elements, pH levels, and other factors that could jeopardize the integrity of foundations, retaining walls, and other critical infrastructure components.

4.3.1. *Chemical analysis of groundwater samples*

a- Chlorides concentration

The contour map showing the spatial distribution of chloride concentrations in groundwater samples is shown in Figure 17. This map indicates that most of the study area is exposed to high chloride concentrations, with only isolated spots in the western and southwestern parts exhibiting moderate to highly aggressive levels. The chloride concentrations in the study area ranged from 800 to 53,900 ppm. According to [22], groundwater samples are classified as moderately to highly aggressive type.

b- Sulfates concentration

The analysis of the sulfate concentration distribution contour map (Fig. 18) reveals that the majority of the study area is affected by aggressive sulfate concentrations, except the southwestern sector which demonstrates moderately - aggressive levels. Localized spots of highly- aggressive concentrations are encountered in the eastern

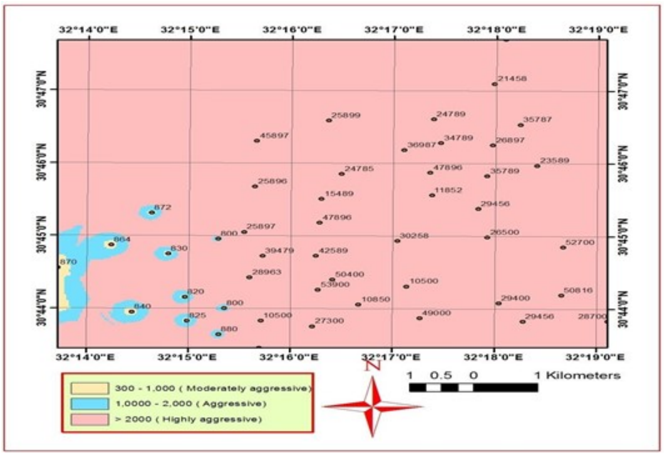

Figure 17: Contour map of chloride concentration of groundwater samples at the study area.

and southern parts which have a considerable risk to construction materials. According to the [22], the sulfate concentrations of the groundwater samples (300 to 8,258 ppm) are as considered moderately to highly aggressive.

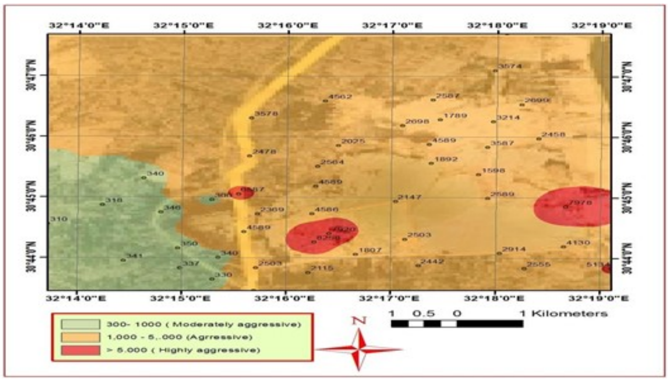

Figure 18: Contour map of sulfate concentration of groundwater samples at the study area.

4.3.2. *Chemical analyses of soil samples*

a- Chloride concentrations

Generally, the chloride concentrations distribution contour map (Fig. 19) shows that the study area is characterized by highly- aggressive soils. The chloride concentration of soil samples is ranging from 1500 to 15000 ppm. These soils are classified as moderately to highly aggressive [22].

b- Sulfates concentration

The distribution contour map of sulfate concentration of soil samples is shown in Figure 20.

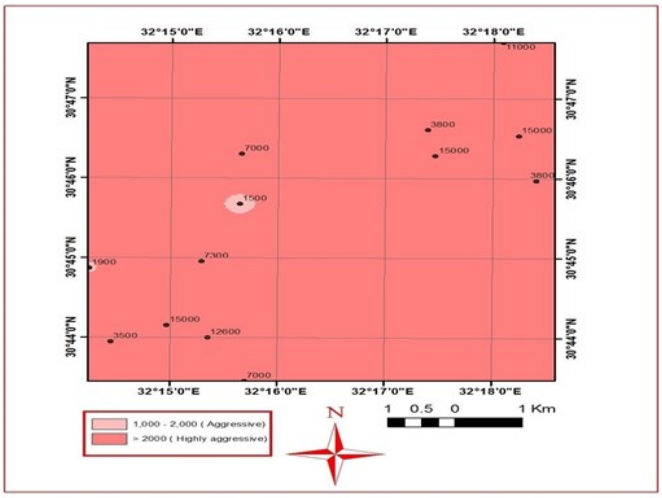

Figure 19: Chloride concentration distribution contour map of soil samples of the study area.

This map shows the majority of the study area is characterized by moderately aggressive sulfate concentrations, except the western and southwestern parts which are characterized by non-aggressive sulfate concentrations. Some spots are found which are characterized by aggressive concentrations. Based on sulfate concentration values (3,400-74,000 ppm) the soil samples can be described as moderate to highly aggressive.

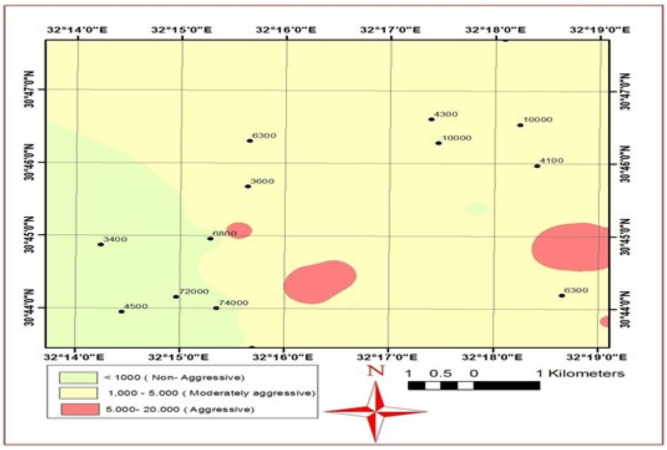

Figure 20: Distribution contour map of sulfate concentration in soil samples of the study area.

5. Discussion

The current research aims to assess the geotechnical properties of the soil, identify the potential risks, and propose practical solutions to ensure the stability and safety of infrastructure projects. Hence, supporting optimal urban planning while minimizing risks related to soil instability. Two major geotechnical challenges in the El-Qantarah Gharb area are present: the waterlogging and ground instability, leading to problems such as soil loosening, surface cracking, and soil saturation with chloride and sulfide salts, which accelerate the corrosion of steel reinforcement and damaged concrete. Additionally, collapsing soils and sabkha, a highly porous and waterlogged soil type prone to liquefaction during seismic events, contribute to subsidence and structural distortions. Tackling these issues requires identifying problematic zones, analyzing subsurface conditions, and implementing appropriate remedial measures before project execution.

The current geotechnical investigation reveals the presence of three primary soil layers were identified, each exhibiting distinct geotechnical properties that influence their behavior under loading and environmental conditions. The first layer (A) (thickness: 1-2 m) is the uppermost fill soil layer, which is composed mainly of fine-to-medium-grained sand mixed with small quantities of silt, gravel, lime, and saline materials. Although it has sandy nature which allows suitable drainage, the presence of process.

The second layer (B) consists of silt and contains fine sand, clay lenses, and occasional shell fragments. Its thickness ranges from 2 to 8 m.at a depth of 2-5 m., exhibiting exceptionally high-water content (up to 83%). The attained resultsshow that the unconfined compressive strength is rangingfrom 0.10 and 0.50 kg/cm^2, classifying it to have very soft to soft consistency.

The third layer (C) (thickness: 10-21 m.) is made up of medium- to coarse-grained sand with interspersed stiff clay lenses. The layer displays excellent geotechnical properties, including high density, moderate to very dense compaction, and high shear strength, as indicated by standard penetration test (SPT) values ranging from 25 to 50 blows per centimeter. The internal friction angle (φ) of the sandy material ranges from 31° to 34°, indicating its suitability for supporting deep foundations. The stiff clay lenses within this layer, with water contents up to 36% and unconfined compressive strengths ranging from 1 to 3.50 kg/cm^2, contribute further to the load-bearing capacity through skin adhesion. Given these attributes, layer (C) is suitable for end-bearing or friction pile foundations, which can effectively transfer structural loads to stable substrata.

The groundwater analysis further complemented the geotechnical study, revealing aggressive chemical conditions in the subsurface environment. Chloride concentrations in the groundwater ranged from 800 to 53,900 ppm, while sulfate concentrations reached as high as 8,258 ppm. These elevated concentrations pose substantial risks to concrete structures, particularly those with steel reinforcement, due to the corrosive effects of chlorides and the expansive reactions induced by sulfates. To mitigate these risks, the study recommends using sulfate-resistant cement, installing proper drainage systems, and adopting advanced construction materials that resist chemical degradation.

The liquid limit (LL) values of soft and stiff clays in the study area demonstrate their relationship to ground deformation. Soft clays, characterized by high water content and LL values exceeding 50%, can reach up to 88%, making them prone to expansion and contraction with moisture fluctuations. These high LL values indicate the soil's ability to absorb significant water, increasing the likelihood of subsidence (Fig. 9). rewrite. High-plasticity clays retain their consistency under varying moisture levels but are prone to volume changes, such as swelling or subsidence, particularly during saturation and drying cycles. Conversely, low-plasticity clays, with plastic limit (PL) values of 23 and 28 (Fig. 10), transition quickly to a solid state as they lose moisture, contributing to their stability and resistance to deformation.

The plasticity index (PI), defined as the difference between the liquid limit and plastic limit, highlights soil behavior under stress. Higher PI values (46-55%) are observed in soft clay, which undergoes substantial deformation and is highly sensitive to moisture changes, often linked to subsidence. Meanwhile, lower PI values (12-18%) in stiff clays signify reduced plasticity and minimal de-

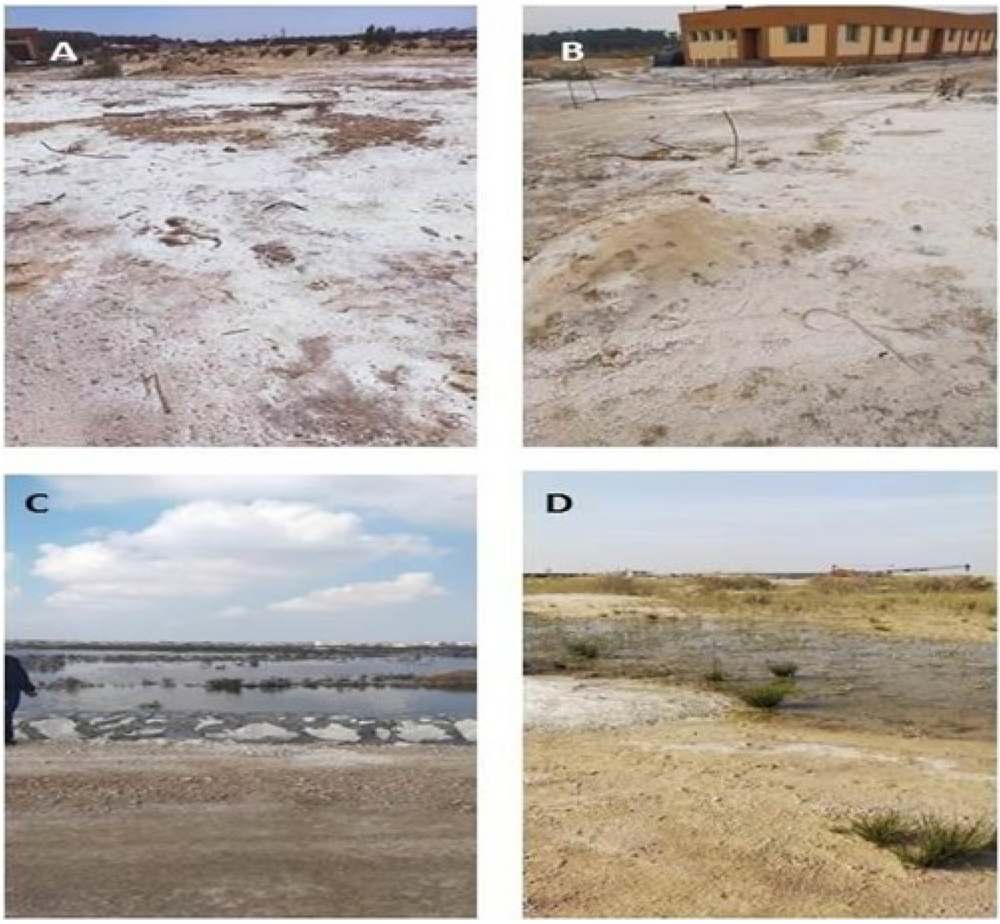

Figure 21: (A & B) Salinization and (C & D) water logging phenomenon in the different localities of the study area

formation, ensuring greater stability. The shrinkage limit (SL), representing the moisture content at which soil transitions from plastic to semi-solid, is another key parameter. Stiff clays exhibit high SL values exceeding 15%, indicating stability and reduced deformation.

The liquidity index (LI) predicts the soil's physical state at natural moisture content. Soils with LI < 0 are in a semi-plastic or solid-state (very stiff to stiff), 0 < LI < 1 indicates a plastic state (medium stiff to stiff), and LI > 1 represents a liquid state (very soft to soft). Consistency indices also provide insights into the firmness of soil. Chloride concentrations in the study area significantly affect construction materials, particularly by accelerating the corrosion of steel reinforcement in concrete. Borehole data reveals shallow salt deposits, primarily within the top 2 meters of soil, at depths ranging from 1.00 to 7.50 meters (Fig. 21). High chloride and sulfide salt levels exacerbate corrosion, leading to cracking and fragmentation of concrete covers, particularly under harsh environmental conditions such as high salinity, temperature, and humidity. These factors contribute to erosion problems in reinforced concrete, especially below ground level, due to direct exposure to groundwater and soil salts. Elevated salt levels in sandy and silty soils further aggravate structural swelling and soil instability. The findings support the importance of addressing these geotechnical and environmental factors when designing and constructing infrastructure in the study area.

6. Conclusions

This study presents a comprehensive geotechnical assessment of the El-Qantarah Gharb area, northwest Ismailia District, Egypt, to evaluate land stability and support sustainable construction. The investigation identifies critical challenges, including high soil compressibility, soft clay layers, and aggressive chemical conditions that pose risks to urban development. The findings indicate that the subsurface comprises three distinct soil layers, with the middle layer exhibiting significant geotechnical concerns due to its high-water content and low strength properties. Additionally, chloride and sulfate salts in soil and groundwater accelerate corrosion, threatening structural integrity.

To mitigate these risks, the study recommends targeted engineering solutions such as soil stabilization, deep foundation techniques, and improved drainage systems. Integrating geotechnical testing with advanced mapping techniques enhances the accuracy of ground stability assessments. The results provide essential guidelines for future construction projects in the study area, ensuring safety and resilience against geotechnical hazards.

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