

Land and Groundwater Assessment for Agricultural Development in the Sinai Peninsula, Egypt



El-Sayed Ewis Omran

Abstract Management of land and water resources in arid regions is vital and opens the way for new agricultural activities and growth of residential communities. The Sinai Peninsula suffers from water scarcity, limiting these types of development in a substantial way. This chapter seeks to evaluate the conventional land and water resources of Sinai, Egypt, using remote sensing (RS) and geographic information system (GIS) techniques. The future of land reclamation in Sinai will depend largely on its groundwater potential.

For major portions of Sinai, however, information on soil resources is limited. Generally, Sinai soils lack pedological features that indicate the soil development under arid conditions. El-Tina plain soils are derived from fluvial-lacustrine deposits with poorly drained, shallow water tables, with clayey or loamy texture and a salic horizon. Sandy soils extend through southern El-Qantara East and the surrounding areas of Lake El-Bardawil; these are considered Aeolian deposits without horizon differentiation. Wadi El-Arish soils are developed from fluvial deposits as influenced from limestone in the upstream. The Wadi El-Arish cultivated area extends from the confluence of Wadi Abu Gidi north to Wadi El-Bruk. The good agricultural land is located along the Wadi El-Arish main channel and its tributary. Wadi Al-Aqabah is also a good agricultural area but is smaller and narrower than the Wadi El-Bruk area.

The assessment of suitable agricultural lands must be associated with an evaluation of water availability. The availability of water is usually the most limiting factor when planning development in Sinai. In this study, areas with the most (soil and groundwater) potential for agricultural development are identified and mapped to inform decision-makers. The best locations for drilling groundwater wells were selected from the decision map, which was produced by utilizing the GIS technique.

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The iso-salinity contour map of the Lower Cretaceous (LC) aquifer shows a general increase of groundwater salinity toward the west and the north, with four salinity zones recognized. The importance of LC groundwater development is essentially related to the necessity of providing basic extension services (mainly water supply for domestic purposes and for small-scale irrigation agriculture) to the existing nomad tribes in central and South Sinai. Moreover, as the groundwater in the LC aquifer is moving down the gradient across the eastern border toward the aquifer discharge area along the Dead Sea-Gulf of Aqaba rift valley, it is desirable to use this water in Sinai before it gets naturally lost in the rift discharge areas. The salinity of the Upper Cretaceous (UC) carbonate aquifer is rather high in most of Sinai (3,200–10,870 ppm) with the exception of its central part along the El-Tih, El-Egma, and Shaira zone, where the groundwater salinity of the UC ranges between 1,100 and 1,500 ppm. Consequently, it is not recommended to rely on exploiting this aquifer for future development projects in Sinai. Favorable areas for groundwater development from the Eocene aquifer include the area between El-Hasana and El-Quseima and the area north of Nakhl and El-Thamad, where the aquifer hydrogeological setting is similar to the northeastern Sinai at Ain El-Guderrate and Ain Qedees. The groundwater quality in South Sinai is better and has more potential than that in the North Sinai.

Keywords Assessment, GIS, Groundwater, Land resources, RS, Sinai, Soil mapping

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1 Introduction

Egypt's land and water resources are finite and under pressure from a growing population as well as climate change. These resources are central to agricultural development, as well as degradation of quality and quantity [1]. After the creation of the El-Salam Canal and six new tunnels under the Suez Canal to connect the Sinai Peninsula to the Egyptian homeland, Sinai has received great attention in respect to future agricultural development. Management of land and water resources in Sinai is vital and will open the way for new residential communities and agricultural activities. However, water scarcity in Sinai is a major socio-economic crisis. Accordingly, many researchers have undertaken studies in Sinai.

Geofizika [2] carried out geophysical, hydrogeological, and soil investigations in the northern, central, and southwestern parts of Sinai to assess the water and soil resources for agricultural development plans. Issar et al. [3] estimated the Nubia sandstone aquifer storage capacity to be several hundred billion cubic meters, although only a small fraction of this water can be pumped. A large part of the water in this aquifer is fossil (paleowater), and dating using ^{14}C indicates an age range from 13,000 to more than 30,000 years old. Dames and Moore [4] carried out a comprehensive study of the water resources of Sinai based on the existing stratigraphic data from 69 wells and 57 columnar sections and hydrogeological data from 716 water points (wells and springs). However, the use of conventional techniques for land and groundwater management is often severely restricted by the lack of adequate data. Frequent and long-term monitoring by these traditional methods is expensive, laborious, time-consuming, and destructive [5].

Innovative technologies, such as remote sensing (RS) and geographic information systems (GISs), have an immense role to play [5–8]. RS techniques were used for land and water assessments over large and inaccessible areas. Visual image interpretation [9] can be used in monitoring the geographic distribution of land and water resources. Vegetation varieties can serve as an indication of approximate groundwater depth [10]. Robinson [11] used seven Radarsat-1 data images to outline the drainage systems, which permitted the definition of passageways and intermediate holding areas. According to Meijerink [12], microwave or radar images have several hydrogeological applications, which are associated with groundwater. Sultan et al. [13] incorporated optical and radar RS and geophysical data for groundwater exploration in the El-Qaa Plain, South Sinai, Egypt. AbuBakr et al. [14] utilized space-borne radar data to define the structurally controlled paleolakes along Wadi El-Arish. The former main channel course of Wadi El-Arish was depicted west with a length of 109 km of Gabal El-Halal. Three major paleolakes were defined in which the largest lake occupied an area of at least 337 km² and contained approximately 10.7 km³ of water when filled during pluvial phases. Kotb et al. [15] utilized the geophysical investigation procedures (magnetic, geo-electrical resistivity, and shallow refraction seismic) to recognize the groundwater aquifers in the southwestern Sinai. Khalil et al. [16] integrated geophysics, RS, and GIS for groundwater assessment, using a direct-current resistivity electrical technique. Mohamed [17] integrated diverse methods such as field geology, geophysics, and RS and GIS technologies for investigating groundwater potential at locations associated with major shear zones in the area. Abuzied [18] took a holistic approach to assessing groundwater locations in the Wadi Watir area, Egypt, based on RS (e.g., Radarsat 2000 and ground-penetrating radar) to define the favorable zones of groundwater occurrences.

It is argued that satellite data can be used if ancillary analysis is used to infer groundwater from surface expressions [19]. Therefore, the objectives of this chapter were to review previous investigations, to assess the land and groundwater information for Sinai, and to identify potential soil and groundwater resources for agriculture development. This assessment is based on information obtained from the following sources:

1. Literature review of documents, reports, and previous studies.
2. Hydrogeologic database of the 2,110 groundwater wells previously drilled in Sinai.
3. Data collected during field visits to several development sites in Sinai.

2 Description of the Sinai Peninsula

The Sinai Peninsula covers an area of approximately 61,000 km² [20]. The length of the Sinai coast is about 700 km; however, the total length of the Egypt's coast is about 2,400 km. Therefore, the ratio of the length of the coast of Sinai is about 29.1% of the total length of the coast of Egypt, or about one-third of the Egyptian coast. This spatial feature of Sinai is unique among the deserts of Egypt; it has three coasts surrounding it. It is triangular with its apex found by the junction of the Gulf of Aqaba and the Gulf of Suez in the south and its base by the Mediterranean Sea coastline between Port Said in the west and Rafah in the east (Fig. 1). The topography of Sinai has an elevation difference of 2,640 m between its highest point and its lowest point. The elevation of the northern part of Sinai ranges from 1,626 m above sea level to the lowest level at the Mediterranean Sea. The elevation of the southern part of Sinai ranges from 2,640 m above sea level to the lowest level at the Gulf of Suez and Gulf of Aqaba. Three-dimensional elevation of the ground is shown in Fig. 1 (left) as extracted from a digital elevation model (DEM) with point data at 30 m intervals.

Climate and soil are the two most important factors that determine the ultimate sustainability of rain-fed areas. In some cases, soil and climate factors will seriously limit the feasibility and practicability of soil reclamation. Fig. 1 (right) shows the average annual precipitation (mm) extracted from TRMM 3B42.v7A 3-hourly data acquired (1998–2013) over Egypt [17]. The annual rainfall falling over Sinai is for the most part under 200 mm in the far northern zone of Rafah and El-Arish and is less than 20 mm in the lower south of the area of Ras Mohammed. High mid-southern zones (the mountain region) have the yearly precipitation sums on range from 50 to 150 mm [17]. Meanwhile, the amount of annual rainfall falling on the southern Sinai heights between 50 and 75 mm. The central Sinai is viewed as the driest zone in the Peninsula, where the greatest yearly precipitation adds up to only approximately 30 mm. The average precipitation sum annually ranges from 80 to 100 mm. Despite the lack of rain in Sinai, in general, it is the most abundant rain compared with the eastern and western desert. Sinai receives a great deal of solar radiation and wind. However, the risk of sand dunes creeping in Sinai is much lower than in the Western Desert, which has the Great Sand Sea.

Sinai in relation to national security has the highest priority over all other deserts of Egypt, including the Western Desert. A special project for national security of any state that does not bear in mind the physical cost and thus development and reconstruction of Sinai is underway. Most of the Egyptian petroleum exist in the Gulf of Suez. It is also rich in mineral wealth, such as manganese, kaolin, marble,

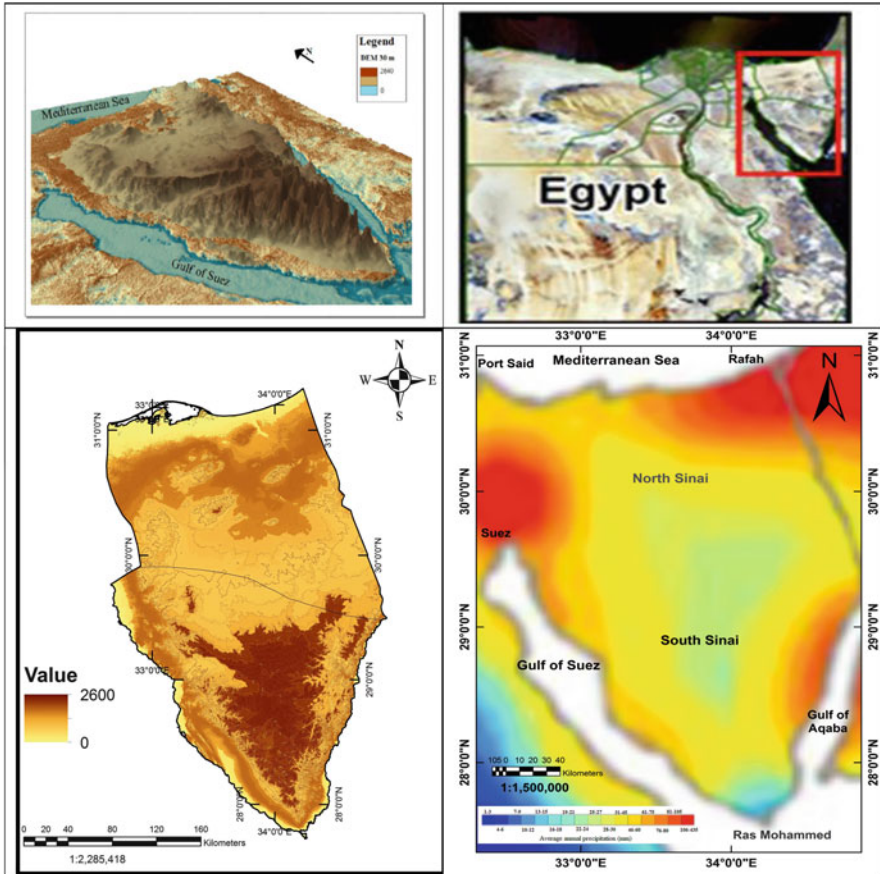


Fig. 1 3D view map created from a digital elevation model representing Sinai topography (left). Average annual precipitation, mm (right) extracted from TRMM 3B42 (v7). A 3-hourly data acquired (1998–2013) over Sinai [17]

copper, gypsum, black sand, and white sand. Since Sinai is close to urban centers of the Delta and the Suez Canal cities, it is a prime area for development. Also, the existence of a global navigation channel of the Suez passageway, on the eastern bank of the Canal and East Port Said, and the consequent ease the export of agricultural and industrial products. Drilling of the new Suez Canal will contribute to the economic sector as well as open the way for many investments. Six new tunnels under the Suez Canal to allow cars and trains to pass are additionally planned. Development in the region will include the El-Salam Canal project, which will increase irrigation by roughly 400,000 acres in northern Sinai [21]. Additionally, there already exists the presence of large tracts of agriculturally suitable land.

3 Geological and Geomorphologic Features

Groundwater resources and watershed areas of Sinai are greatly controlled by the associated geological formations. Therefore, it is necessary to provide general foundation knowledge about these formations. The general geology of Sinai was outlined by Said [22] and Shata [23]. Geologically, the Peninsula is divided into a number of distinct zones. In the north, a strip of loose sand and dunes run inland from the coast for 16–32 km and afterward level off to a flat, barren plain. This gravel and limestone plain proceeds for almost 241 km, ascending at its southern extremity to the El-Tih plateau. From this level toward the southern tip of Sinai, it is intercepted by a jagged system of mountains and wadis. Figure 2 (left) demonstrates the fundamental geology for Sinai.

Paleozoic rocks overlay the Precambrian basement in the southwestern Sinai [25, 26]. Mesozoic strata crops in the northern Sinai, where an almost complete sequence from Triassic to Cretaceous is known [27], create a subsurface section achieving an exceptionally gigantic thickness (955 m for Jurassic rocks) at Ayun Musa. A standout among the most imperative Mesozoic rocks is the Nubian sandstone of LC, which represents the main water-bearing unit in the region. It achieves the highest thickness at around 500 m, while at central Sinai it has a thickness of 70–130 m [26]. Sinai was classified geologically into 15 formations, e.g., basalt, carbonate rocks, granite rocks, limestone and phosphate rocks, metamorphic rocks, and sand dune volcanic rocks (Fig. 2).

Soil resources of Sinai are greatly affected by the associated landform types. Sinai was classified into six landform units [28], which are highlands (southern mountains, central tableland, El-Egma tableland, and northern folded blocks); northern Piedmont plain; western outwash plain (Feiran, Sidri-Baba, and Sudr-Abu Suweira plains); morphotectonic depressions (El-Qaa Plain, Wadi Araba, El-Saghir, Bitter Lakes, Lake Timsah, the area between El-Maghara and Risan Aneiza, and the area between Gabal Yelleq and El-Halal); northern coastal plain; and sand dunes. Geomorphologically, the Peninsula includes seven regions (Fig. 2, right). The southern elevated mountain district involves the southern part of Sinai assuming a triangular shape with its apex at Ras Mohammed to the south. The central plateau district involves the central part of Sinai as two principle quests: El-Egma to the southwest and El-Tih to the north [29]. A hilly region lies to the northeast of Sinai. It is gently sloping toward the northeast and is characterized by local isolated hills. Likewise, a coastal district of gently undulated surface is set apart by sand ridges of thick sandstones. Muddy and marshy land districts occupy the shorelines and some lakes (e.g., Lake El-Bardawil, Timsah Lake, and Bitter Lakes). The southern part of Sinai is occupied by the high mountain complex, such as the Gabal Catherina (2,641 m above mean sea level – amsl), Um Shomar (2,586 m amsl), and Serbal (2,070 m amsl). Toward the north of this mountain mass occurs the great El-Egma limestone plateau, which inclines from more than 1,000 m downward the Mediterranean Sea. The southern mountains are highly dissected by watersheds draining either to the Gulf of Suez or to the Gulf of Aqaba,

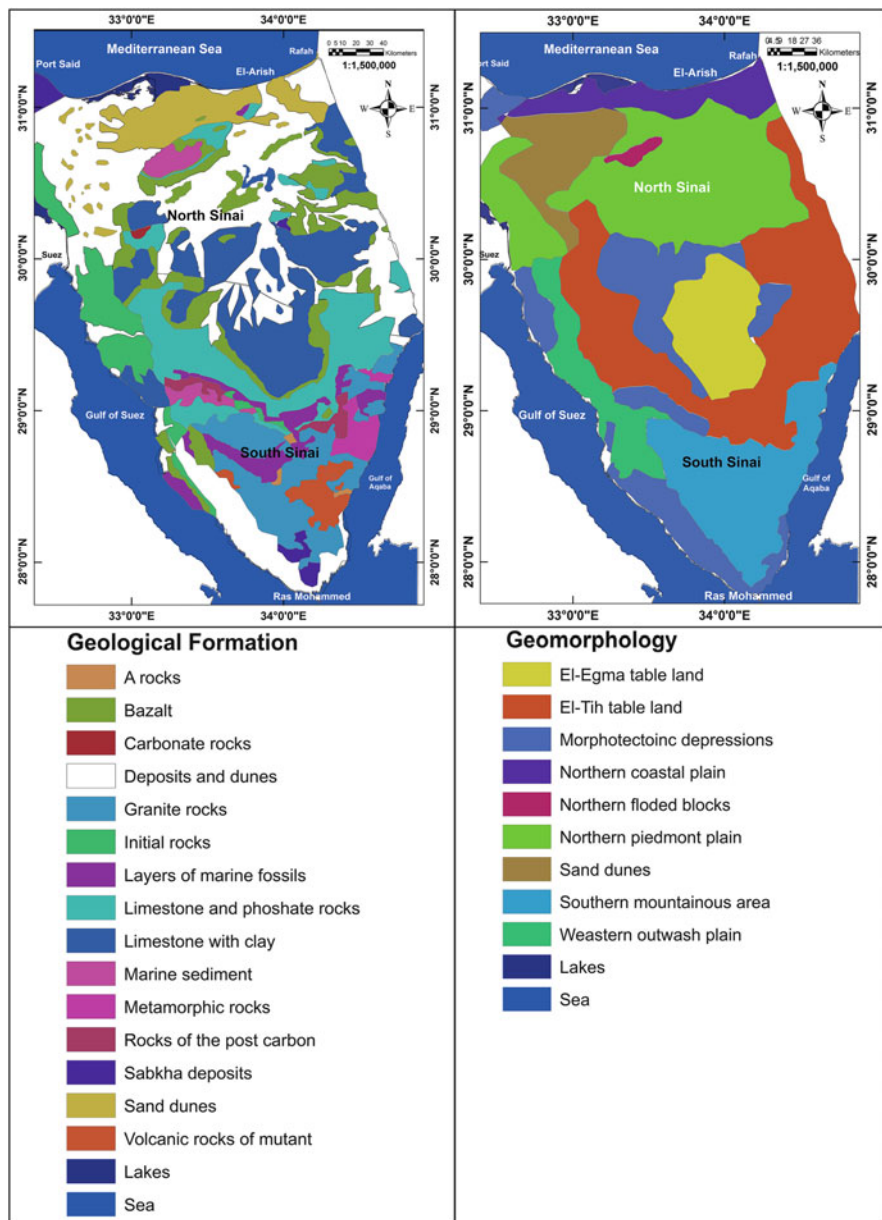


Fig. 2 The main geological (*left*) and geomorphological units (*right*) of Sinai [24]

though the majority of the drainage basins of the northern plateau are debouching northward to the Mediterranean Sea (Fig. 2). Two gulfs represent two grabens, which continue along the Suez Canal and Wadi Araba.

4 Case of Studies

4.1 *Groundwater Resources in the Sinai Peninsula*

Water resources in Sinai are dependent on the following:

- Rainfall: The northern strip of Sinai receives the maximum amount of rainfall during winter time (200–300 mm/year), and this amount decreases southward (25 mm/year).
- Springs: Few springs were discovered in North and central Sinai, and only two springs are of particular importance (Ain El Gedeirat and Ain Qedees).
- Nile water mixing with drainage water, conveyed by the El-Salam Canal.
- Existing groundwater supplies.

4.1.1 Large-Scale Groundwater Mapping

The existing deep aquifer systems in Sinai derive their characteristics from past geological events and structural movements and from regional and local recharge conditions occurring over the past centuries. The results of 2,110 deep drilling wells (Fig. 3) for oil and groundwater investigation in the different parts of Sinai show that seven deep lithostratigraphic units serve as the primary deep aquifers in Sinai. These include Pleistocene coastal, Quaternary alluvial, Middle Cretaceous, Eocene, Miocene sandstone, crystalline, LC sandstone, and Nubian sandstone.

Miocene units serving as aquifers are sandstone, belonging to the Lower Miocene Gharandal Group, and sandstone and grits forming a thin basal Miocene unit. These units occur on the west side, along the Gulf of Suez, in the Bitter Lakes area, Wadi Feiran, and the coastal foreshore area (south of Rafah and El-Magdaba). The results of testing the Miocene sandstone in the northern coastal foreshore area at well Misri-1 (well no. 2022) showed that its groundwater is of poor quality (salinity of 10,000 ppm). At the Habashi oil exploration well (well no. 2045), east of the Bitter Lakes, Miocene sandstone units produced water with a salinity of 1,020 ppm. South at Ras Misalla, wells tapping basal Miocene yielded water with a total salinity ranging from 2,600 to 5,000 ppm. Further south, aquifer groundwater salinity progressively increases to reach 380,000 ppm at well Lagia-2 Downstream of Wadi Feiran. At the Petropel Co. well-field, wells tapping Miocene sandstone units (well no. 2103) yield water with salinity ranging from 3,900 to 5,300 ppm [4].

The Eocene fractured carbonate aquifer is represented by limestone and marl. It extends outcropping from El-Tih and El-Egma plateaus in central Sinai to cover

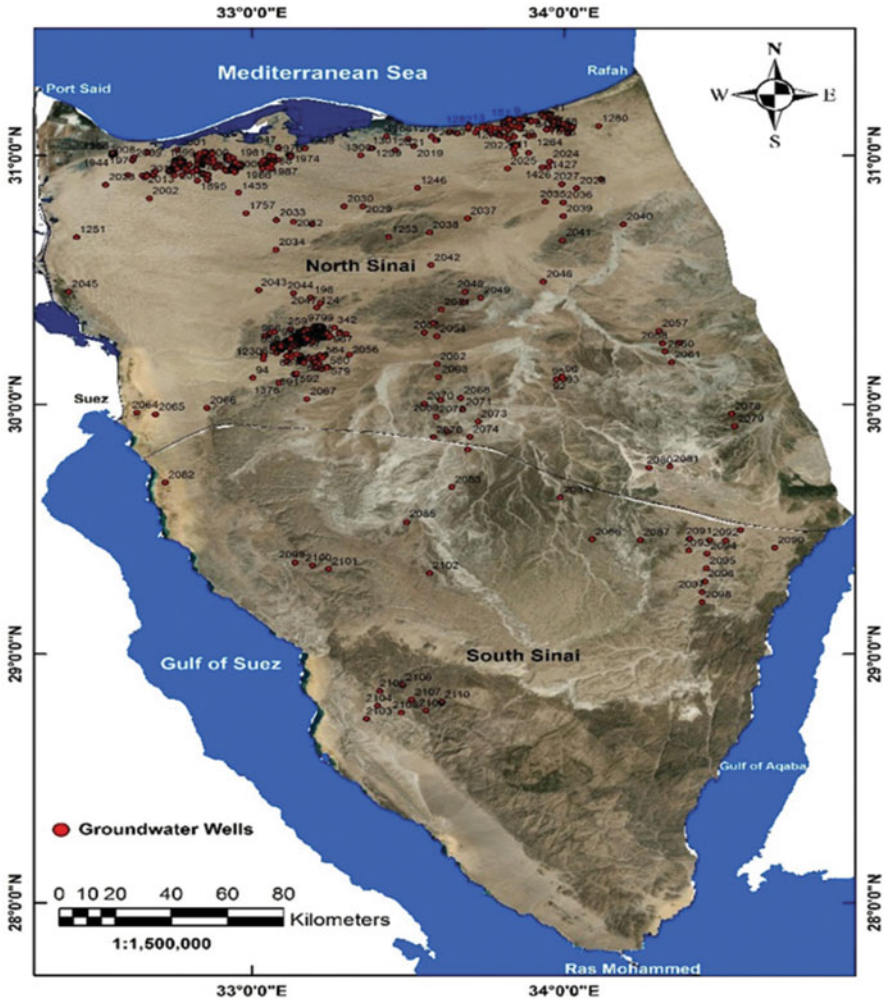


Fig. 3 Locations map of 2,110 groundwater wells in Sinai

vast areas northward to the line between Risan Aneiza and Gabal El-Maghara and attains a thickness of 200–360 m. A characteristic of the Eocene aquifer, developed in the limestone, is the shortage of groundwater at the basal part of the limestone underlain by the impervious Paleocene Esna shales. This is clearly demonstrated at Ain El-Guderrate and Ain Qedees in El-Quseima area, which issues from the Eocene limestone and discharge water at daily rates of 1,500 and 480 m³ with a total salinity of 1,440 and 1,200 ppm, respectively. Well located northeast of Ras Sudr (well Abu Qiteifa 1) yielded water from the Eocene rocks with a salinity of 1,990 ppm, which increases progressively to reach 310,000 ppm at Lagia area south of Ras Sudr [4]. All other wells tapping the Eocene aquifer north of the zone between Gifgafa and El-Quseima yielded water with a total salinity ranging from

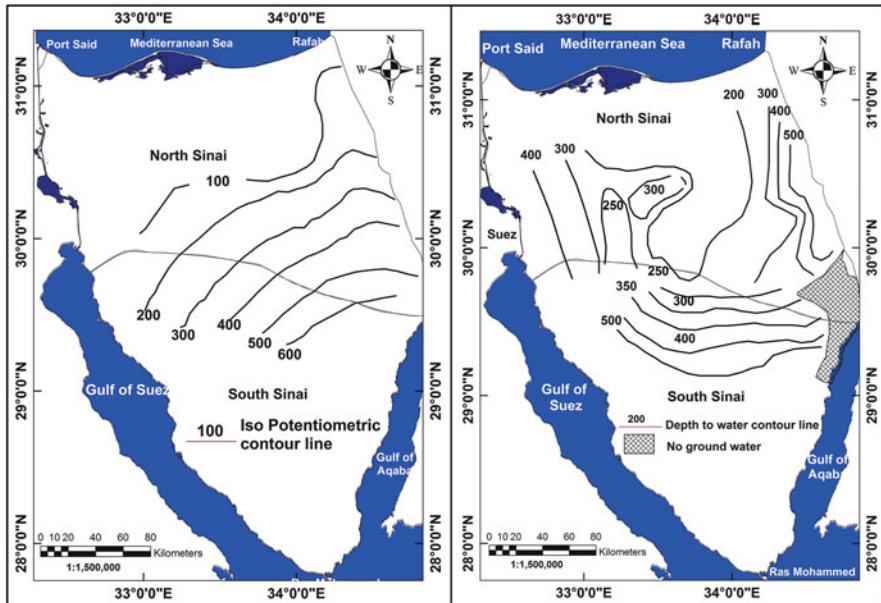


Fig. 4 Potentiometric surface map of the Upper Cretaceous aquifer (left) and depth to groundwater in the Lower Cretaceous aquifer (right) in Sinai [30]

8,500 ppm to reach 19,000 ppm at El-Mowaleh well (well no 2040). Favorable areas for groundwater development from the Eocene aquifer include the area between El-Hasana and El-Quseima and the area north of Nakhl and El-Thamad, where the aquifer hydrogeologic setting is similar to that prevails in northeastern Sinai at Ain El-Guderrate and Ain Qedees.

Data obtained from test wells tapping the Upper Cretaceous (UC) carbonate aquifer in Sinai indicate that the depth to water ranges from 85 m at well Shaira-2 (well no. 2092) and 180 m at El-Hasana well (well no. 2050) to 40–90 m at Wadi El-Amro/El-Magdaba areas in the North Sinai [30]. Figure 4 shows the potentiometric surface map of the UC aquifer. The recharge of the UC aquifer occurs through the direct infiltration of rainfall or from surface flow on its exposed areas. The estimated rate of recharge to the UC aquifer is expected to be 190,000 m³/day [4]. However, the LC aquifer was recharged in the South Sinai area approximately 20,000 years ago and the groundwater quality in South Sinai is better and has more potential than that in northern Sinai. The LC sandstone aquifer is the most promising aquifer in terms of its potential capacity and water quality. The storage capacity of the aquifer is estimated to be 320 bcm. Figure 4 shows the depth to water from the groundwater surface in the LC aquifers. It indicates that at the north of the Ragabat El-Naam fault, the depth to water is about 200 m below the ground (mbg) around the Nakhl- El-Hasana road and gets deeper eastward and westward to reach 300–400 mbg. South of the fault, the depth to water in the LC aquifer in

El-Tih-El-Egma plateau areas ranges between 300 mbg in the northern part and 400 mbg near the southern outcrops of the Malhah formation.

According to El Osta and ElKashouty [31, 32], the groundwater in the southern Lake El-Bardawil (northern Sinai) is tapped from different water-bearing formations, which are Holocene and Pleistocene. The Quaternary aquifer (Holocene and Pleistocene) thickness varies from 150 m (Bir El-Abd well) to 330 m (Qatia-1 well) and rests directly on the Pliocene clay. The Holocene sand aquifer is developed along the coastal plain from Gilbana to El-Massaid along a distance of about 150 km with an average width of 20 km in the form of elongated sand dunes (coastal) or sand sheet (inland) or saline sand (sabkhas). This aquifer wedges out at El-Tina plain until it vanished. Groundwater of the Holocene aquifer exists under a free water table condition, where depth to water ranges from 2 to 9.92 m below ground surface. However, this depth is very near to the ground surface and close to the seashore. In El-Tina plain, the groundwater comes very near to the ground surface. The depth to water varies from less than 1 m in the north to about 2 m in the south because of the presence of cap rock (30 m clay). To the southern part of El-Tina Plain (East El-Qantara), the Pleistocene aquifer is about 170 m thick, and it rests directly on the Pliocene aquiclude, where both the Holocene and Pleistocene aquifers are partially hydrogeologically interconnected [31]. In the Qatia area, the Pleistocene aquifer attains about 300 m in thickness due to the presence of a graben structure.

4.1.2 Small-Scale Groundwater Mapping

The area of El-Sheikh Zuweid-Rafah was studied by many authors [33–35]. It received many of the studies since the 1950s and so far in the fields of geology, hydrology, geochemistry, and soil. It was found that the aquifer capacity of El-Sheikh Zuweid-Rafah area is limited and depends mainly on two sources. First is the direct rainfall, which ranges between 200 and 300 mm/year, and second is the water leakage from the floods that hit the region from the south via the streams of some valleys. The sand dunes stretching along the coastline are considered a major source to feed the aquifers in the area through vertical leakage. The drilled wells are concentrated in the narrow coastal strip and noted a high density of wells around the towns of El-Sheikh Zuweid and Rafah. The groundwater levels in the El-Sheikh Zuweid-Rafah area ranged from 0.5–1.5 to 4.5–6 m (Fig. 5). The winter crops are important to avoid groundwater salinity in the summer, which is due to seawater intrusion in the area affected by falling groundwater levels. This is illustrated in the southern dune areas and to the existence of underground water with salinity up to 7 g/l, which invades region from the south via the main fault of Lehefin. All of this has an adverse impact on the environment, which leads to soil salinity.

At the El-Qaa Plain area, the flow direction of the main channels was determined using integrated optical and radar RS and geophysical data for exploring groundwater [13]. The hydrological investigations of the digital elevation model (DEM) extracted the drainage network pattern to elude the relationship between

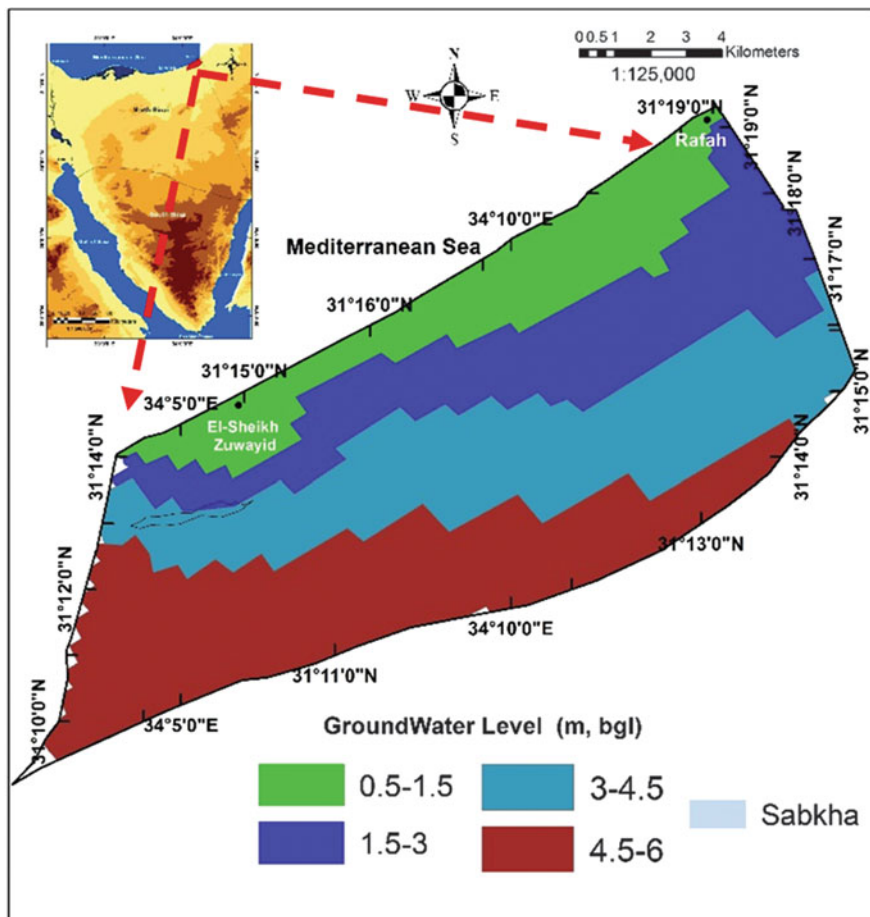


Fig. 5 Groundwater level map for the El-Sheikh Zuweid-Rafah area

paleochannels and structural elements. The water table maps developed from interpreted geo-electrical data show that the elevation of the water table declines from the east and north toward the west. In the El-Qaa Plain, Sultan et al. [36] report an investigation of the Quaternary aquifer utilizing gravity, magnetic, and geo-electric surveys. One hundred twelve gravity and magnetic stations have been measured and interpreted. The region is dissected by faults with orientations consistent with the gulfs of Suez and Aqaba and the Nile valley. Groundwater data demonstrated an E–W flow and an increase in salinity toward the Gulf of Suez. The variation of resistivity with depth below the ground surface was derived utilizing the vertical electrical soundings (VES) and associated with the access to geological information. The VES interpretation results were utilized to build iso-resistivity, depth maps, and isopach maps for the upper part of the Quaternary aquifer. The iso-resistivity map (Fig. 6a, left) demonstrates that the true resistivity decreases from east to west.

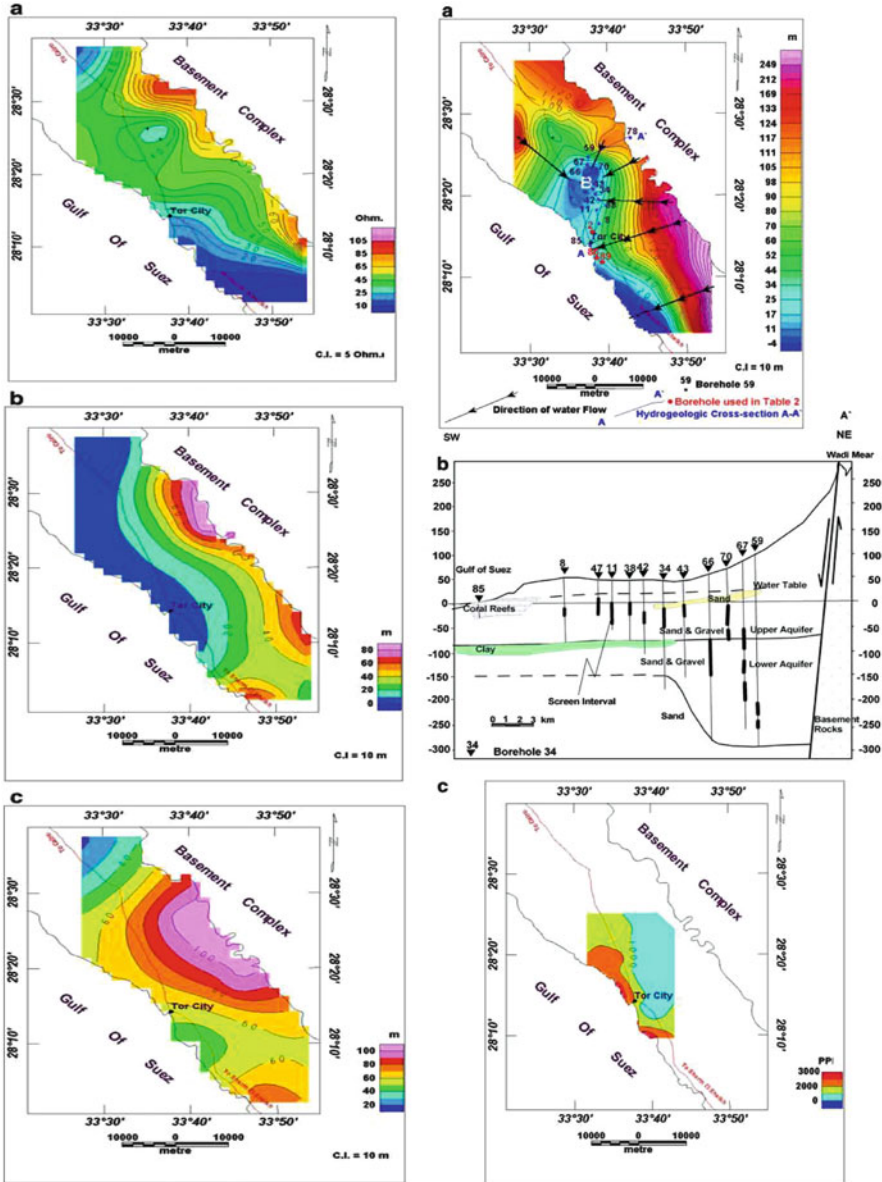


Fig. 6 (Left) (a) an iso resistivity map, (b) depth map of the aquifer, (c) isopach map of the upper unit of El-Qaa aquifer; and (right) (a) water table map, (b) Hydrogeological cross-section A-A' [37], (c) salinity map [38]

The eastern part is close to the wadis, which dissects the basement rocks and represents the recharge zone. This is reflected in the increased resistivity (55–90 Ω m) at the freshwater-bearing zone compared with the higher resistivity because of salinization of groundwater toward the west and south. Figure 6b shows that the depth of the aquifer increases gradually eastward from a few meters to 80 m. The isopach map (Fig. 6c) indicates the thickness of the upper unit of the aquifer (the freshwater component consisting of gravel and sand), which increases gradually from 20 m in the north to 100 m in the eastern part of the central area.

The water table map (Fig. 6a, right) indicates that the elevation of the water table decreases from the east and north toward the west. The water table is at around 10 m depth at zone B. The water flow direction is southwest, toward the Gulf of Suez. Hydrogeological cross section A–A' incorporates a group of boreholes situated in the central part of the area and begins from A at the Gulf of Suez to A' at Wadi Mear (Fig. 6b). The aquifer comprises of an upper and lower horizon, with thicknesses diminishing from east to west. An ordinary fault is apparent between the basement rocks and the Quaternary aquifer. The central part of the region (Fig. 6c) has fresh and brackish water with salinity values ranging from 500 to 3,000 ppm.

Abu Zenima groundwater was studied through an integrated geophysics, remote sensing, and GIS assessment [16]. A direct-current (DC) resistivity electrical technique was applied in Abu Zenima area to determine and evaluate the main aquifer. The first surface layer was characterized by variable apparent resistivities (70–955 Ω m) and corresponds to Plio-Pleistocene and recent surficial deposits: silt, sand, and gravel sediments. The resistivity value variations could be attributed to areal variations in the grain size distribution and variation in the gravel-sand-silt-clay ratios. The thickness of this layer ranges between 1 and 8 m. A second layer represents the fresh to slightly brackish water-bearing formation. The layer resistivity reaches between 36 and 71 Ω m corresponding to Plio-Pleistocene and recent silt and sandstone. The layer thickness ranges between 10 and 66 m (Fig. 7). A third layer is characterized by very low resistivity (2.2–5 Ω m). Comparing to Miocene evaporites (marl, gypsum, and anhydrite), the low-resistivity estimations of this layer are because of the salt seawater intrusion and in addition to the dissolution of the Miocene evaporites. The thickness of this layer ranges from 162 to 405 m. A base layer was characterized by very low resistivity extending between 3.1 and 3.8 Ω m and is most likely Miocene limestone.

At El-Tor area, Kotb et al. [15] distinguish the groundwater aquifers between latitudes 27°52' and 28°05' N and longitudes 33°55' and 34°05' E in southwestern Sinai utilizing the distinctive geophysical exploration methods (magnetic, geo-electrical resistivity, and shallow refraction seismic). The outcomes demonstrate that the maximum depth to the basement surface is 180 m. The structure elements, which are influenced in this area by various typical faults, have different patterns and directions, which make two grabens confined by one horst. Tariff Sandstone bed recorded as water-bearing formation and the basement ridge gates in the Gulf direction are not capable to pass the groundwater from the area to the Gulf of Suez. The basement ridge gates in the Gulf direction are not capable to pass the groundwater from the area to the Gulf of Suez. This region must be created by

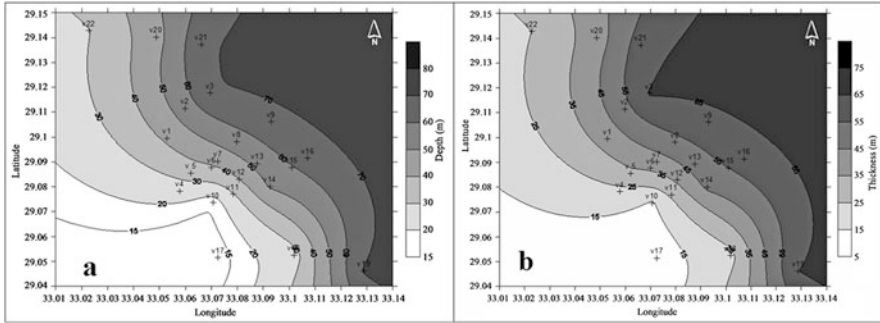


Fig. 7 Contour maps showing (a) the depth (m), (b) the thickness (m) maps of the fresh water-bearing layer. The thickness of fresh to slightly brackish aquifer ranged from 10 and 66 m. The aquifer thickness increased toward the northeastern part of the area with resistivity ranges from 36 to 71 (Ω m), which increased toward the northeastern part

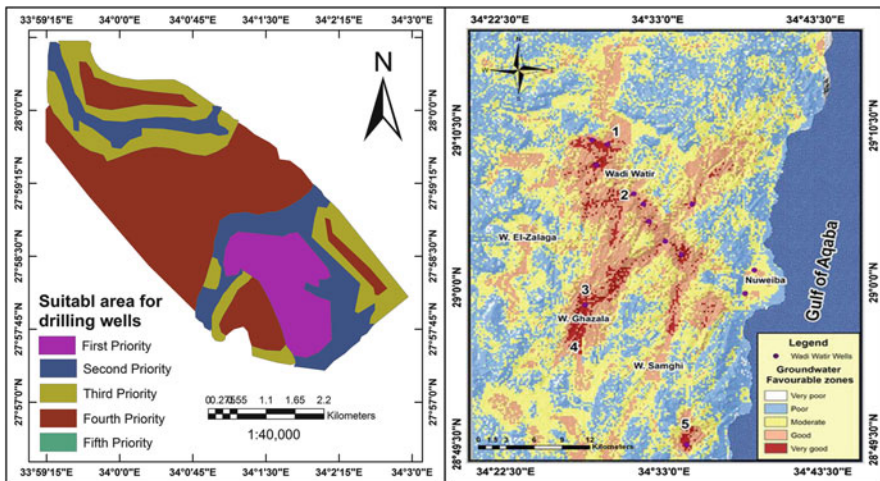


Fig. 8 Reliable and less cost decision map for drilling water wells in El-Tor area (left). The groundwater potential map of the Wadi Watir area (right)

establishing farms and foundations, which are suitable since it is located strategically between El-Tor city (capital of South Sinai) and Sharm El-Sheikh (the first touristic city in the region). The suitability map for drilling water wells (Fig. 8) outlines five priority classes. These classes are based on depth to water, which defines the reliability, and are less costly for drilling water well. The first and second priorities are concentrated mostly in the southwestern depression (graben).

In Wadi Watir area, Abuzied [18] took a holistic approach to assessing groundwater locations based on topographical, geomorphological, and geological factors to define the favorable zone of groundwater occurrences. These layers include lithology, lineaments, faults, landforms, elevation, and slopes, which were prepared

from different data sources including SPOT5, Radarsat 2000, Alos PALSAR, SRTM, and ground-penetrating radar. Multisource data are the most suitable technique to extract the structural elements and textural characteristics of the alluvial deposits. The final groundwater potential map (Fig. 8) points to the promising localities for groundwater accumulations, which are mostly located at highly permeable areas, which are found at the downstream of Wadi Watir, Wadi El-Zalaga, Wadi Ghazala, Wadi Samghi, Wadi Nekhil, and Wadi Sada El-Beida. Most of the wells in the downstream area of Wadi Watir are found in the low to moderate elevated zones tapping alluvial aquifers. Low elevation, low drainage density, high lineament density, and gentle slope nominate highly probable good groundwater source. The generated map was checked using different sources including field investigations, previous work, and high spatial resolution satellite images. Hence, the generated map can be used in the future as a preliminary reference map to select sites of promising wells and in land-use planning for groundwater exploration.

In the Saint Catherine and Wadi Feiran area, Mohamed [17] integrated different methods such as field geology, geophysics, remote sensing, and cost-effective GIS for investigating groundwater potential locations that are associated with major shear zones (Fig. 9). The shear zones within the basement complex were delineated using false color images that were generated from Landsat-8 band, high spatial 1 m resolution Orb-view3 image, Google Earth images, hillshade, and band ratio images. The spatial and temporal precipitation events over the basement complex were then identified from TRMM data. Observations extracted from temporal change in backscattering values in radar (Envisat ASAR radar scenes) were used to identify the water-bearing shear zones. Finally, field observations and very low frequency (VLF) investigations were then applied to test the validity of the satellite-based methodologies for locating targeted aquifer types and for refining the satellite-based selections. Many wells in the Saint Catherine area were found along the shear zones especially at the intersection of two or more shear zones or at the intersection of the shear zone and fault system. The area is generally affected by two main sets of shears: NNW-SSE and NE-SW. Groundwater in the Saint Catherine area exists in both the shared basement rocks and the Quaternary alluvial deposits.

4.1.3 Priority Areas for Groundwater Development in Sinai

The future of land reclamation in Sinai will depend largely on its groundwater potential. The best locations for drilling groundwater wells were chosen from the decision map, which was produced by utilizing the GIS technique.

The iso-salinity contour map (Fig. 10, left) of the UC aquifer indicates a general trend of salinity, which increases toward the north, with the lowest values of 1,100 and 1,500 ppm observed at Shaira well (well no 2092) and Yerqa Spring (located in the western part of El-Tih), respectively. The highest salinity (5,628 ppm) was observed at the El-Bruk well (well no 2062) and 10,870 ppm at El-Magdaba well

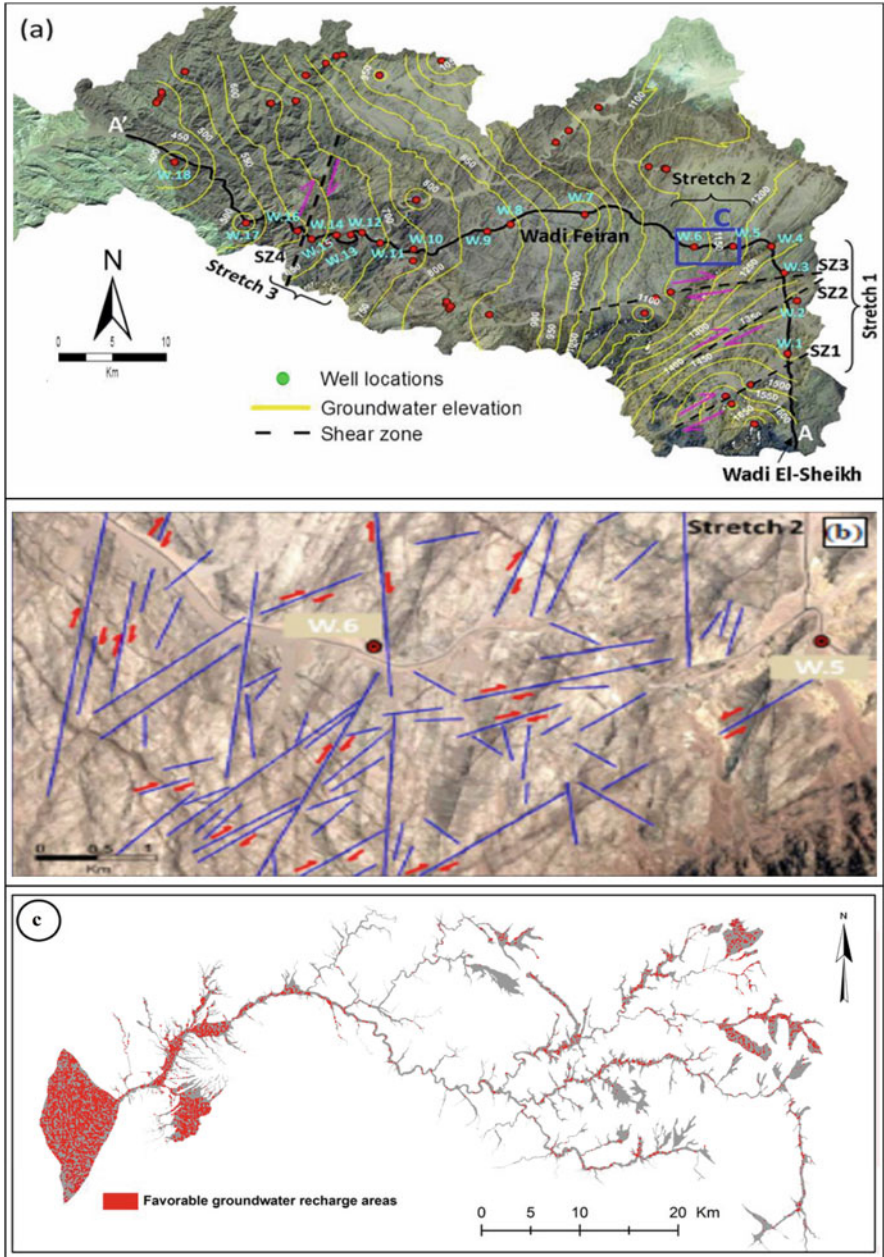


Fig. 9 Change in groundwater flow direction related to the structural control of Wadi Feiran. (a) Landsat TM image over the Feiran watershed showing the approximate groundwater levels (yellow contours), and the regional groundwater flow direction; also shown are locations of traverse A–A' along Wadi El-Sheikh and Wadi Feiran, sections (stretch 1, 2, and 3) along traverse A–A' where shallow groundwater levels were reported, well locations along traverse A–A', and

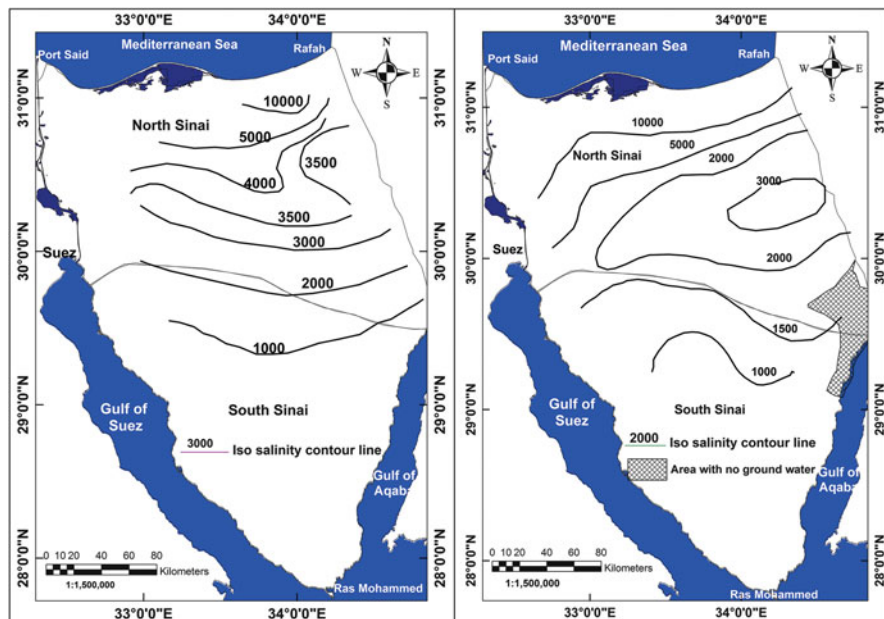


Fig. 10 Iso-salinity contour map of Upper Cretaceous aquifer (*left*) and of Lower Cretaceous aquifer (*right*) in Sinai [30]

(well no 2025). Although the UC aquifer contains relatively low groundwater salinity in the El-Tih-El-Egma plateau area, the observed salinity at Wadi Gharandal well (well no 2099, same aquifer) was reported to be about 5,000 ppm. The reason may be attributed to the fact that the Cretaceous aquifer in Wadi Gharandal is hydraulically separated from the other part of the aquifer in El-Tih-El-Egma plateau. Figure 10 (right) represents the iso-salinity contour map of the LC aquifer. It shows a general increase of groundwater salinity toward the west and the north, with four salinity zones.

Zone I has a groundwater salinity of <1,500 ppm. It occupies the area of the aquifer located south of the main road Joining Sudr El-Heitan, Nakhl, and Ras El-Naqb. The recorded aquifer salinities of the Sudr El-Heitan, Nakhl, Wadi Feiran, Shmra and the Gharandal wells are 1,246, 1,600, 800, 1,500 and 1,330 ppm, respectively. Test drilling in the LC aquifer in the southwestern part of the El-Egma plateau (well no 2102) indicated a salinity of 500 ppm. Zone II occurs to the east of the line joining Sudr El-Heitan – Nakhl – El-Bruk – El-Menashereh – El-Hassana – El-Quseima, where the aquifer salinity ranges between 1,500 and

Fig. 9 (continued) the distribution of shear zones (SZ1, SZ2, SZ3, and SZ4). (b) Enlargement of area covered by blue box in (a) (stretch 2) showing the distribution of dike swarms (dark streaks) that are intensively displaced by dextral faults (outlined by blue lines). (c) Map showing groundwater recharge areas

2,000 ppm within this zone and in the vicinity of the folded structures at El-Bruk, Gabal El-Menashereh and Gabal Arif El-Naga. Salinity appears to be high due to the possible groundwater stagnancy around these highly elevated structures allowing for more dissolution of salts. This occurs at El-Menashereh well number 2054 (2,973 ppm) and Arif El-Naga well number 2061 (3,008 ppm). Zone III is characterized by salinities ranging between 2,000 and 5,000 ppm. It occupies a narrow area surrounding Zone I and extends to Ayun Musa area in the west and Gifgafa north of Gabal El-Halal in the north. Zone IV occurs to the north of Zone III and has salinities in the LC aquifer ranging between 5,000 and 10,000 ppm. Zone V occupies the northern and western parts of Sinai where the LC aquifer has been deeply buried by faulting. The rather high salinity values in this zone (14,000 ppm at well no 2024, 19,000 ppm at well number 2023) may be due to the ineffective flushing of the formation's saline water by the recharging meteoric water due to the interruption of the groundwater flow paths by block faulting.

Along the eastern coast of the Gulf of Suez, the salinity of the LC aquifer is high (227,000 ppm at Ras Sudr well no 2082) because it is deeply down-faulted and the formation water has not been diluted or flushed by groundwater inflow from the east. The exception to this is the aquifer discharging area at Ayun Musa where groundwater salinities of 2,536–3,180 ppm were observed at wells numbers 2064 and 2065. This could be attributed to the fact that the aquifer occurs at a shallow uplifted block and it is possible that hydraulic continuity occurs with the aquifer in the east. Because of its wide extension, considerable storage and good water quality, the Cretaceous aquifers are considered to be of high potential, and therefore it has the priority areas for deep groundwater development. The salinity of the UC Carbonate aquifer is rather high in most of Sinai (3,200–10,870 ppm) with the exception of its central part along Gabal El-Tih, El-Egma, and Shaira zone, where the reported groundwater salinity of the UC ranges between 1,100 and 1,500 ppm in this zone [30].

Although the recorded depth to water is relatively shallow (85 m below ground level, bgl, at well Shaira-1), the aquifer productivity proved to be very poor (well specific capacity 0.08 m³/h/m). Consequently, it is not recommended to rely on exploiting this aquifer for future development projects in Sinai. The priority areas for the development and utilization of groundwater of the LC aquifer based on its potentiality are shown in Fig. 11 and as follow: first priority is found in Western Sinai (Downstream of Wadi Feiran and Wadi Gharandal) and in Central and South Sinai (El-Minshera Nakhil, El-Burk, Wadi Watir). Second priority is found in El-Quseima Arif El-Naga El-Kuntilla, El-Thamad, Sudr El-Heitan. Third priority is found in El-Tih plateau, south of Sudr El-Heitan, El-Thamad road, Shaira. Fourth priority is found in Ayun Mosa, Gifgafa, El-Hasana, Talat El-Badan, El-Hala, Um Shitan, Wadi El-Amro, El-Kherim.

The areas located north of Gabal El-Maghara, Gabal El-Halal and El-Ouga, and along the eastern coastal zone of the Gulf of Suez between Ras Sudr and Ras Mohamed, where groundwater salinity ranges from 5,000 ppm to more than 200,000 ppm, are not recommended for the development of the LC groundwater. The identified deep groundwater development priority areas should be considered

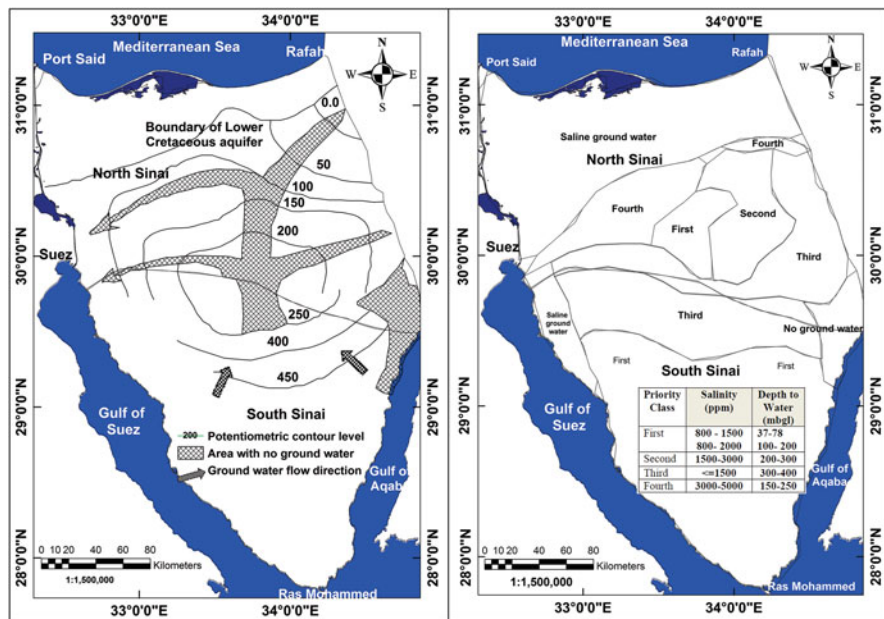


Fig. 11 Potentiality surface map of Lower Cretaceous aquifer (left) and a map of development priority areas of Lower Cretaceous aquifer (right) in Sinai [30]

in the evaluation of their sustainable potentials, applying groundwater modeling and an assessment of the economics of their use for different sectors should be done.

The LC Malhah water-bearing formation is considered the main aquifer system in the central and southern parts of Sinai. The importance of LC groundwater development is essentially related to the necessity of providing basic extension services (mainly water supply for domestic purposes and for small-scale irrigated agriculture) to the existing nomad tribes in central and South Sinai. Therefore, they will establish permanent settlements and not migrate north to EI-Salam Canal project development areas. Moreover, as the groundwater in the LC aquifer is moving down gradient across the eastern border toward the aquifer discharge area along the Dead Sea-Gulf of Aqaba rift valley, it is desirable to use this water in Sinai before it gets naturally lost in the rift discharge areas.

Elewa and Qaddah [39] integrated Enhanced Thematic Mapper Plus (ETM+) images, GIS, a watershed modeling system, and weighted spatial probability modeling (WSPM) to recognize the groundwater potential zones in Sinai, Egypt. Validation utilizing measured well yield data was performed to check the WSPM results. The resulting map (Fig. 12) shows that the diverse geographic locations are appropriate for groundwater storage with various magnitudes and potentialities, yet the overall groundwater potential is of the moderate class.

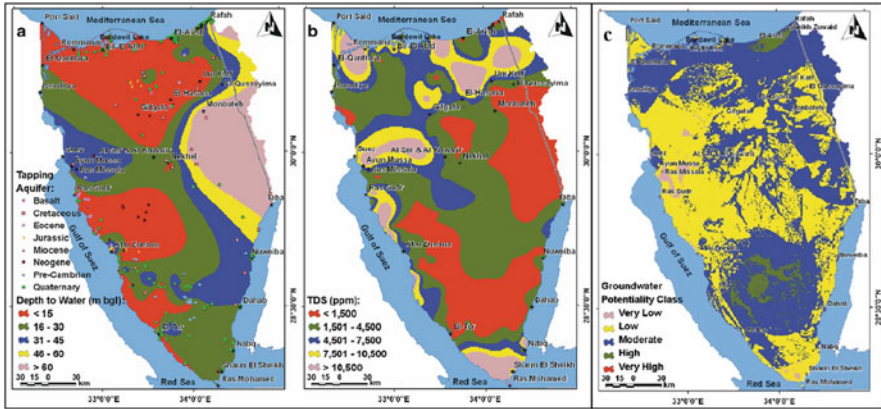


Fig. 12 Groundwater depth (a), salinity (b), and potentiality map (c) of Sinai [39]

4.2 Land Resources Mapping in the Sinai Peninsula

Sustainable agricultural development is an important issue in light of the increasing population and limitation of natural resources. Therefore, the assessment and mapping of land resources is of great importance for Egypt. Increasing attention has been paid since the liberation of this region in 1973 and it was decided to rehabilitate and develop the area. The northern part has wide scope potential for agriculture. However, in the southern part, the El-Qaa Plain and some other wadis (e.g., Wadi Feiran) are the areas that have agricultural potential based on the ground and rainwater amounts.

4.2.1 North Sinai Soils

Soils of El-Sheikh Zuweid-Rafah Area

The soils of El-Sheikh Zuweid-Rafah area are mostly sandy. There are few sandy loam to loamy soils; low in salinity. Most of the cultivated lands are considered fair to good lands for agriculture [40]. Soils of El-Sheikh Zuweid-Rafah area have been categorized as follows:

1. Flat to almost flat soil, loam and low salinity.
2. Undulating soil, sand over clay layers at different depths.
3. Sandy soil, subsurface loamy layers to a depth of at least 1 m from the soil surface; salinity is very low.
4. Saline soils, waterlogged, mostly concentrated in the swampy El-Sheikh Zuweid and unfit for agriculture.
5. Sandy soils of coastal dunes.

Abed El-Salaam [33] classified the soils of El-Sheikh Zuweid-Rafah area into several main units within an area of 151.23 km² as follows:

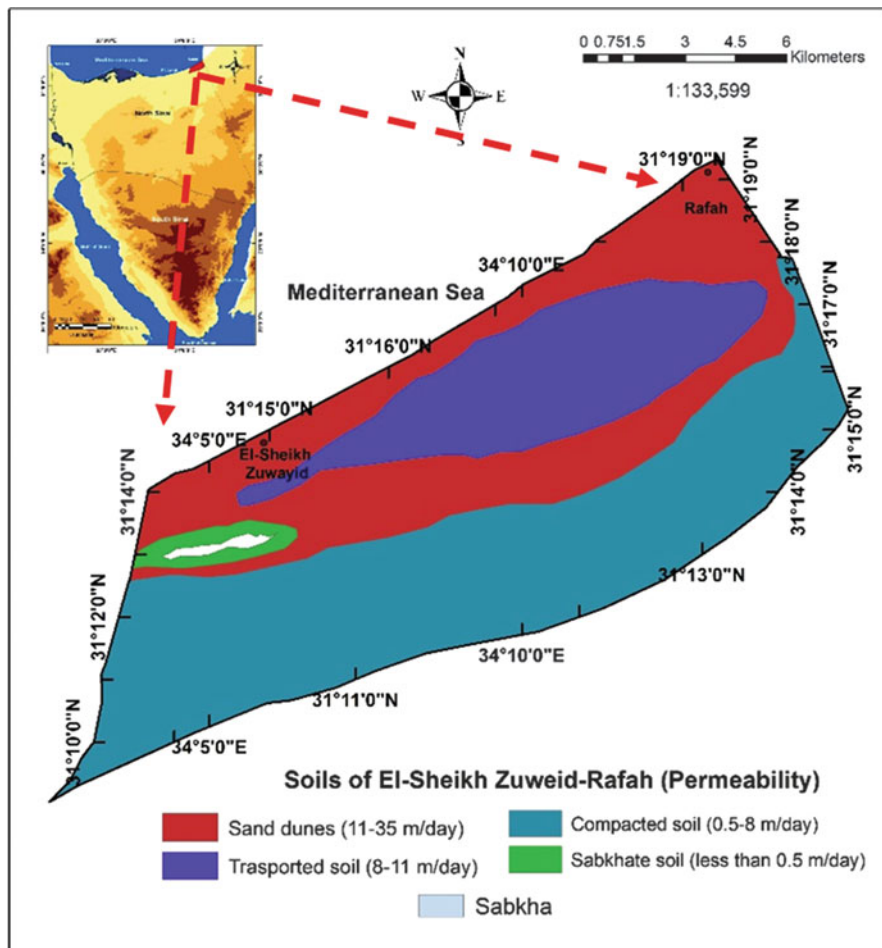


Fig. 13 Soils of El-Sheikh Zuweid-Rafah area

- Sand dunes extended along the coastline with an area of about 15,450 acres (64.9 km²).
- Interdunal depressions also extended on the coastal strip and covers 684 acres (2.9 km²), which planted vegetables and fruits.
- Sandy loam soil is located south of swampy El-Sheikh Zuweid with an area of 772 acres (3.2 km²).
- Loam soils with thickness of 20 cm and occupy an area of 523 acres (2.2 km²).
- Saline soil where the groundwater level is close to the surface and is characterized by high concentrations of salts with an area of 269 acres (1.13 km²).
- Sandy soil with various thickness and distributed in different parts of an area of 18,300 acres (76.9 km²).

Based on the vertical permeability coefficient of the soil, the soil was divided into four main types (Fig. 13):

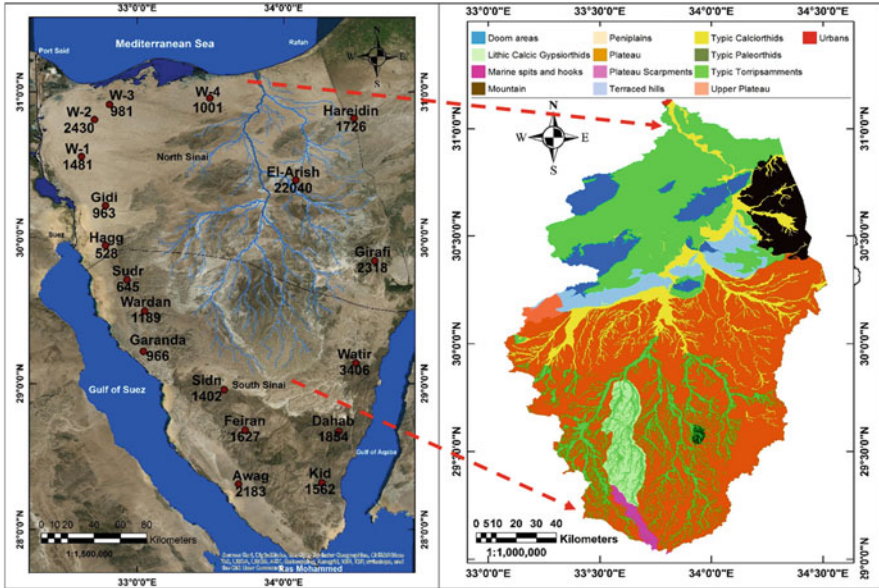


Fig. 14 (Left) The outlet of Wadi El-Arish and distribution of different wadis networks in the Sinai. Also shown are the areas (in Km²) covered by the identified watersheds. (Right) The soil dominant in the Wadi El-Arish basin

- Soil sand dunes along the coastline, where the permeability coefficient ranged between large permeability (11 m/day) and a very large permeability (35 m/day).
- Transported soil in the middle of El-Sheikh Zuweid-Rafah area where the permeability coefficient ranged between a medium permeability (8 m/day) and large permeability (11 m/day).
- Consolidated soil, which extended south the El-Arish-Rafah road where the permeability coefficient ranged between low permeability (0.5 m/day) and medium permeability (8 m/day).
- Sabkha soils, which are located in the area where the swampy Sheikh Zuweid with permeability coefficient very few (<0.5 m/day).

Soils of Wadi El-Arish Basin

Soils of the Wadi El-Arish basin consist of the area between the Mediterranean Sea and Bir Lehefin, El-Qseama, El-Ser and El-Qawarir, Wadi El-Brouk, Gifgafa, El-Gidi, and Nakhl area. Wadi El-Arish basin is situated in Sinai where it flows toward the Mediterranean Sea, and its downstream part is located in El-Arish City (Fig. 14, left). Wadi El-Arish is bound on both sides by three terraces, namely, upper terraces (33 m above the Wadi floor), middle terraces (20 m), and the lower

terraces (10 m) [41]. The Wadi infrequently receives flash floods from much of southern and central Sinai, which are a great threat to the life and to the properties located in El-Arish City. Wadi El-Arish (250 km distance from the drainage basin to El-Arish town) is one of the largest drainage basins in Egypt and comprises about one third of the whole Sinai area (20,000 km²). It is located between latitudes 29°00' and 31°10' N and longitudes 33°05' and 34°40' E (Fig. 14). The Wadi has two main tributaries, Wadi El-Aqaba on the eastern side and Wadi El-Bruk on the western side. The Wadi is associated with many secondary tributaries: Wadi Hareidin, Wadi El-Azarq, Wadi El-Hadeira, Wadi El-Hassana, Wadi El-Geraf, and other wadis. These wadis pour into Wadi El-Arish, which receives rainfall from different regions of El-Egma and El-Tih plateaus. The soil dominant in the Wadi El-Arish basin could be categorized under the following subgroups, namely (Fig. 14, right), *Typic Torripsamments*, *Typic Calciorthids*, and *Salorthic Calciorthids*, and could be categorized under two orders, namely, Entisols and Aridisols.

The sustainable development of the Wadi El-Arish watershed depends mainly on soil and water resources for agriculture and other purposes. Mohamed et al. [42] classified Wadi El-Arish soils to the following classes:

- The high suitability class is represented by wadi deposits (2617.5 km²) especially in the north and middle of the El-Arish basin, reflecting their higher capability for agricultural use. It can contribute to the storage of floodwaters to raise the soil moisture needed for agriculture, which is indicated by the distribution of natural vegetation along the wadis. These soils are characterized by very gently sloping, deep soil profile (>120 cm), loamy to gravelly sand texture, and mostly non-saline soils (<4 dS/m).
- The moderate suitability class is represented by sand sheet (1884.0 km²), which is characterized by nearly leveled topography, deep soil profile (>120 cm), sand texture, and mostly non-saline soils (<4 dS/m).
- The low suitability class for land use is represented by alluvial plains, terraces, and footslope deposits having gently to strongly sloping surfaces (3316.3 km²) and consisting mainly of loamy sand to very gravelly sand texture. The depth of soil profiles is more than 80 cm and mostly moderate to high saline soils (>4–16 dS/m).
- The non-suitable class is represented by the hill and plateau unit.

The area between El-Arish and Lefhen is covered by beach soils, Aeolian soils, and alluvial soils. Soils of Wadi El-Brouk are classified as an outwash plain, flood plain, and wadi bottom. Soils of Wadi El-Brouk range from sand to sandy clay loam, and CaCO₃ content ranges between 34.5 and 71.5%. Organic matter content ranges between 0.1 and 0.9%. The soil is neutral to moderately alkaline as pH values range between 7.0 and 7.9. Soils of gullied and isolated remnants were extremely saline as the EC values exceeded 17.0 dS/m, while soils of the wadi are non-saline to slightly saline. Gypsum content is varied and exists between 6.6 and 10.1% with an irregular distribution pattern with depth. Soils of Wadi Sabha at El-Quseima are highly calcareous as they are derived from calcareous rocks.

Alluvial deposits of Wadi Sabha are surrounded by the gravelly plains and cultivated olive trees and other plants. Soils are sandy to sandy loam texture and have high calcium carbonate and low salinity, with soft and hard lime segregation. These soils are similar to some extent to the soils of Wadi El-Geifa (El-Quseima). Alluvial soils of Gifgafa are sandy to sandy loam texture and have low CaCO_3 and low salinity. Aeolian sandy soils are present as isolated patches within the wadis with dense natural vegetation, and a sand sheet covers a relatively large area. Soils of gravelly plain occupy a large area of Gifgafa, including sandy soils, gravelly soils, and heavy-textured soils.

Mahmoud [43] carried out studies on some soils along El-Salam Canal, northeast of Egypt. Sand sheets, hummocks, and dunes of both of the deflated old deltaic plain and El-Gifgafa-El-Maqdaba depression reflect the prevailing aridity, while the wet soil materials of the lacustrine plain refer to the effect of both Nile and seawater on soil climate. Due to the climatic conditions of the study area, chemical weathering and soil development are weak, and there exists mostly physical weathering due to the variation in temperature, scarcity of rainfall, and wind erosion in most parts of the area. Salinization, gypsification, and calcification are the main processes in some parts of the area. They are quite common in soils of the El-Gifgafa-El-Maqdaba depression and small spots of the lacustrine plain. The accumulation of salts occurred because of capillary rise of the saline water table. The soluble salts, gypsum, and carbonates are formed in these soils as evaporates, which are formed by the evaporation of water. In addition, features related to the previous climatic conditions occur because of changes in climate during the Pleistocene period, which had an effect on soil formation, and numerous dry drainage lines, i.e., Wadi El-Arish. From the geological history of the deposits covering different geomorphic units of east of delta and northern Sinai, the lacustrine plain and the deflated old deltaic plain are recent deposits of Holocene period. These deposits have a young pedological age, resulting in very weak pedological processes. The deposits of the El-Gifgafa-El-Maqdaba depression belong to the Pleistocene period; therefore, they show a certain degree of development reflected in the presence of lime segregations, gypsum, and salt crystals. The statistical size parameters indicate that the soils are generally formed of homogenous well-sorted sediments, which means that the soil parent materials were transported from a source, which is not far from the soil site, and/or by currents (wind in most cases) with moderate energy. Smectite and kaolinite are the dominant clay minerals, whereas quartz and feldspars dominate the silt fraction. The dominance of smectite in soils of the lacustrine plain can be attributed to the poorly drained environment. Kaolinite, on the other hand, is expected to be formed in a marine environment. Predominance of feldspars in the silt fraction indicates that a part of soil materials is derived from Nile sediments.

El-Ser and El-Qawarir are plains in the eastern part of North Sinai. The area is located between latitudes $30^{\circ}47'$ and $30^{\circ}56'$ N and longitudes $33^{\circ}40'$ and $34^{\circ}00'$ E (Fig. 15). The area (135,000 feddan) is classified according to their elevation to three categories: 66,000 feddan less than 90 m (48.9%); 54,400 feddan, 90–100 m (40.3%); and 14,600 feddan (10.8%), 100–110 m above sea

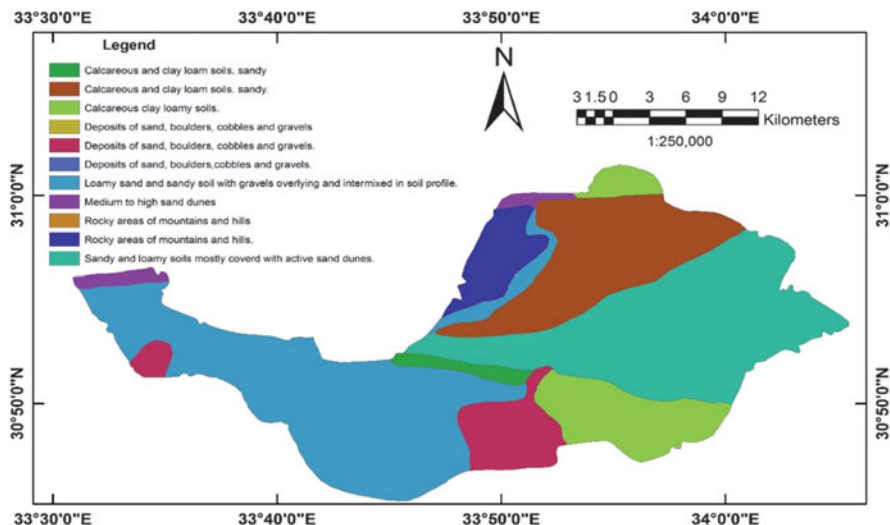


Fig. 15 El-Ser-El-Qawarir area in the eastern part of North Sinai

level [44]. Sand sheet occupies the majority of the northeastern district of the area, which represents many landforms, i.e., sand sheets, sabkhas, plains covered with desert pavement, and wadi bottom and terraces. The area of El-Ser and El-Qawarir is characterized by its irregular shape, bounded by Risan Aneiza at the north, the foothills of Gabal Lobna at the south, and on the east by Wadi El-Arish. Sandy to sandy loam soils are dominant in the north. The sand sheet and the sand dunes in the central and western part and gravelly sand are found in other parts [44]. These soils contain the highest values of calcium carbonate (11–30%) and gravels. The drainage water flows toward the main channel of Wadi El-Arish with a gradient. The water drain could be used for cultivation of forests of different trees, which could have many benefits such as wood supplies, positive changes in the ecosystem, and fixation of sand dunes. An opinion exists which suggests that it is better to exclude the area because of the high cost of raising the water (60–110 m). This opinion is reasonable from the economic point of view. Nevertheless, the development of central Sinai is an urgent initiative for the national security regardless of economic cost.

Soils of El-Ser and El-Qawarir are generally sandy in texture, non- to strongly saline, and slightly to strongly calcareous. These soils display no signs of presence of any secondary formation or any diagnostic horizon. Therefore, they are classified as *Typic Torripsamments*. Sabkha is located in the southern part of the depression. Soils vary between coarse and moderately fine textured, strongly to extremely saline, slightly to strongly calcareous, and gypsum content from slightly to moderately in fine crystals form. Some soils have weakly developed gypsic horizon though other soils have salic horizon accompanied with weakly developed calcic one. Therefore, these soils belong to *Typic Haplogypsid*s and *Calcic Aquisalids*.

Soils of the plains extend over different districts covering a relatively large area and cover a wide range from fine to coarse textured, strongly to extremely saline, slightly to strongly calcareous, and gypsum content from slightly to moderately. These soils can be distinguished into soils with weakly developed calcic or gypsic horizons and soils that have no secondary formation. Therefore, these soils belong to *Calcic Haplosalids*, *Typic Haplogypsis*, and *Typic Haplocalcids*. Soils of wadi terraces are moderately fine textured, extremely saline and calcareous, and located in *Calcic Haplosalids* and *Typic Torrifluvents*.

Soils of El-Salam Canal Basin

The land reclamation area comprises the low-lying Mediterranean foreshore strip between the Suez Canal and the El-Arish and the area lying along the eastern bank of the Suez Canal. The 400,000 feddan scheduled for irrigation on the eastern side are marginal lands. Studies on the coastal area located on the North Sinai were performed by Ibrahim [45]. Soils of South El-Qantara East (70,000 feddan), Rabaa (70,000 feddan), Bir El-Abd, and South El-Bardaweil (70,000 feddan) differ in their properties according to the mode of formation, parent material, and geographic position. Most soils of the coastal strip are located at low elevations. Sandy soils constitute most of the sandy terrain at south El-Qantara East, Rabaa-Qattia, Bir El-Abd, and south El-Bardawil. The area extends south to the El-Tina plain, parallel to the Suez Canal, with almost sandy soils (75,000 feddan), and about 20,000 feddan need drainage [44]. The northern part (10,000 feddan) at an elevation of 1 m above sea level consists of clay to clay loam surface soil. The rest of the area, at elevations ranging from 5 to 40 m above sea level (65,000 feddan), is sandy soils. Soils of El-Qantara East are mostly sandy and have a shallow to deep soil profile and shallow water table at many sites [6]. Many sabkhas with shallow (50–75 cm) to moderately shallow water tables (75–100 cm) are scattered throughout the area especially on the northern part. Salinity is low in most of the soils except some sites are highly saline. El-Salam Canal basin in North Sinai is subdivided into El-Tina plain area, south El-Bardawil area, and El-Ser and El-Qawarir area (these are similar to those mentioned in soils of the Wadi El-Arish basin).

Reda and Ragab [46] studied the area (70,000 feddan), which occupies a part of Bir El-Abd district (Fig. 16). The area is bound by the Mediterranean Sea and the Lake El-Bardawil to the north and Rabaa to the west and adjoins the sand dunes zone of the southern and the eastern edges. The area is covered with the sandy terrain of Aeolian origin. The salinity was very high (4.5–6.5 dS/m), which may be attributed to the mixing ratio or the high evaporation. Soil mapping units identified are as follows: soils of flat sandy terrain of the coastal strip, soil of the flat sandy terrain, soils of the undulating sandy terrain, and soils of the interdunal sandy terrain. Soil potentiality is poor arable land to moderate arable land (Fig. 16).

The area located between Rabaa-Qattia and Bir-El-Abd has elevations ranging from 20 to 30 m above sea level. The undulating sandy terrain cover the areas of El-Maraibah, Rabaa-Qattia, and north El-Nasr, while the rolling sandy terrain

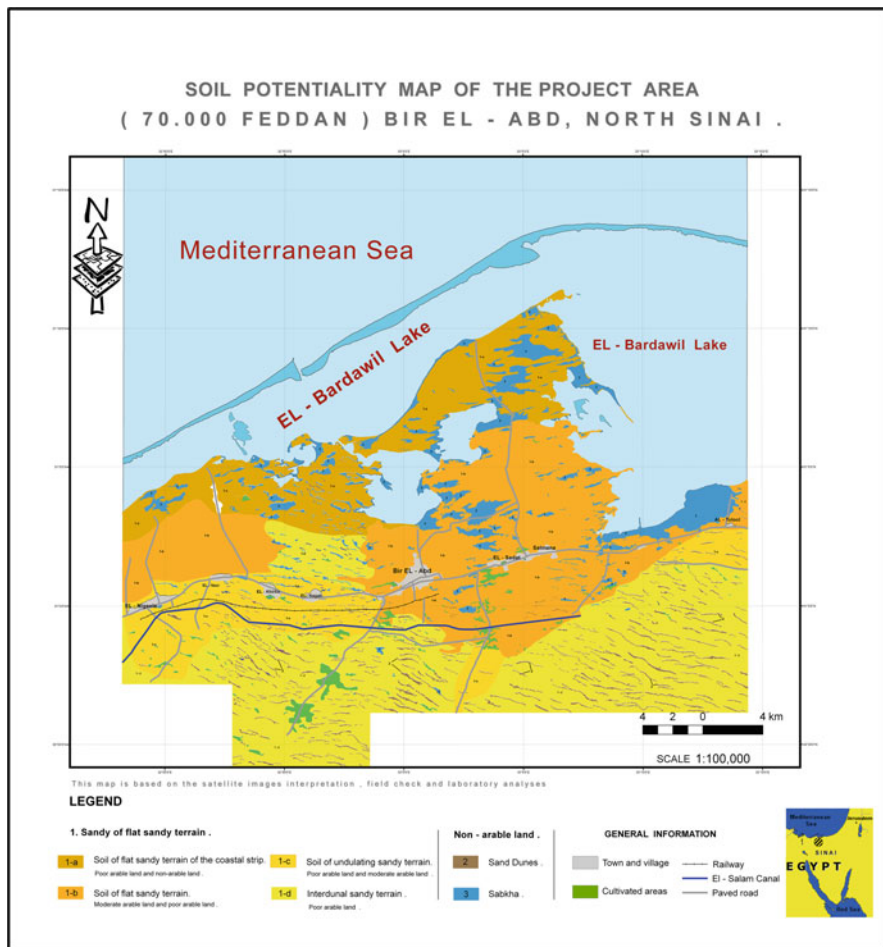


Fig. 16 Land suitability map of Bir El-Abd area [46]

covers the area of north Balouza and 6th of October [41]. Many sabkhas are present especially near Rommana, Rabaa-Qattia, 6th of October, and south El-Bardawil. The sand dunes are common especially at Bir El-Abd and south El-Bardawil. Soils are mostly sandy and very poor in calcium carbonate, with a variable amount of soluble salts. Salinity is mostly low while at some sites can be very high. Most of sandy soils are surrounded by shifting sand dune especially at Bir El-Abd and south El-Bardawil. South El-Bardawil basin is located south El-Bardawil from El-Khriba in the east and extends to the western side of El-Arish. Most of the soils are sandy and surrounded by shifting sand dunes. The water table is generally high, and the water quality is brackish or saline [44]. Therefore, without Nile water from El-Salam Canal for irrigation and subsurface drainage, little can be done for crop production. $CaCO_3$ is very low (0.5–2%).

Abd-Allah et al. [47] studied the soils along El-Salam Canal territory in the North Sinai Peninsula. The effect of erosion by wind is obviously noticed in the formation of desert pavement where coarse materials such as gravels and pebbles are left behind as well as the presence of ventifacts. However, the wind erosion effect was observed in the soils southeast of El-Qantara, Bir El-Abd, El-Ser, and El-Qawarir. These soils have been developed under arid conditions. The prevailing arid climate, different in the parent materials, and the age of the area are the dominant factors affecting the formation and nature of the soils. Soils of south El-Qantara, Rabaa, and Bir El-Abd are classified into Torripsamments and Psammaquents.

Soils of salinized lacustrine plains occupy the low-lying flat clay flat El-Tina plain (50,000 feddan). El-Tina plain is located in the northwestern corner of Sinai between latitudes 30°50' and 31°15' N and longitudes 32°20' and 32°40' E. The elevation is at mean sea level or just above or below and varies between 0 and 2 m a.s.l. [48]. El-Tina plain consists mainly of a mud flat of young lacustrine and deltaic deposits (fluvio-marine clay). Nile sediments were transported to the area through the old branch of the Nile (Pelusiac). Low sandy spots have very high salinity (sabkhas), without external drainage. Level terrain of Aeolian deposits with hummocky surfaces is common. The soils of El-Tina plain have been formed from three different origins, old deltaic, lacustrine, and Aeolian deposits. Soils of El-Tina plain have severe limitations, such as extremely high salt content (sometimes 200 dS/m or more), thin to thick salt crust, waterlogging, alkalinity, claypans, and very shallow saline and hypersaline water table [41]. Soil texture varies between sandy loam to clay. Calcium carbonate (0.5–3%) is very low, and exchangeable sodium is relatively high at many sites. The soils developed in the ancient Nile Delta have medium to fine and moderately to strongly salinity. The lacustrine soils are weakly developed or undeveloped and of medium texture. Salt crust, gypsum crystals, mottles, decomposed organic materials, and anhydrite segregations were the main pedo-feature in these soils. Aeolian deposit soils are coarse textured, moderately saline, and slightly to strongly calcareous. The presence of a high water table level with high salt content and the dominant aridic condition in El-Tina plain have led to the accumulation of salts on the soil surface. The differences of salt crust forms in El-Tina plain may be due to different degrees of salinization, heterogeneity of parent materials, texture, and soil depth [49]. Abou E-Hag [50] studied the soils of the northern coastal area of the Sinai Peninsula. The study indicated that these soils are strongly to non-saline and the texture ranged from clay to gravelly sand. Soils of El-Tina plain contain a saline horizon; therefore, these soils are classified into Haplocalcids.

Nawar [51] utilized satellite images, geographic information systems, and geo-statistical analysis to produce soil maps for El-Tina plain. The soil map (Fig. 17) shows that soils of the area consist of 18 soil mapping units. Calcium carbonate content ranged between 0.1 and 6.3%. Organic matter content ranges between 0.1 and 2.1%. The total soluble salts ranged from 4.5 to 164.4 dS/m. Cation exchange capacity ranged between 3.4 and 64.4 cmol (+)/kg soil. Gypsum content ranges between 0.1 and 7.9%. The studied soils were classified to eight subgreat groups, i.e., *typic aquisalids*, *typic haplosalids*, *aquic torriorthents*, *typic torriorthents*, *aquic torripsamments*, *typic torripsamments*, *gypsic aquisalids*, and *gypsic haplosalids*.

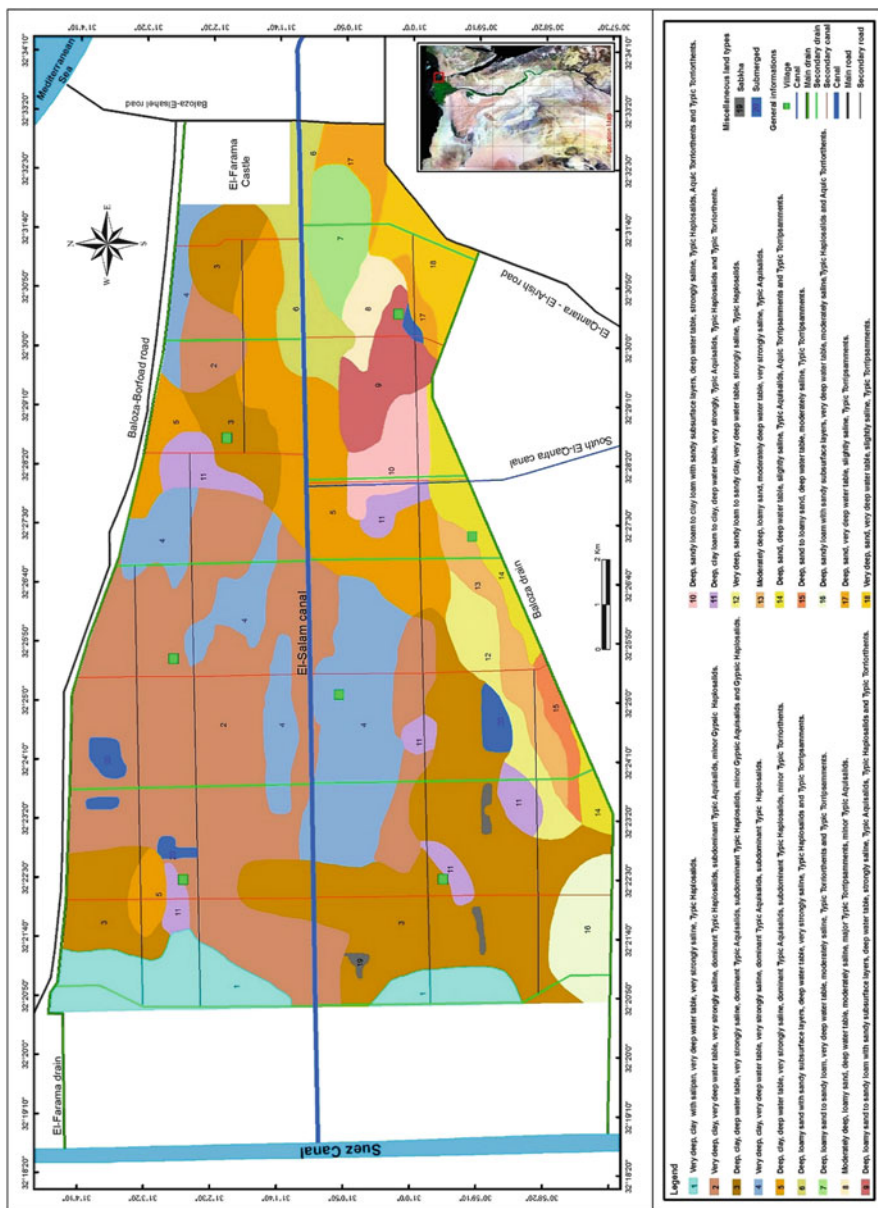


Fig. 17 Soil map of El-Tina plain [51]

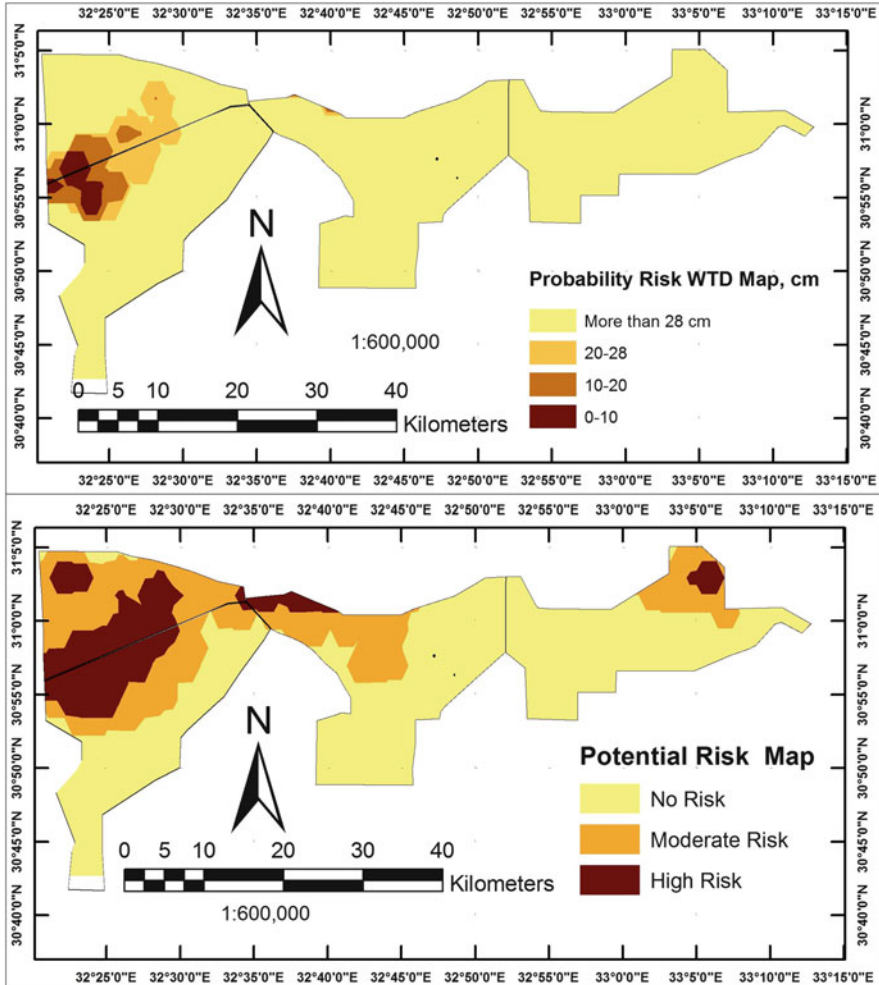


Fig. 18 Expected risk map that at April 1st (*upper*) in a future year, WTD will be shallower than 50 cm, and areas with risk of WTDs deeper than 50 cm on October 1st (*lower*). Three small susceptible areas were detected with potential risk of shallow WTDs at April 1st and four areas were detected on October 1st

Omran [6] developed a potential risk map for water table depth (WTD) in North Sinai using an early warning technique incorporated in GIS, simulation model, and stochastic methods (Fig. 18). A stochastic model is useful for estimations of WTDs because uncertainties can be quantified. Utilizing a time series model is conceivable to simulate over periods that do not have observations, as long as data on explanatory series are available. The uncertainty about the true WTD can be perceived in stochastic methods by creating large numbers of possible realizations utilizing simulations. The results indicate that on the chosen date, April 1, 2016, there is a negligible risk of shallow WTDs that could influence agriculture. The maximum prediction of WTD level in the

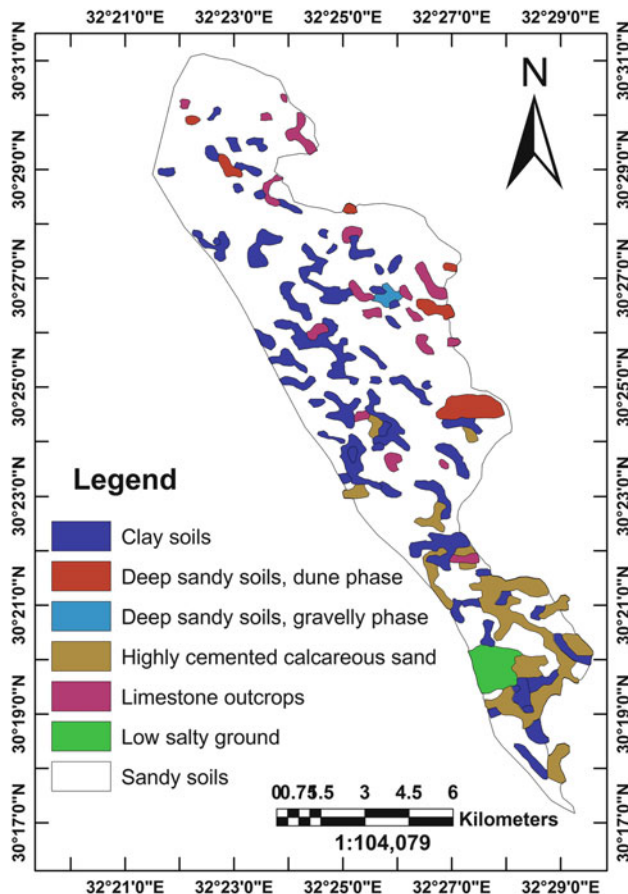


Fig. 19 East Bitter Lakes soils

following 20 years will increase from 145 cm depth to 100 cm depth. However, the minimum future WTD level will increase from 60 cm depth to 30 cm depth. This implies the future high water level will be about 0.30–0.45 m higher than the present level.

Soils of East Bitter Lakes

Soils of East Bitter Lakes (Fig. 19) were studied [52–55]. The area is relatively flat to undulating, and the elevation increases toward the east. Many depressions are located at low elevations and at water table at less than 2 m from the soil surface. The soils were found to vary greatly with respect to the sequence of layers and intrinsic properties of each layer. The main soil groups are the deep sandy soils, the clay soils, and the miscellaneous land types. Analysis indicated the presence of alkalinity and high-salinity conditions. Permeability and infiltration tests produced high values for sandy soils, while

clay soils were impermeable. X-ray analysis revealed the presence of clay type "hectorite," which is a magnesium-rich member of montmorillonite. Regarding the classification for land use, the soil could meet the criteria given for class 4, with priority given for sandy soils. Miscellaneous land types are class 5, which includes the nonagricultural land. Most of the soils are sandy soils except some clay soils present as patches in between sandy terrain. Soils mostly have a high salt content, very low CaCO_3 , high gypsum, and very low organic matter. Many severe soil limitations such as pan layers at various depths, salinity, wet depressions, sand dunes, and rocky outcrops exist [55]. Large areas of cultivated land are degraded and became unsuitable for agriculture because of the occurrence of the pan layers (claypan, gypsipan, and calcipan). Induration and hardness of pan layers could limit the chances for agricultural use. Their presence leads to the formation of shallow water table, poor drainage, and high salinity.

4.2.2 South Sinai Soils

Soils of South Sinai consist of three areas: Suez basin, El-Qaa Plain, and Feiran basin.

Soils of Suez Basin

Soils of Suez basin (Wadi Sidri, Wadi Wardan, Wadi Sudr, Wadi Kahali, and Wadi El-Hage) have sand, sandy loam, and loamy sand textures. CaCO_3 content ranged from 13.77 to 65.61% without any specific pattern with depth throughout the soil profiles at Kahali and El-Hage wadis. Organic matter content did not exceed 0.52%. The soils are neutral to moderately alkaline as pH values varied between 7.3 and 8.3. The soils are non-saline to extremely saline, and salinity increases with depth. Gypsum content ranged from 0.06 to 38.17%. Sudr outwash plain has many cultivated areas in patches particularly in the Delta of the Wadi, which is being irrigated from the present wells. Soils of Wadi Sudr are variable according to the sites in the main channel or the Delta. These soils are considered poor agricultural lands. Sudr-Abu-Rudies area is located east of the Gulf of Suez and extends along the coastal plain from Sudr at the north to Abu-Rudies at the south [40]. Sandy soils occupy the coastal plain from Abu Zenima at the north to Abu-Rudies at the south, while sandy peneplain with igneous and metamorphic mountain is located westward. This sandy soil was derived from the igneous and metamorphic rocks through wadis: Wadi Wither, Wadi Sidri, Wadi Naga, Wadi Babda, Wadi Dafori, Wadi Beida, Wadi Mattuia, Wadi Daft, and others. Soil salinity is low and CaCO_3 is very low. Under good soil-water management, these soils could be suitable for cultivation. Stoney sandy carbonatic soils are common within the area between Wadi Lahata and Wadi Kahali on the east of slopes of El-Tih plateau and hilly landscape. Loamy alluvium deposits are found in few areas mainly at Ras Malab (outlet of Wadi Gharandal) and Abu-Suwaira (outlet of Wadi Wardan).

Gobran and Osman [56] investigated the soils of the main wadis, i.e., Wadi El-Murr, Wadi Wardan, and Wadi Gharandal in south of Sinai. These wadis are situated between

latitudes $27^{\circ}35'$ and $305^{\circ}06'$ N and longitudes $32^{\circ}15'$ and $35^{\circ}6'$ E. The parent material of the soils belonging to sedimentary deposits and soil surface is covered with little gravel and stones. Generally, soils have gravelly sand to sandy clay loam texture in surface layers and sometimes become finer in deeper layers. The profiles of Wadi Gharandal have the lowest ratings, indicating slight horizontation or differences between the horizons compared with the profiles representing Wadis El-Murr and Wardan. This indicates that the soils of Wadi Gharandal are lower in pedological development than other studied soils in other wadis. The ratios of resistant minerals have different values in most profiles representing studied soils in these wadis [57]. The differences are relatively clear between the layers of the same profiles, which indicate the stratification of these profiles. The majority-studied profiles are considered young from the pedological point of view. The high resistance of quartz to weathering and the presence of feldspars could be taken as indication of weathering during soil formation and evolution, which were not drastic enough to cause a complete decay of feldspars. In addition, the soils located in Wadi Gharandal and some soils located in other wadis are relatively weathered based on the distribution of resistant minerals and weathering ratios. The relative dominance of both weatherable and ultra-stable minerals compared with opaque minerals in the soils of the studied wadis can be considered an indication of the occurrence of active physical weathering for soil sediments. In addition, some transformation of iron minerals and the immature conditions prevail in the studied soils.

Soils of Feiran Basin

Sediments of Quaternary age are preserved in lowland settings as wadi floor alluvium; as terrace remnants of older, higher wadi floors; as alluvial fans variably dissected to suggest terraces; as colluvial spreads; and as badland terrain developed in the Pleistocene beds. Under present conditions, wadi floors are awash with aperiodic floods. In higher order wadis, such as the Wadi El-Sheikh, catastrophic discharge is sufficiently competent to transport small boulders. Prehistoric artifacts occasionally were found on the surface of wadi alluvium. Since these are active channels, none was in primary sedimentary contexts, and cultural material buried in these sediments should be expected to be derived. Wadi Feiran is considered as the main important valley in southern Sinai, where it stems from mountainous areas and flows into the Gulf of Suez. The upper part of the valley has three main tributaries: Wadi Solaf, Wadi El-Sheikh, and Wadi El-Akhadar. Most of Wadi El-Sheikh, Wadi El-Akhadar, St Catherine, Wadi El-Raha, and Nuweiba-Dahab are initially of tectonic origin modified later by the drainage courses, which lead to either Gulf of Aqaba or Gulf of Suez.

Erosion and sedimentation cycles appear to be strongly affected by the grading of stream beds according to the level of the Red Sea during Pleistocene times. Although the area is now experiencing a severe arid cycle, heavy rainstorms occur once or twice every year in winter and are responsible for bringing rock debris and weathering products from the mountain slopes to be deposited along the wadi bottoms (Fig. 20). These sediments are hardly affected by pedogenic processes. Soils of Wadi Feiran (Wadi El-sheikh, Wadi El-Tarfa, El-Watti Pass, Wadi

El-Akhadar, and other wadis) are formed because of water action, and their materials are mainly poorly sorted. Soils are formed then, with minor and negligible symptoms of horizon differentiation. Soils of Wadi Feiran are mostly sandy to skeletal sands with many boulder and cobble in the main channel of the wadi, except some loamy soils on the remnants of some terraces on both sides of the wadi. These soils are characterized by very low content of salts and calcium carbonate. Soils of Wadi El-Sheikh are similar to the soils of Feiran except of the absence of stones on the soil surface. The soils are mainly poor on agricultural land. Rocks are regarded as weathered under conditions leading to the physical breakdown of various rock fragments. Transformations of primary minerals into secondary minerals are highly predictable most probably at the rock surfaces before and during breaking down of rock bodies.

Lacustrine deposits are scattered in different locations in the Wadi Feiran, Wadi Solaf, Wadi El-Sheikh, Wadi El-Akhadar, Wadi Sahab, Wadi El-Tarfa, and Wattia Pass at levels ranging between 600 and 1,250 m, with a thickness ranging between 3 and 30 m (Fig. 20). These deposits are made of sand with moderate amounts of silt and small amounts of clay and calcium carbonate and with a few gravel and rocks. The main drainage channels of wadis Feiran and El-Sheikh are filled with a series of yellowish silts and clays interbedded with minor sands and gravels. The mineral composition of the clay and sand for these sediments using X-ray and polarized microscope shows that the montmorillonite is the dominant clay minerals and is accompanied by smaller amounts of kaolinite and illite and very small amounts of chlorite and vermiculite. While the sand fraction prevails by mica and hornblende as heavy minerals, quartz and feldspars are prevailing light minerals [58].

For the formation method of these Lacustrine deposits, Issar and Eckstein [59] believe that these deposits were formed as a result of new Dykes, which have worked as barriers to water, leading to the formation of freshwater lakes, as well as barriers to the flow of groundwater, thus recharging the reservoir of Feiran Oasis. However, Reda [58] rejects this theory, where these Lacustrine deposits were formed under swampy conditions rather than separate lakes during rainy times, because the new local Dykes existed before Wadi Feiran formation, and therefore the valley and its branches have made their small wadis and canals unimpeded. In addition, the new dykes are unequivocally relatively less resistant from local rocks. There is another suggestion: El-Sherbini [61] considered the Glacial Periods as mainly responsible for the formation of lakes and sand and gravel were moved by the output water of the ice that have worked as barriers for water, which closed valley branches. The area of South Sinai is exposed to heavy floods through some valleys, especially the active ones like Wadi Feiran, Wadi Dahab, Wadi Watir, Wadi Gharandal, and Wadi Suder, which are considered hazardous and most risky areas and most vulnerable to floods, causing agricultural and infrastructure projects to be destroyed and sometimes extending damage to human life. Many cultivated areas are scattered at different sites especially at Feiran Oasis, Wadi El-Tarfa, Wadi El-Sheikh, and Wadi El-Sahab. Well water is the main source for irrigation.

Soils of El-Qaa Plain

El-Qaa Plain is an extensive longitudinal plain occupying a stretch of land trending NW–SE between latitudes $27^{\circ}45'$ and $28^{\circ}45'$ N and longitudes $33^{\circ}15'$ and $34^{\circ}15'$ E with a total area of about 1742.6 km^2 . Soils of El-Qaa Plain (Wadi Mahash, Wadi Isla, El-Qaa Plain, and Wadi Feiran) are ranked as high-priority development areas in South Sinai. Soil texture is varied from sand to sandy loam. Total carbonate content ranges between 6.1 and 35.69% with an irregular distribution pattern with depth. Organic matter did not exceed 0.29% in the different layers of the soil profiles. Soluble salts indicate that soils were saline to extremely non-saline where electric conductivity (EC) ranged between 0.9 and 36.4 dS/m. The highest value was found in soils of Wadi Feiran, while the lowest value was detected in the soils of Wadi Mahash. Soil is neutral to alkaline (pH 7.0–8.7). Gypsum content varied between 0.05 and 16.0% with an irregular distribution pattern with depth.

Morphological analysis of the soils of El-Qaa Plain revealed that these soils are highly calcareous and coarse textured. The soil layers are mostly due to the sedimentation regime. All layers of these soils contain carbonate nodules. The increase of carbonates is caused by local enrichment of secondary carbonate nodules. This feature, however, does not implicitly mean considerable leaching of carbonates downward. The dissemination of lime nodules in almost all horizons would suggest the syngenic formation (calcic and salic horizons). Since there is no extensive weathering or translocation after deposition, statistical analysis proved that these soils are of alluvial origin as they are generally poorly sorted. The obtained results indicated an alluvial origin at least from the northern part of El-Qaa Plain where several wadis descending from both eastern and western hills are depositing their loads in the plain. In the El-Qaa Plain, it appears that wind action has minimum effect probably because of the coarse nature of sediments. The characteristics of the parent materials of the area based on skewness are in general similar although the kurtosis ranges are not always the same. It is quite apparent that these soils especially at northern parts of El-Qaa Plain are derived from several common rocks of different igneous, metamorphic, and sedimentary origin. Primary, secondary, and accessory minerals are present frequently in most of the soils and could account for the origin of these soils, which is known to be alluvial. At both sides of the plain in northern extremities, wadis draining the country hills are cutting through the three types of the major common rocks [62].

Shereif [63] investigates the soils of the El-Qaa plain area using remote sensing: unsupervised classifications of ETM images. Image analysis and fieldwork show that the soils, especially in northern part of El-Qaa plain, are derived from several common rocks (igneous, metamorphic, and sedimentary). However, in northern extremities of the plain in the area of country hills, wadis are cutting through the three types of major common rocks. They identified six kinds of soils (Fig. 21, left):

1. Rocky surfaces. Soils of this unit are classified as lithic leptosols.

Inter-ridge sand flats. Depth of soils is ≤ 50 cm, soil texture class is coarse sand, saturation percentage of these soils ranges between 21 and 22, pH values tend to

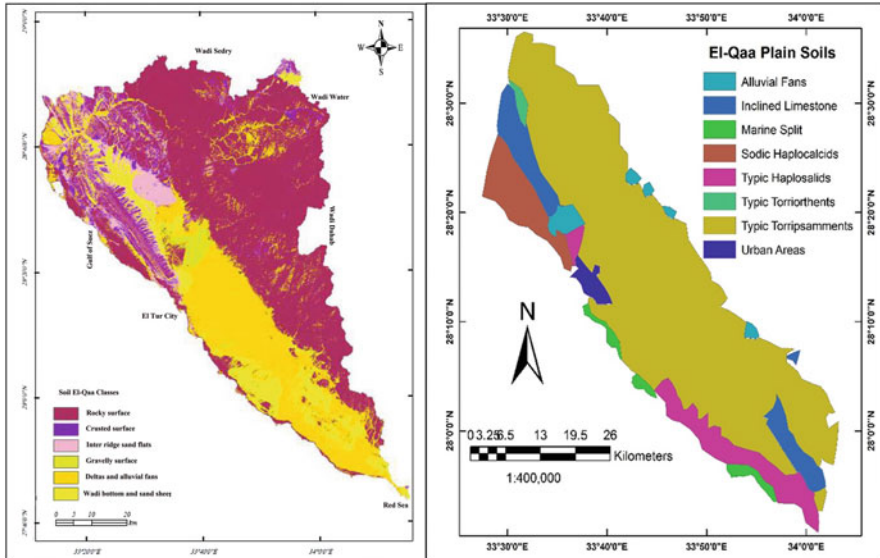


Fig. 21 Soil maps of the El-Qaa plain using remote sensing (*left*) and using analysis of 26 soil profiles (*right*)

be slightly alkaline (8.0–8.4), EC values range between 2.5 and 5.0 dS/m, and CaCO_3 content ranges between 7.7 and 8.7%. Lithic contact at 50 cm defines the depth of this soil profile. Soils of this unit are classified as *Lithic Torripsamments*.

2. Crusty and gravelly surface. Gypsum and/or carbonate crust covering more than 60% of the area. It is distributed mostly in the northeast of the area (Qabilyat mountain area), in the northwest of El-Qaa plain, and in the lower part of Wadi Feiran basin.
3. Gravelly surface. These deposits were found at the wadi mouth and mostly coarser than the other deposits that built up fans. Soils of this unit are classified as *Typic Torripsamments*.
4. Deltas and alluvial fans. Soils of this unit are classified as *Typic Torripsamment*. Consecutive series of alluvial fans are forming a foot plain along the edge of a linear mountain range.
5. Wadi bottom and sand sheet. The wadi bottom is covered mostly by sandy and silty sediments. Soils of this unit are classified as *Typic Haplocalcids*.

Land resources of El-Qaa Plain were studied using a database of 26 soil profiles [64]. Soils of El-Qaa Plain area (Fig. 21, right) include sand sheet (low, moderate, and high) classified as *Typic Torripsamments* and *Typic Haplosalids*, bajada classified as *Typic Torripsamments* and *Sodic Haplocalcids*, wadis classified as *Typic Torripsamments* and *Sodic Haplocalcids*, basin classified as *Typic Torriorthents*, dry sabkhas classified as *Typic Aquisalids*, and wet sabkhas classified as *Sodic Psammaquents*.

4.2.3 Land Resources: Priority Areas for Sinai Development

For major portions of Sinai, information on land characteristics and soils was limited. Remote sensing (RS) can provide valuable and timely information about natural resources and environment as an important basis for sustainable development. Geographic information system (GIS) can provide effective tools for decision-makers. Based on an assessment of resource potentials, the areas most suitable for various land uses are identified (Fig. 22). In terms of agricultural suitability, major limitations to the development of an area include such constraints as local relief in excess of 150 m, slopes in excess of 8%, shallow rock and thin soils, stony residuum, sand dune movement, saline soils, and severe erosion and gullying. These constraints, either individually or in combination, could be potential limiting factors in determining a particular area's suitability for agricultural development. The assessment of suitable agricultural lands must be combined with an evaluation of water availability. The availability of water is generally the most limiting factor to be taken into consideration when planning development in Sinai. Areas with the most potential for development will be identified by matching the quantity, quality, and data shown on the groundwater potential map with the land resources map.

All of the good agricultural lands (Fig. 22), those having 0–8% slopes, 0–50 m of local relief, and a deep soil cover, are located in northern and central Sinai. There is suitable agricultural land located along the wadi channels. The main areas are along Wadi El-Bruk, extending from Gabal El-Kaib north to Bir El-Thamada and then east to the confluence of Wadi El-Arish near Gabal Kherim including the Wadi El-Arish main channel and its tributary. Wadi El-Aqabah is also a good agricultural area but a smaller and narrower one than Wadi El-Bruk. The Wadi El-Arish agricultural area extends from the confluence of Wadi Abu Gidi north to Wadi El-Bruk. The Wadi El-Aqabah branch extends south along the wadi channel to the confluence with Wadi El-Misheiti. There is also good agricultural land from the confluence of Wadi El-Bruk north to the El-Mitmetni Gorge. Feeding into this area from the east is a large area formed by the flood plain of Wadi Geraia. From the El-Mitmetni Gorge, a narrow belt of good agricultural land runs north along Wadi El-Arish to the confluence of Wadi Gayifa. This narrow strip of good land also runs eastward up Wadi Gayifa to near Ain Qedees. The other major region of good agricultural land in North Sinai includes the El-Qawarir area east of Gabal Maghara and Wadi El-Hamma, which drains the lowlands between Gabal Maghara and Gabal Yelleq. It is restricted on its eastern side by Gabal Libni. An additional area of good agricultural land runs along Wadi El-Arish from the town of El-Arish south to El-Mitmetni Gorge.

Fair agricultural areas (Fig. 22) are usually more dissected than good areas and have a slightly stonier surface. Areas are designated as fair tends to extend upstream along the wadi channels from the good areas. They may also form narrow belts along the outwash plains of the mountains. There are several significant areas of fair agricultural land in Sinai. On the western, northern, and southern sides of Wadi El-Bruk, between the wadi and the mountains, there is an irregular, narrow band of fair agricultural land. This band broadens and becomes quite extensive in the

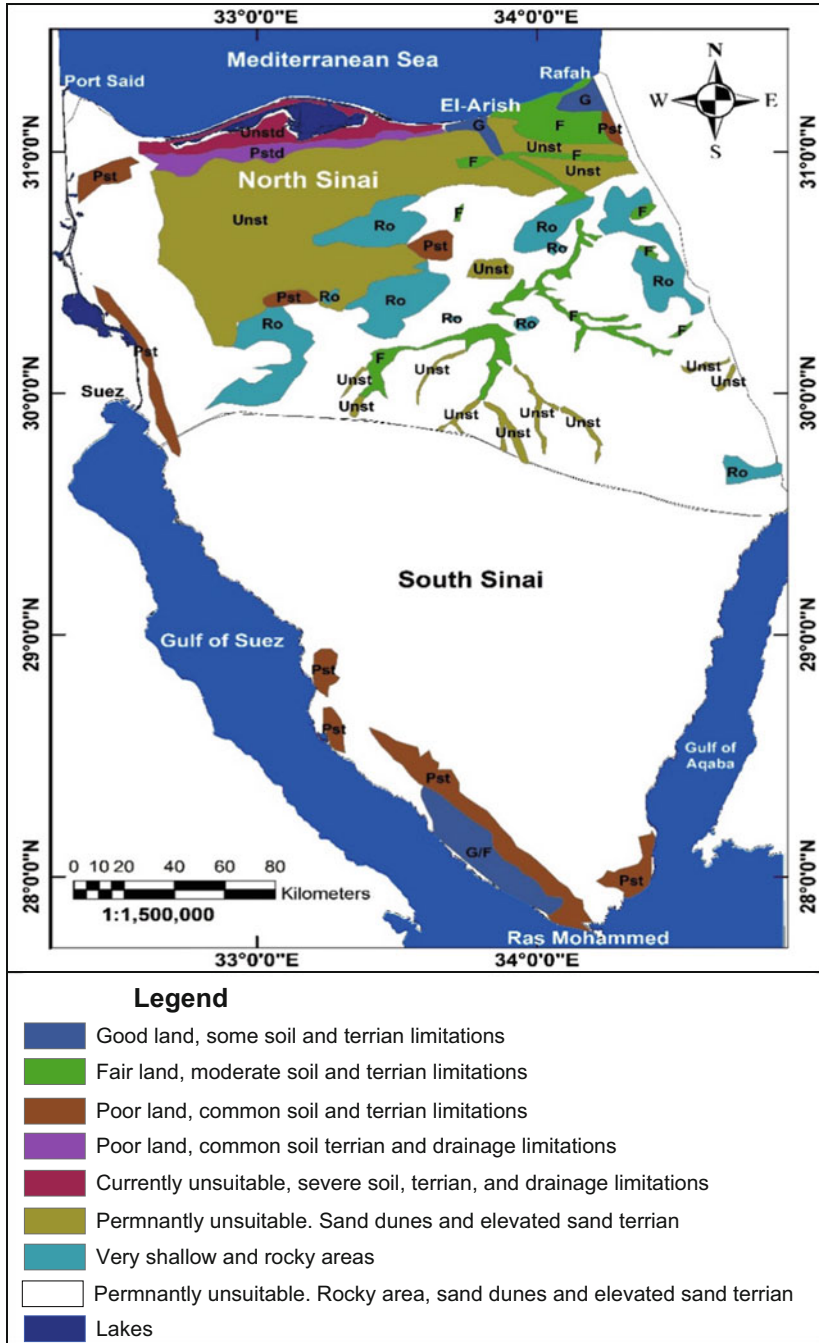


Fig. 22 Land resources priority areas in Sinai

Harabet Es Saheimi area. A large area of fair agricultural land lies around the base of Gabal Libni. It occupies most of the area between Gabal Libni and the El-Ser areas. It also extends to the west over much of the Wadi E1-Hamma flood plain. Along the northeastern coast between the town of El-Arish and the border, extending inland about 10 km is a small strip of fair agricultural land. This strip coincides roughly with the Mediterranean coastal aquifer. On the eastern side of Sinai, a narrow strip of fair agricultural land lies along the flood plains of Wadis Gerafi and Khadakhio near El-Kuntilla. Another large area of fair agricultural land in North Sinai is a 5–20 km strip that trends north–south along the Great Bitter Lake area. In South Sinai, the largest area of fair agricultural land lies in the El-Qaa Plain. This area runs north–south, encompassing most of the central stretch of the E1-Qaa plain. At its broadest point around El-Tor, it widens to about 10–15 km. Two further areas of fair agricultural land are found at Abu Rudeis and Belayim. These areas occupy alluvial fans developed by Wadis Baba and Feiran, respectively. Long narrow strips of fair agricultural land are located in most of the major wide wadis of South Sinai.

There are several extensive areas of poor agricultural land (Fig. 22) in Sinai. These areas generally occupy the colluvial deposits upslope from the fair agricultural land. One of the most extensive areas of this class practically surrounds Gabal Yelleq, except on the east where it is bounded by the flood plains and good agricultural land of Wadi El-Arish. This area covers the El-Nehaidein area between Gabal Maghara and Yelleq and extends westward to Bir Gifgafa and then south along Wadi E1-Hegayib to Bir E1-Thamada. It occupies a narrow east–west strip on the upper alluvial slopes of Gabal Yelleq. Another large and extensive area of poor agricultural land has formed in the headwater drainage basin of Wadi Geraia. This area occupies the entire region between Gabal Arif El-Naga (Shaira and El-Gunna) and the confluence of Wadi El-Baluhi and Wadi Geraia. A slim (5 km wide) 40 km-long strip of poor agricultural land is located along the Little Bitter Lake and the Gulf of Suez to about Ras Misalla. In South Sinai, the eastern flank of the El-Qaa Plain is occupied by a strip of poor agricultural land that broadens in the extreme south pinching out the fair agricultural land near Ras El-Millan. Other areas of poor agricultural land in South Sinai are along the alluvial fans bordering the Gulf of Aqabah.

By far the vast majority of Sinai's terrain is categorized as unsuitable for agricultural purposes (Fig. 22). This land has been evaluated as being unable to support any agriculture on an economic basis. Much of the land classified as unsuitable contains either no soil or a very thin veneer of soil.

5 Conclusions

The Sinai Peninsula is characterized by the occurrence of six deep aquifers. Due to the limited extension of the Miocene aquifer, low productivity, and poor groundwater quality of the Eocene/UC aquifer, the LC sandstone is considered the most important aquifer in Sinai with the highest potential quantity and quality of groundwater. Potential areas for development of the LC groundwater in Sinai were

identified based on the aquifer hydrogeological characteristics and groundwater quality. The iso-salinity contour map of the LC aquifer shows a general increase of groundwater salinity toward the west and the north, with five salinity zones recognized as follows:

Zone I has groundwater salinity $<1,500$ ppm. It occupies the area of the aquifer located south of the main road joining Sudr El-Heitan, Nakhel, and Ras El-Naqb within this zone.

Zone II occurs to the east of the line joining Sudr El-Heitan, Nakhel, El-Bruk, El-Menashereh, El-Hassana, and El-Quseima, where the aquifer salinity ranged between 1,500 and 2,000 ppm within this zone and near the folded structures at El-Bruk, Gabal El-Menashereh, and Gabal Arif El-Naga. Salinity appears to be high due to the possible groundwater stagnancy around these highly elevated structures allowing for more dissolution of salts.

Zone III is characterized by salinities ranging between 2,000 and 5,000 ppm. It occupies a narrow zone surrounding Zone I and extends to Ayun Musa area in the west and Gifgafa north of Gabal El-Halal in the north.

Zone IV occurs to the north of Zone III and has salinities in the LC aquifer ranging between 5,000 and 10,000 ppm.

Zone V occupies the northern and western parts of Sinai where the LC aquifer has been deeply buried by faulting. The rather high salinity values in this zone (14,000 ppm at well no. 2024, 19,000 ppm at well no. 2023) may be due to the ineffective flushing of the formation's saline water by the recharging meteoric water due to the interruption of the groundwater flow paths by block faulting.

For major portions of Sinai, however, information on land and soil resources was limited. Generally, Sinai soils lack pedagogical features indicating the soil development, under arid condition. El-Tina plain is clay flat consisting of fluvio-lacustrine deposits of loamy and clayey texture. Flat sandy terrain is formed of Aeolian sand deposits and is very gently undulating. The soils are non-saline and deep sandy textured, and water table is moderately shallow. Undulating sandy terrain are susceptible to wind erosion. The water table is expected to be very deep, and the drainage is excessive. The soils of the Wadi El-Arish bed have been formed of calcareous fluvio-marine deposits and are loamy texture with moderate drainage. Calcareous sandy terraces are located between Rafah and El-Sheik Zuweid. The soils are fine sand or loamy sand in texture and have moderately deep water table. Factors restricting land reclamation are lowland sabkhas and mobile sand dunes. All of the good agricultural lands, those having 0–8% slopes, 0–50 m of local relief, and a deep soil cover, are located in northern and central Sinai. The good agricultural land is located along the wadi channels. The main areas are along Wadi El-Bruk, extending from Gabal El-Kaib north to Bir El-Thamada and then east to the confluence of Wadi El-Arish near Gabal Kherim and the Wadi El-Arish main channel and its tributary. Wadi El-Aqabah also forms a good agricultural area but a smaller and narrower one than the Wadi El-Bruk area. The Wadi El-Arish agricultural area extends from the confluence of Wadi Abu Gidi north to Wadi El-Bruk. There are several significant areas of fair agricultural land in

Sinai. On the western, northern, and southern sides of Wadi El-Bruk, between the wadi and the mountains, there is an irregular, narrow band of fair agricultural land. A large area of fair agricultural land lies around the base of Gabal Libni. Another large area of fair agricultural land in North Sinai is a 5–20 km strip that trends north–south along the Great Bitter Lake area. In South Sinai, the largest area of fair agricultural land lies in the El-Qaa Plain. Two additional areas of fair agricultural land are found at Abu Rudeis and Belayim. These areas occupy alluvial fans developed by Wadis Baba and Feiran, respectively. Long narrow strips of fair agricultural land are located in most of the major wide wadis of South Sinai.

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