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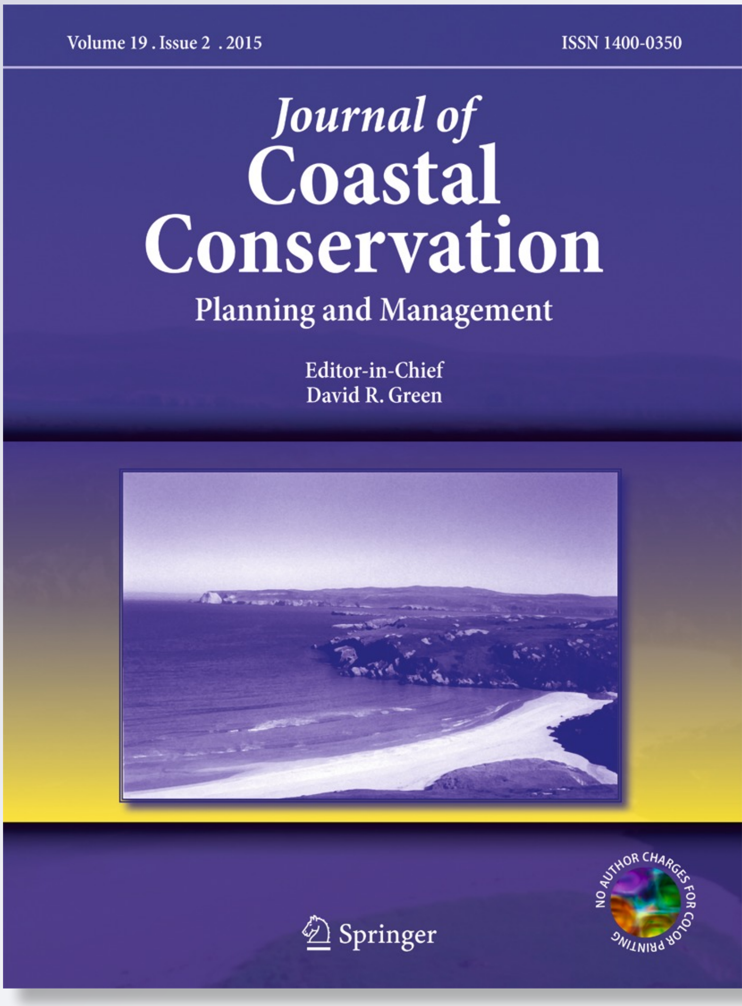

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Control of Late Holocene Geo-processes on the sustainable development plans of the Tineh Plain, NW Sinai coast, Egypt

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Abstract The Tineh Plain NW Sinai coast has been the subjected of several studies related to its stratigraphy, geoarchaeology, and sustainable development. Recently, the name of the Tineh Plain has emerged following the government of Egypt's decision to establish a new economic project to develop the Suez Canal Sector (Suez Canal Corridor Mega Project). Landsat and SPOT satellite images acquired for years 1984, 2000, 2006, 2008 and 2010 to detect temporal changes coupled with field relations, verification, sampling, analyzing and photographing were conducted. Change detection of LU/LC show six classes; the beach, the wetland (El-Mallaha lagoon), Sabkhas or salt marshes, urban, agriculture, and fish breeding farms. In 1984, the beach (4.2 km^2), El-Mallaha lagoon (26.4 km^2), sabkhas or salt marches (236.7 km^2) were reduced due to expansion of agriculture (120.3 km^2), fish breeding farms (35.7 km^2) and controlled by sediment characteristic (salinity and grain size). Accordingly, fish farms grow northward of the Tineh Plain while reclamation and cultivation extends southward. Such activities may threaten the archaeological sits at Tell El-Farama (The City of Pelusium). Three geomorphic units detected, these are the beach, the strand plain, and the deltaic plain. The beach is flat with concavo (accreted) - convex (eroded) shoreline. The strand plain made of accreted beach ridges of very low bundles, set at slight mutual angles, which sometimes truncate one another. The deltaic plain surface composed of intercalations of sand and mud of shoreface, mouth bar, and distributary channel fill. The accreted ridges representing four paleoshorelines related to Late Holocene and dated back to 400–500BP, 1100–1200BP, 1400–1500BP, and 1700–1900BP, those record the Late Holocene history (sea level, floods, and tectonics) of the Tineh Plain. The study area is waiting a plan of sustainable development, it represents phase "A" East Port Said of the Suez Canal Corridor Mega Project. This study raise the alarm of constructing heavy industries and other logistics related to shipping on the fragile environments of the Tineh Plain. This is in fact due to active tectonism, and sediment characteristics. The activities related to agriculture, fish breeding, and salts and food industries are recommended in the framework of sustainable development. It is important to include the Suez Canal Corridor Project a plan to save the ruins of fortifications of Tineh Plain. These are not only Egyptian heritage but also a world one record the history from the Persian invasions of Egypt about 6th or 7th Century B.C., through the Byzantines in 859–860, the Greeks in 954–955, the Arabic Conquest, and the Crusaders in the 12th Century. A cooperation and support from the international organization such as UNESCO should be conducted.

Keywords Change detection, LU /LC, Geomorphology · Sedimentary lithofacies · Shoreline changes · Strand plain · Deltaic plain · Tineh Plain · Tell El-Farama · Sinai coast

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Introduction

The Nile Delta in Egypt is one of the world's earliest recognized deltaic systems. It is an "arcuate" delta, as it resembles a triangle or lotus flower when seen from space. It was formed in northern Egypt due to the spread of the Nile River sediments north of Cairo for 160 km. The historical accounts of Strabo 1st Century A.D. reported that, seven branches of the Nile River once ran through the delta. Five of these branches have degenerated and silted-up in the course of history with two main outlets remaining: the present day Rosetta to the west and Damietta to the east. The defunct branches were from the west; the Canopic (the present Rosetta), the Bolbitic, the Sebennytic (is the outlet at the Burullus lagoon), the Phatnitic (the present Damietta), the Tanitic, and the Mendesian. Both the Tanitic, and the Mendesian are the outlets of the Manzala lagoon at El-Gamiel and El-Deiba villages along the Mediterranean Sea. The eastern most of these defunct branches was the Pelusiac, which opens at the mouth of the ancient City of Pelusium (Tell El-Farma, possibly 5th Century B.C.) (Sneh and Weissbrod 1973; Sneh et al. 1975). Pelusiac branch, however, was not itself the eastern border of the Nile Delta. A natural boundary was formed by a long stretch of dunes covering the higher ground, and running southwest to northeast, from the vicinity of Qantara City to the area of Tell El-Mahmoudiya at the apex of the Tineh Embayment. The difference between the high dune and the nearly sea level delta plain to the north and west may be the expression of an active structure (Neev 1977). The latter was mapped and identified as major strike-slip fault (Neev et al. 1985) bordering the eastern Nile Delta, known as the Pelusium fault line (Stanley 1988), and running NE-SW (Fig. 1). It extends from about 9 km to the north east of the Pelusium City, pssing east of Cairo (Gamal 2013) and reach to Qatara depression at about 60 km to the west of the Nile Delta (El Gammal 2013). The Qatara depression may initiated because of fault series including this fault. This structural events affected by many faulting activities through the history most probably related to the old Mediterranean shoreline.

Several studies have been conducted related to the geology of Sinai especially on the Late Quaternary evolution and geoenvironmental changes in the frame of sustainable development. Stanley (1988) concluded that the plain is subsiding at a rate of about 0.5 cm/yr., it is estimated that the sea level could rise 50 cm by the year 2100. In 1996 a project of core samples drilled by an engineering company as a part of the feasibility study of El-Salam Canal project, the study of these samples led El-Asmar (1999) to improve understanding of the geology of Late Quaternary along the Tineh Plain and the related palaeoshorelines, and then to construct the Late Quaternary sequence stratigraphy in relation to sea level changes. More recently, the satellite remote sensing data, in addition to Geographic Information Systems (GIS), offers an excellent alternative to conventional mapping techniques in investigating, monitoring, mapping rapid land use (activities) / land cover (resources) (LU / LC) changes and assessing geohazards areas. Among those related to Sinai were the work of Kaiser (2009), Arnous (2011) Arnous and Green (2011), Chichagov (2013). Kaiser (2009) focused on the study of (LU/LC) of the Tineh Plain. It was an attempt to forecasting the human impact on this coastal strip after the construction on the Eastern Harbor, at Port-Said, with possible extension to industrial, shipping and logistic activities on the expense of the traditional fish breeding, agriculture and solar salt activities.

The purpose of the present work is threefold: (1) To update the knowledge and understanding of the of geo-environment of the Late Holocene stratigraphy and how the geological history influences the sedimentary sequence that reflected on lithofacies and sculpted the geomorphology and their implication on archaeological sites in the study area. (2) To monitor the recent anthropogenic activities and their influences on the changes in LU /LC. (3) To recommend the preferred activities in a framework of sustainable development as the area is expected to receive mega projects after the construction of the new Suez Canal Corridor, with expected accelerated rates of different developments and human activities.

The study area

The Tineh Plain (30° 50′–31° 20 N′ and 32° 20′–32° 40′ E; Fig. 1) occupies the northwestern corner of the Sinai. It is an integral part of the ancient Nile Delta (Stanley 1988), cuts from the proper delta after excavating the Suez Canal in 1869. The Tineh Plain has a triangular shape of 818 km^2, bordered to the west by the Suez Canal, to the north by the NW-SE trending Mediterranean shoreline, and to the south by a sharp straight contact with northern Sinai sand dune sheet. It has a concavo-convex shoreline configuration that is about 39 km long (Dewidar and Frihy 2003; Kaiser 2009). The north-western corner of the Tineh Plain, south of Port-Fouad and directly east of the Suez Canal, is covered by El-Mallaha lagoon. It occupies a large triangle area of about 56 km^2 with a 14 km base and up to an 8 km maximum width. El-Mallaha lagoon is filled with hypersaline water all year. The Mediterranean Sea is connected to this lagoon by a small entrance near Port-Fouad and other shallow tidal inlets (Frihy and Lotfy 1997). El-Mallaha lagoon has shallow depth ranging from 0.15 to 0.5 m and its salinity is higher than that of the Mediterranean Sea (Kaiser 2009). The Tineh Plain is an extensive mud flat covered by a salt crust with thickness of 5 to 20 cm.

The Tineh Plain divided into three geomorphic units, the beach, the northern strand plain and a southern delta plain (El-

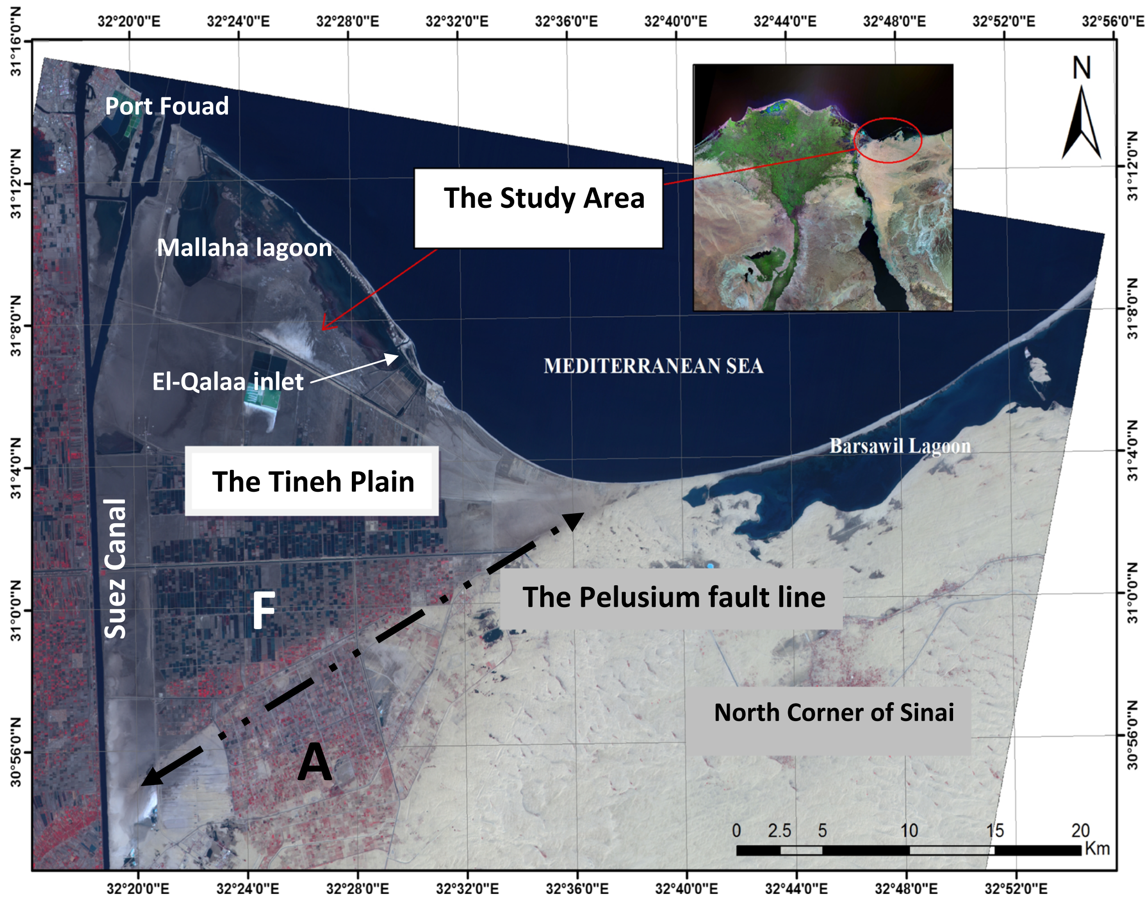


Fig. 1 Satellite image showing location for the study area at Tineh plain, NW coast of Sinai, Egypt and the Pelusium fault line as mentioned in Neev (1977), "*A*" is agricultural land, "*F*" is fish breeding farms

Asmar 1999). The beach has a NW–SE trend; it is a low slopped, smooth sandy beach, with no anthropogenic structures, except at the western part. The only engineering structures built coast are the 7.7 and 2.0 km jetties constructed to protect the inlet at Port Said and the East Port Said Harbor, respectively (Dewidar and Frihy 2003). The strand plain is a sandy one trending NW–SE, with 35 km long and varies in width from 1 km in the east to 12.5 km in the west. It is covered from the west by El-Mallaha lagoon. Toward the east, it consists of bundles of low accretional beach ridges (about 18 ridge), a few tens of centimeters (20–30 cm) to about 1.5 m higher than the surroundings (El-Asmar 1999; Goodfriend and Stanley 1999).

The Pelusium is a city in the extreme eastern Nile Delta of Egypt, 3.8 km to the south of the Mediterranean coast, about 32 km southeast of Port Said and 23 km east of the Suez Canal. It was a fortified port coastal city; its history possibly begins after the Persian invasions of Egypt from about 6th or 7th Century B.C., (Goodfriend and Stanley 1999; Stanley et al. 2008). Some historians have suggested that the city was established before that time. During the Arabic Conquest, starting 640 A.D. the city was still have been in a coastal position (Goodfriend and Stanley 1999). By the 12th Century, the city became a deserted. Its decline seems related to the evolution of the northeastern Nile Delta, having been cut off both from the coast and The Nile. Historical accounts by Al-Makrizi in the 15th Century indicated that in 853–854, the sultan El-Moutawakel built fortifications in the region, including Tineh, which was built "next to the sea" (Bouriant 1900). Al-Ya'akubi found the strand plain already in existence when he visited the area in the late 800 A.D. While Fontaine (1951) identifies Tineh as the inland ruins northwest of Pelusium, Tamari (1978) considered these a much later 15th Century Mameluke structure. Because by 853–854 progradation of the strand plain would already have occurred, the position of the fortress described by Al-Makrizi should be somewhere along the present coast (Stanley et al. 2008). Later landings at Tell El-Farama by the Byzantines in 859–860 (Casanova 1906), by the Greeks in 954–955 (Bouriant 1900), and then by the Crusaders in the 12th Century would have occurred when it was already in an inland position. Goodfriend and Stanley (1999) indicated that sequence of great flood records during 813, 816 and 820 A.D. may have been the triggering events. This sudden displacement of sand

caused Pelusium, and then the principal port and fortified city of the northeastern Nile Delta located at the mouth of the Pelusiac branch, to be cut off from both the Nile and the Mediterranean.

Suez Canal Corridor Mega Project (SCCP)

The Suez Canal Corridor Project (SCCP) is a mega developing project in Egypt. It dates back to 1970s when Hassab Allah El Kafrawy (former Minister of Housing) submitted his proposal for first time and then he renewed the submission for a second time in 1990's. He wanted to change the Suez Canal corridor to an important international region rather than being only a canal for ships to pass through. Finally, on August 5, 2014 the project launched, and expected to expand the trade along the fastest shipping route between Europe and Asia. The project's aim is to increase the role of the Suez Canal region in international trading and to develop the three canal cities: Suez, Ismaïlia, and Port Said, and will transfer these cities into global centers for logistic and ship services (Zaafarany and Alsahar 2014). The project involves building a new Ismailia City, an industrial zone, fish farms, completing the technology valley, building 7 new tunnels, improving 5 existing ports, and digging a new canal parallel to the Suez Canal (GAFI 2014). The new canal will increase the canal capacity by allowing ships to sail into both directions at the same time, which will decrease waiting hours from 18 to 11 h for most ships, and doubled the capacity of the Suez Canal from 49 to 97 ships a day. The New Suez Canal is expected to be 72 km long, and will involve 35 km of dry digging, and 37 km of "expansion and deep digging". The revenues from the Suez Canal (after the completion of the New Suez Canal) will jump from 5 billion dollars to 12.5 billion dollars annually.

The SCCP has designed for implementation in three phases, over a total of 20 years. In first phase, Port Said and the Suez harbors will transform into global warehouses. Facilities will build to serve the navigation traffic, associated businesses and industrial projects. A container terminal as well as shipyard will build and a new wave breaker, dock walls, railways, and telecommunications equipment will put in place. In the second phase, an industrial zone will establish to host industries (such as the production of machinery, textiles, building supplies, packaging factories, ship maintenance centers) and light tourism. The third phase will set up a technology center in Ismailiya for technology, commerce, communications, and tourism. According to governmental experts, the project is expected to offer about one million jobs.

The existing west of Port Said Harbor is considered largest central harbor in the world due to its location on the Suez Canal and its area (Fig. 2), which is about 35 km^2, with 37 quays for various purposes. Adjacent to the harbor is the largest industrial free zone in Egypt with an area of 99 Km^2 and an

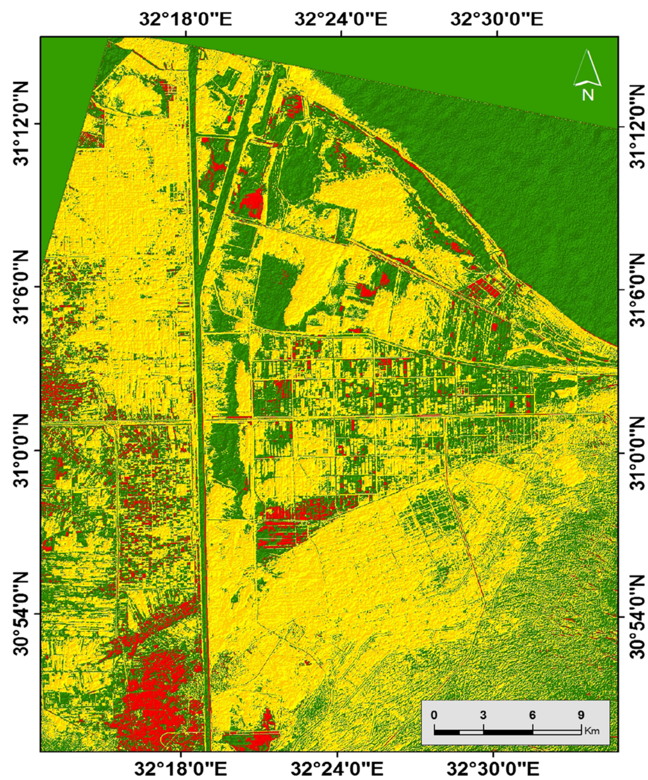


Fig. 2 Change detection analysis map used to identify, describe and quantify areas of changes and un changes for satellite images of 1984-2010 at the Tineh Plain. Areas of increased changes appears in red, the other of decreased changes are in yellow color while the green areas indicate no changes

agricultural zone of 50,000 acres (SCC 2013). The existing harbor consists of four major zones divided into: The Touristic Zone, which has 3 quays for the large touristic vehicles and a submersion of 11 m. The North Zone, which is the general cargo zone which has quays along 580 m and a submersion of 6–8 m and the dry cargo quay along 246 m with a submersion of 12.7 m. The South Zone, which contains TUE quays along 974 m and a submersion of 13.2 m and the liquid poring quay along 575 m and a submersion of 3.8 m. Finally, an RORO quay also found in this zone along 40 m and a submersion of 8.2 m (SCC 2013). The Eastern Port-said Harbor lies on the northwestern entrance of the Suez Canal branch near Port Fouad City (Fig. 2), which is a unique location because it connects three continents. The harbor built in 2004 to serve international trading and act as a transit center between the continents. The harbor borders the Mediterranean Sea from the north, the industrial zone from the south, the salty El-Mallaha lagoon from the east, and the Suez Canal branch from the west. The harbor authority plans to expand it into a logistic hub, which requires build docks of 12 km long and an industrial zone south of the harbor covering 87 km^2 (EPM 2014). Increasing the quays in the target year of 2017 to 8 quays and 8 stations with docks 8 km long, in 2022 four more quays and will be add and creating 15 stations with docks 16 km long. In the target year 2030 the harbor will reach its full capacity, with

10 more quays to add up a total sum of 22 quays. The total area of the East harbor after development is expected to be 1.5 million m^2 (Zaafarany and Alsahar 2014).

Materials and methods

Remote sensing techniques consider the best solution for detecting the regional changes and exploring the new phenomena over the earth surface and even for the other planets surfaces. Satellite remote sensing has the potential to provide accurate and timely geospatial information describing changes in LU/LC (Foody 2003; Herold et al. 2002; and Yuan et al. 2005). Generally, change detection involves the application of multi-temporal data sets to quantitative analysis of the temporal change of the phenomenon (Lu et al. 2004; Srivastava et al. 2012). The basic principle behind using digital data is that any subtle change in LU/LC results in a change in the radiance of that object detected by satellite sensors (Mass 1999) at a range of spatial, spectral and radiometric resolutions. For example, the conversion of land use from rural to urban land causes change in the visible portion of the spectrum (brightness) the changes from vegetation to non-vegetation land use cause difference in the near-infrared (NIR) radiation (greenness) and the change in the shortwave-infrared (SWIR) reflects change in moisture content (wetness) (Lunetta and Elvidge 1998). A number of techniques on LU/LC changes have been reviewed (Lu et al. 2004). LU/LC change detection generally employs one of two basic methods: pixel-to-pixel comparison and post-classification comparison (Dennis and Colfer 2006; Dewidar 2004; and Mukherjee et al. 2009), which compares two or more separately classified images of different dates (Serra et al. 2003; and Shalaby and Tateishi 2007). Post classification comparison is considered the more appropriate and commonly used method for change detection (Lillesand et al. 2004).

Two types of remotely-sensed satellite data were utilized to achieve the objectives of the present study (Table 1). The first is a set of satellite images acquired from the (Landsat and SPOT + 4 sensors). The Landsat images were acquired in 1984, 2000, 2003 and the SPOT + 4 images were acquired in 2006, 2008 and 2010. The second source of data is a set of two seamless digital elevation models (DEM) acquired from the Shuttle Radar Topography Mission (SRTM) in 2000.

Landsat images data covering the study area have been digitally processed, analyzed and interpreted to produce a LU/LC map at a scale of 1: 50.000. This is based mainly on the multilevel LU/LC classification system for use with remote sensor data adopted by the U.S. Geological survey. The produced Landsat images classification maps clearly displays the major classes of LU/LC in the study area. The accurate special registration of the two images is essential for all change detection methods. This necessitates the use of geometric rectification algorithms that register the images to each other or to a standard map projection. In addition, most of the methods require a decision as where to place the threshold boundaries in order to separate areas of change from those of non-changes.

Atmospheric correction applied to the Landsat and SPOT images, using the dark object subtraction method of Chavez (1996). Geometric correction was performed through image-to-image geo-referencing in the Universal Transverse Mercator Projection (UTM / zone 36 WGS 84) using a first-order polynomial transform. At least 20 prominent well-distributed ground control points (GCP) selected in the master Landsat and SPOT images, located in the other images, and then a nearest neighbor resampling method was applied. The root mean square error (RMSE) was less than 0.5-pixel for the registered Landsat images and less than 1.0 pixel for the other three SPOT images. ERDAS Imagine software was used to perform image processing of the satellite images. Two subset images were created in each of the Landsat and SPOT images to boundaries of the study area during 1984, 2000, 2003, 2006, 2008 and 2010. The near infrared (NIR) and the middle infrared (MIR) bands are of high well suited for detecting water bodies (Lillesand and Kiefer 1994) and, therefore, are useful in wetland detection and monitoring. We applied the Normalized Difference Water Index (NDWI) of McFeeters (1996) to highlight the water body in each date. The NWDI was calculated in the Landsat and SPOT images using the

Table 1 Different landsat and SPOT satellite data acquired and utilized in the present study at Tineh Plain in a chronological order from 1984 to 2010

Mission	Country	Instrument	Path/Row	Number of Bands	Acquisition Date	Spatial resolution (meters, at nadir)				Swath (km)	Repeat cycle (day)	Orbit altitude (km)
						PAN	VNIR	SWIR	TIR			
Landsat-4	USA	MSS	176/38	4+	Jan. 1984	15	30	30	60	180	18	705
Landsat-5	USA	TM	176/38	7+	May 2000	15	30	30	60	180	16	705
Landsat-7	USA	TM	176/38	8+	August 2003	15	30	30	60	180	16	705
SPOT-4	France	2xHRVIR	114/287	4+	September 2006	10	10, 20	10, 20		60	3	822
SPOT-4	France	2xHRVIR	114/287	4+	February 2008	10	10, 20	10, 20		60	3	822
SPOT-4	France	2xHRVIR	114/287	4+	February 2010	10	10, 20	10, 20		60	3	822

following equation: (Green - NIR) / (Green + NIR), where Green and NIR are the digital numbers (DN) of individual pixels in the green and near infrared bands in the Landsat images from 1984 to 2003. The water index which is termed the modified normalized difference water index (MNDWI) (Xu 2006), was calculated in the three SPOT images using the equation: (Green − MIR) / (Green + MIR), where Green and MIR are the DN in the green and middle infrared bands of the SPOT images. The water body at El-Mallaha lagoon and the surrounded wetland was carefully examined to testify the accuracy of each index. The index threshold value of the lagoon water was estimated in the resulted pseudo-color image. Any value equals or greater than the threshold value was recorded in blue color and counted as water (El-Asmar et al. 2013). All other pixels below the threshold value were considered as non-water objects. The gross area of the water body in each date was calculated and compared. A careful ground truthing was applied to examine the accuracy of the threshold value of water of each index. The test points were distributed mainly along the suspect areas. The water body area change was then estimated in 1984 and 2010.

The dynamic movement of the coastline along the study area in terms of advancing by accretion or retreating by erosion was highlighted and measured using ArcMap software by digitizing the shoreline position in the Landsat and SPOT satellite images. Two thematic maps showing the relative coastline position in each date were prepared to present the regions, which experienced erosion and those exposed to accretion. A geographic information system (GIS) is a system used to describe and characterize the earth and other geographies for the purpose of visualizing and analyzing geographically referenced information. Many have characterized GIS as one of the most powerful of all information technologies because it focuses on integrating knowledge from multiple sources (for example, as layers within a map) and creates a crosscutting environment for collaboration.

The topography of the coastal zone of the study area is analyzed using the digital elevation models for the region. In ArcMap software, the two digital elevation models were classified into two elevation levels: below 1-m and above 1-m elevation to highlight areas and their surroundings which are prone to sea-level rise of 1-m above its current zero level due to the eustatic global sea level rise. The boundaries of the study area were digitized and superimposed the two classified digital elevation model. Supervised classification techniques require the analyst to specify the types of ground cover in a scene through the use of training data (Lillesand et al. 2004). The generation of a classification has two distinct steps: training and classification. Training is the process of setting a spectral envelope for a class and, for supervised classification, requires a priori information about the image data and habitats to be mapped (Saadat et al. 2011; Shao and Lunetta 2012). Field validation was conducted by selecting random points at the same latitude and longitude in both images for each habitat class along the entire area of study. About 150 points were selected as a reference for each habitat class at different locations including all area (land and water body)]. In addition, GPS measurements were also taken for the validation of the image data.

It was clear for us that the study area includes several geomorphic features with different sedimentary facies and reflect several interacting depositional processes in the coastal environment. It was a great task during our fieldwork is to represent all geomorphic features and sedimentary units of different depositional environments. 185 samples collected from 17 exposures representing our database of fieldwork started since 1998. In addition to, 220 samples collected representing the geomorphic unit including beach, accretion ridges, sabkha, and deltaic plain and recent dunes. In addition, three core data drilled by an engineering company for the purpose of industrial construction have been used (El-Asmar 1999). All samples were subjected to grain size analysis. The field relations, geomorphology and sedimentary lithfacies have been used for interpretation of the depositional environments. Some shell bivalves collected and analyzed for radiocarbon using accelerated mass spectrometry at LGQ, Marseille, France, and MOAG, Athens, Greece with collaboration with Dr. Yannis Foundolis. The results corrected according to Stuiver and Polash (1977). Finally, 20 thermo-luminescence (TL) and Electron Spin resonance dates were analyzed in collaboration with P. Wood, department of Geography, University of London, and the analyses methods described in Wood (1996). Together the age dating results supported with depositional environments have been used to construct the geologic history of the Tineh plain and offer us good knowledge about the sedimentary characteristics of different sedimentary units. Knowing sediment characteristics may help in distribution of human activities in a frame of sustainable development.

Results and discussion

Remote sensing application

Change detection is a process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, it involves the ability to quantify temporal effects using multi-temporal data sets. In this study, the change detection using remotely sensed data carried out initially for the whole land cover types. Four of the most commonly used change detection methods were applied to the registered, normalized multi-temporal Landsat images. These methods are: (1) post-classification (2) image differencing (3) image rationing, and (4) principal components analysis (PCA). The outputs of this stage are the changed / unchanged image (Fig. 2)

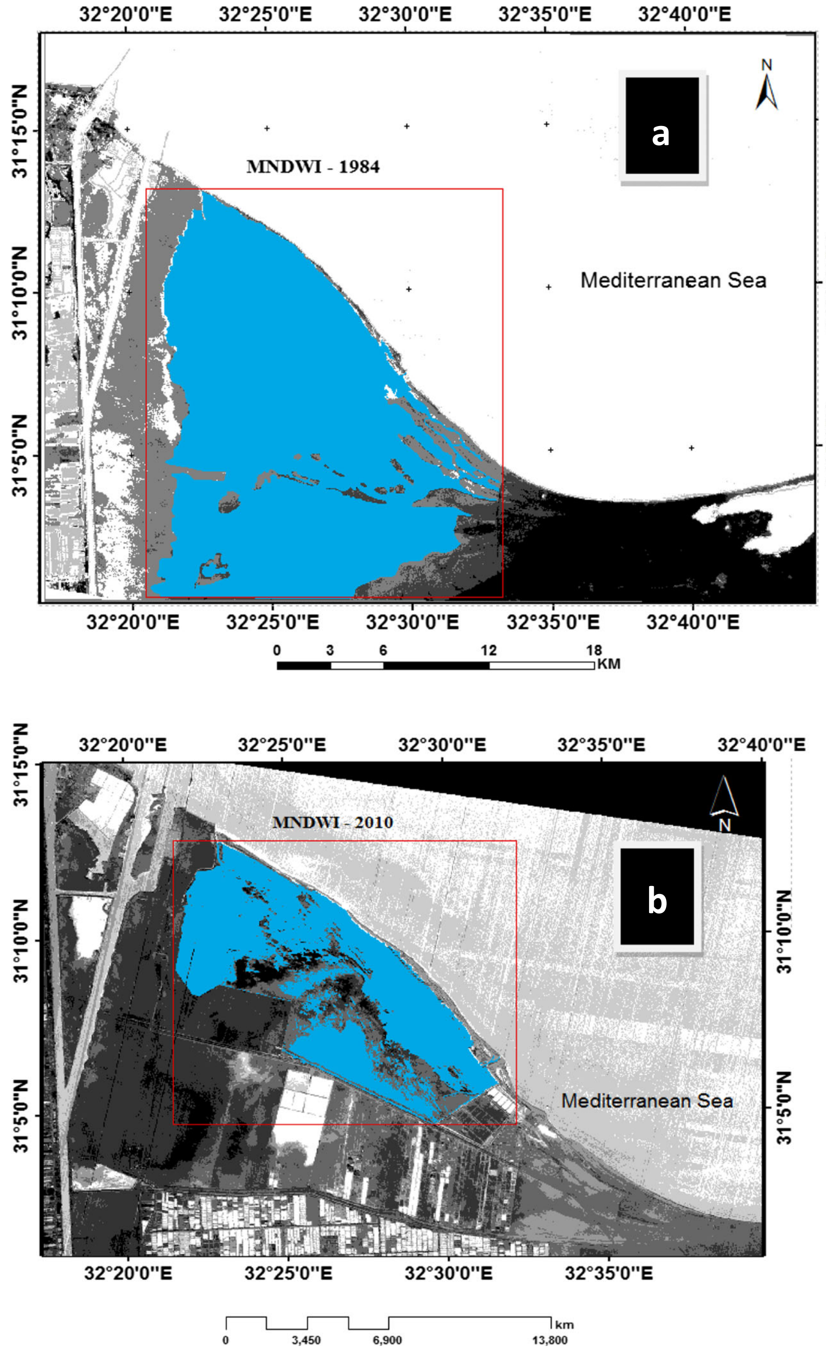
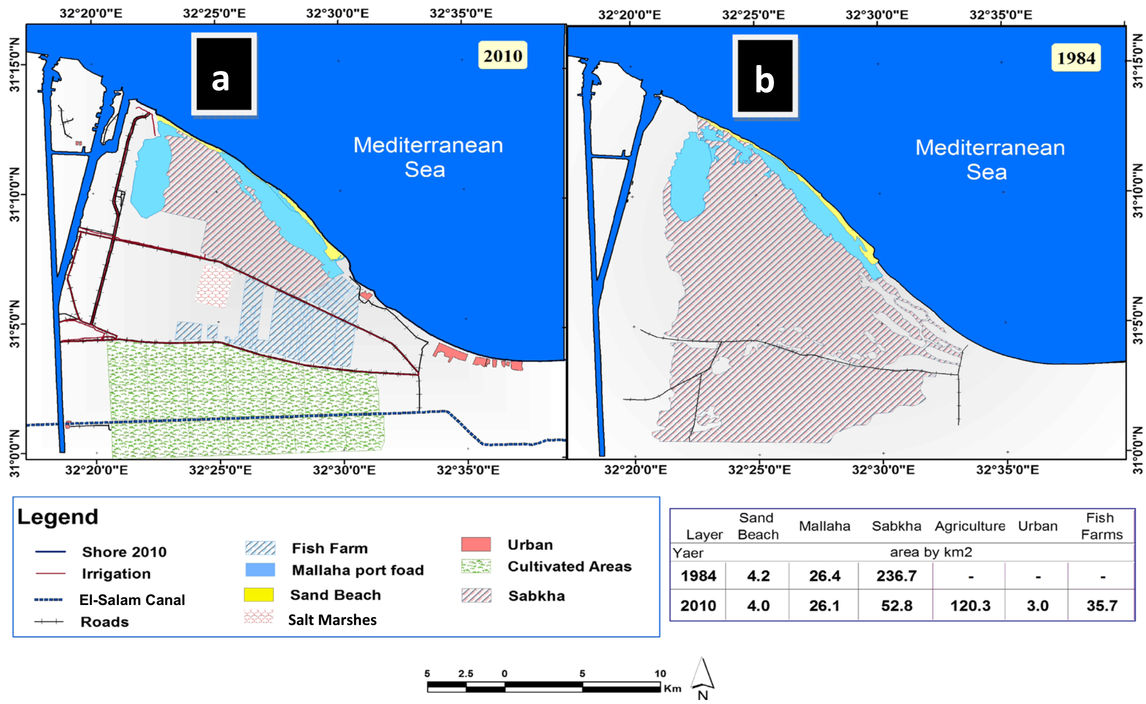


Fig. 3 Pseudo color image show laboratory measure sensitivity of MNDWI to change in water body (blue) thickness and show how wetland area was dimensioned from of 1984 (**a**) and 2010 (**b**)

which identifies the total areas of changes and unchanged. It is also show classification of the changed areas into certain class of increase and decrease between 1984 and 2010.

Satellite data were analyzed using the method MNDWI (Modified Normalized Difference Water Index) to separate the water body from the ground and vegetation. The MNDWI is very efficient and accurate in delineating water body (Xu 2006). The index value equal or greater than the threshold value recorded in blue color, and counted as water in a pseudo color image (Fig. 3). Correlation of MNDWI images of 1984 and 2010 reveals that; in 1984, (Fig. 3a) the area of the wetland area was 263.17 km^2 and clearly demonstrates a series of accretion ridges emerged above the water level at the southeastern part of the image (Fig. 3a). In 2010, (Fig. 3b) the wetland clearly dimensioned into 78.9 km^2 with a total decrease of 184.2 km^2. In LU / LC the wetland comprises both El-Mallaha lagoon and sabkhas (salt marshes).

The analysis of LU/ LC of the Tineh Plain between 1984 and 2010 reveals six major classes (Fig. 4), verified in the field work (Fig. 7a–c). These are the beach, wetlands (El-Mallaha lagoon) and Sabkhas (salt marshes), urban, agriculture areas, and fish breeding farms. Such classes



Layer / Yaer	Sand Beach	Mallaha	Sabkha	Agriculture	Urban	Fish Farms
	area by km2					
1984	4.2	26.4	236.7	-	-	-
2010	4.0	26.1	52.8	120.3	3.0	35.7

Fig. 4 Correlation of LU/LC of the Tineh Plain deduced from satellite images of 2010 (**a**) and 1984 (**b**) showing major units and the changes in each unit in square kilometers

observed in most studies on the eastern coast of the Nile Delta (e.g. El-Asmar and Al-Olayan 2013; El-Asmar et al. 2012, 2013, 2014). No human activities (urban, agriculture, and fish farms) were observed on the image 1984 (Figs. 4b and 5 1984). In 1984, the area of El-Mallaha lagoon was 26.4 km^2, while the sabkha (salt marches) area was 236.7 km^2. The development activities came later on 1991 and well developed by year 2000 after excavation of El-Salam (Peace) Canal, and the establishment of a project of development communities targeting reclamation and cultivation of 400 000 ac. east of the Suez Canal. In 2010, the development activities obviously reflected in agricultural

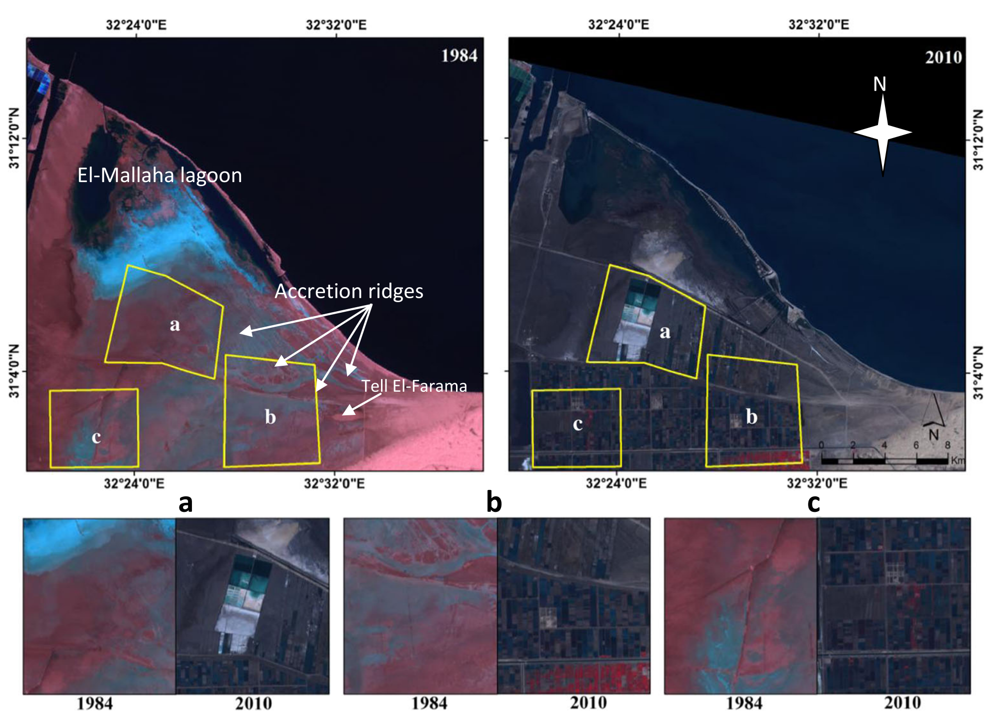


Fig. 5 Delineation of some examples of the changes in LU /LC from 1984 to 2010. (**a**, **c**) Fish farms appear in 2010 on expense of sabkhas 1984. (**b**) Fish farms and agriculture 2010 appear on expense of accretion ridges and at the peripheries of Tell EL-Farama 1984

area reached 120.3 km^2, while fish breeding farms 35.7 and 3 km^2 for urban area. The increase in agriculture, fish breeding farms and urban areas mainly came on the expense of sabkha and accretion ridge areas (Figs. 4a and 5 2010). The expansion of agriculture concentrated to the area south of El-Salam Canal while fish breeding farms focused to the north of the canal. Such human activities may represent one of the hazardous problems threatening the archaeological sites at Tell El-Farama (Figs. 5b and 7d, e).

Geomorphological aspect

Three geomorphic units are identified along the study area, these are, beach, strand plain with the characteristic accreted beach ridges and deltaic plain (Figs. 3, 4, 5 1984).

The beach, and shoreline change

The beach of the Tineh Plain is described as a very narrow strip. It is wider and gently sloping to the east than the west. The average width near El-Qalaa inlet is 125 m, and the slope ranges from 2 to 5°. The sand beach area was 4.2 km^2 as measured on 1984 image and became 4 km^2 in image 2010 (Fig. 4 and 6). Shoreline change detection along the Tineh Plain from 1984 to 2010 reveals two distinguished segments. A convex shoreline segment extends eastward from Port Fouad to El-Qalaa inlet with an average erosion of about −8 m/yr. (Fig. 6a), and a total loss of an area of about 3.94 km^2 of the beach (Fig. 6b). The second segment is a concave shoreline extends from El-Qalaa inlet to the City of Pelusium the eastern tip of Tineh Plain triangle. It shows evidence of general accretion with an average of about 5 m/yr. (Fig. 6a), with a total growth of an area of about 1.93 km^2 (Fig. 6b). Similar averages were detected along the coast east of the Damietta Promontory to Port Said (El-Asmar 2002). The accreted sector of the beach is characterized by coarse to medium sands with low concentration of heavy minerals, while the eroded sector is characterized by medium to fine grains with high concentration of total heavy minerals, similarly observed in El-Banna and Hereher (2009). Frihy and Lotfy (1997) studied the shoreline changes along northern Sinai coast. They revealed a significant erosion occurred down-coast east of Port Said, followed by accretion along the embayment of the Tineh bay, the latter is interpreted as a sediment sink. This represents a simple pattern of erosion from the eastern tip of the Port Said headland, with the eroded sand moving by waves coming from the NW. The resulting eastward longshore currents deposited sediments within the embayment of the Tineh bay. Ratios of erosion between −4 to −11 m/yr. and accretion between 3 and 8 m/yr. for both segments of shoreline were detected in El-Asmar (1999) using landsat TM 1984, 1987 and 1999. Kaiser (2009) in evaluating the impact of East Port Said Harbor on the coast of the Tineh Plain indicated an increase from −13 m/year during 1984–1991 to −15 m/year during 1991–2003. The change in shoreline from erosion to accretion is attributed to the change in morphology of the coast and its orientation toward the dominant waves and currents (Fig. 6b); in addition to the amount of sediments drift (El-Asmar et al. 2012, 2014). The controversial variations in measurements and results of shoreline changes deduced from satellite images are due to the accuracy of detection of the line separating seawater from ground, in addition to the resolution of the used images and method.

The strand plain

In satellite image of 1984, the strand plain extends from Port Fouad (west) to the City of Pelusium (east) (Fig. 5 1984). The width of the strand plain varies considerably in a reverse trend to the beach (El-Asmar 1999). It is wider to the west (13 km) where it is occupied with the EL-Mallaha lagoon than the east (1 km). The strand plain is characterized by presence of parallel accretionary beach ridges (Taylor and Stone 1996; Otvos 2000) parallel to the present shoreline (Fig. 8a, b). Some of these ridges are eroded by both wind and anthropogenic activities leaving isolated hills (yardangs) (Fig. 8c). The latter continue for about 25 km forming a series of islands running in El-Mallaha lagoon (Figs. 3a and 5 1984). The beach ridges are few tens of centimeters height and spaced 10–30 m near the City of Pelusium and their width vary from 5 to 30 m (Fig. 8a, b). The beach ridges are composed mainly of medium to fine sands with accumulations of shell debris and characterized by several sets of planar tabular cross laminations. They have been described as very low bundles, set at slight mutual angles which sometimes truncate one another. Dewidar and Frihy (2003) studied the geomorphology and texture analysis of the Tineh plain, and were able to identify 14 textural classes using supervised classification of 1995 TM image data. They indicated that the accreted ridges are mainly composed of clayey sand to sandy clay. It was believed that they had been deposited by the dominant longshore current in front of the deltaic plain along the ancient shoreline, silting up the mouth of the distributary channels and responsible for the degradation of the Pelusiac branch. Sneh and Weissbrod (1973) were able to trace the defunct Pelusiac branch based on the distribution of the archaeological sites at Tell El-Lulli, Tell El-Faram El-Makhazen and Tell Mefarih (Fig. 7d, e). These hills (possibly river levees) have been favorite for the establishment of the villages at elevated areas to avoid drowning risks during floods and at the same time to be close to the fresh water for agriculture purpose and fishing resources.

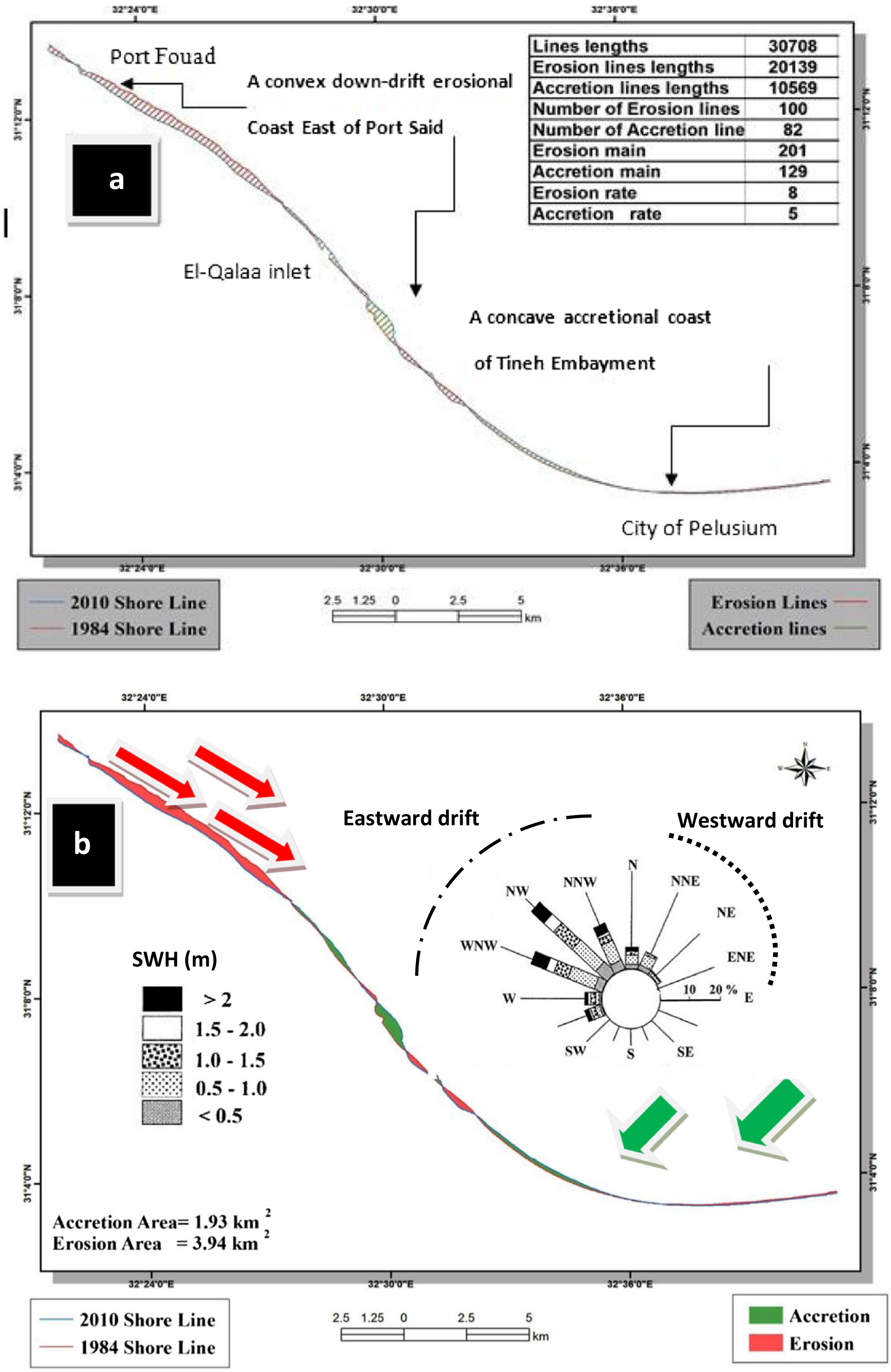


Fig. 6 Detection of shoreline changes from 1984 to 2010, and segments under erosion and accretion, the calculated rates in distance in m/yr (**a**) and the total loss in beach area in km^2 (**b**)

In the present study, shells *Donax spp.,* in addition to debris of bivalves *Anadara diluvia*, *Callista chione*, *Venericardia aculeate*, were collected from the several remnants of accreted beach ridges at different locations (Fig. 9) during our field trips from 1996 to 2005. Five paleoshorelines dated back to Late Holocene, these are from younger:

1. **The present day shoreline 400-500BP,** it is related to the beach mentioned in Al-Makrizi accounts in the 15th

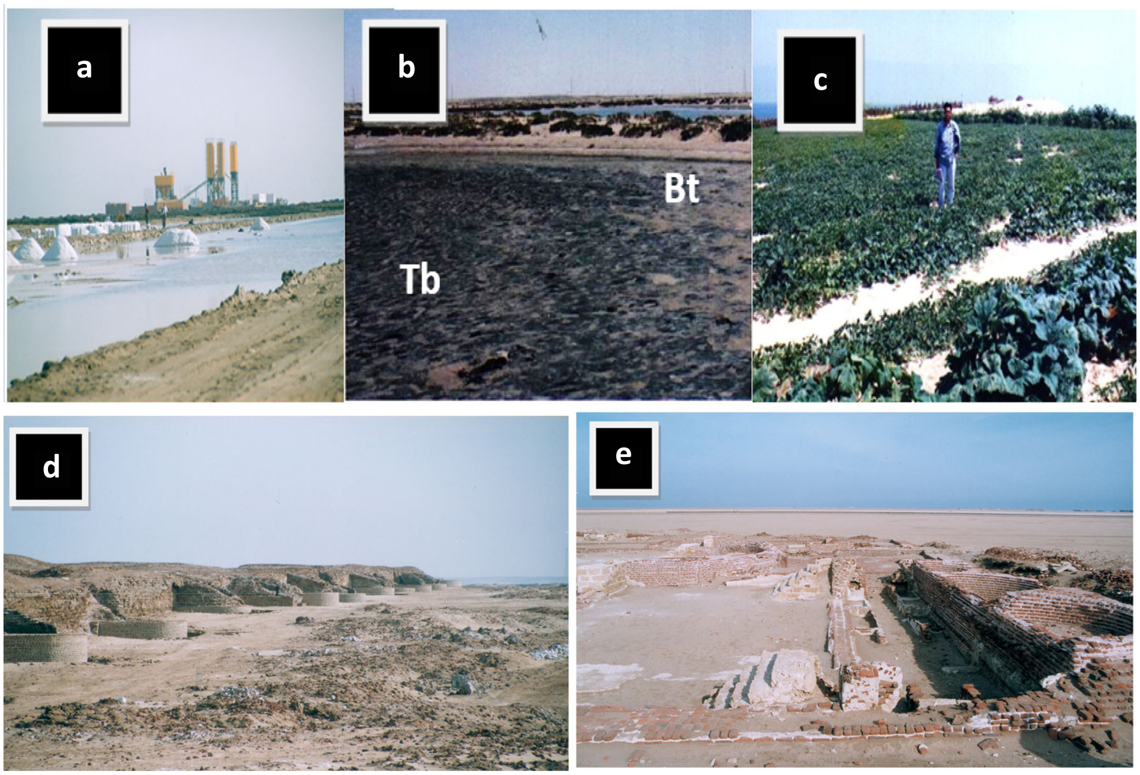


Fig. 7 LU/LC elements in field (**a**) Salt industry near Mallaha lagoon. (**b**) Associated sabkhas with incipient inorganic Teebee structure "Tb" and algal mat Beetee structure "Bt". (**c**) The cultivated land at Tineh Plain. The archaeological sites at Tineh Plain: (**d**) City of Pelusium from outside (**e**) Ruins of Byzantine church at Tell-El Makhzan, near Pelusium

Century, in which he mentioned that in 853–854, the sultan El-Moutawakel built fortifications which was built "next to the sea" (Goodfriend and Stanley 1999; Stanley et al. 2008). Part of these fortifications possibly is of Qalat Um Mefarih near to what is knowen as El-Qalaa inlet.

2. **The shoreline 1100–1200BP,** it is a possible transitional beach associated with Late Holocene short high stand, which continued to the present sea level. This shoreline associated with transgressive phase of the Mediterranean covered Tell El-Farama with deposition of 2 m of sediments (El Gammal 2013). This event continues for a while after 1140BP with evidences of several active faults related to minor tectonic activities associated the Pelusaic line (Fig. 9) related to the last decade and highly affected different parts in Tell El-Faram (Stanley et al. 2008; El Gammal 2013).
3. **The shoreline 1400-1500BP**, it may be related to that described in Goodfriend and Stanley (1999). When the Pelusiac branch receives great floods between 813 and 820, and followed by catastrophic tectonic activity at 870 AD (El Gammal 2013), and a possible high stand of sea level was recorded from 800 to 500 AD (Baeteman et al. 2011). These were responsible on the cut off the Palusiac branch either from the Nile or from the Mediterranean. Evidences of active
4. **The shoreline 1700-1900BP,** it is possibly represents a barrier beach separating an old lagoon from the Mediterranean Sea. It may also originated as a beach ridge derived its sediments from littoral drifted sands delivered by Tanitic and Mendesiasn branches during Late Holocene sea level rise. This beach ridge appears aligned as isolated hills (or islands) and extends in El-Mallaha lagoon (Figs. 3a and 5 1984) Evidence such Late Holocene sea level rise appears associated with a tectonic movement during the "Early Byzantine Tectonic Paroxysm" (EBTP) in Lebanon between ca. 1750 and 2000 BP. (Morhange et al. 2006). Such movement also described in El Gammal (2013) as a catastrophic event affected the Tineh Plain related to 33BC., and in several areas around the Mediterranean (Shennan et al. 2012; Gehrels 2010; Baeteman et al. 2011).

The deltaic plain

The Tineh plain is part of the Nile Delta Plain, the latter is essentially covered with top mud of Bilqas Formation of lagoonal and marsh deposits (Rizzini et al. 1978). Study of several sections excavated along this plain revealed a thick sequence of medium to coarse sands of mouth bar and

distributary channel fill (Fig. 8d), separated by a scoured base with flat bedding to faint cross laminations. A bed of sand and mud intercalations topped the sequence and characterized by the presence of bifurcated wavy flaser and/or wavy bedding (Fig. 8d) related to mid-tidal (mixed) flat as described by Reineck and Wunderlich (1968). Northward, a section is composed of two parts (Fig. 8d); an upper and lower shoreface. The upper shoreface is represented by a sequence of sands of low angle cross stratification (2–10°), formed from a bedload of coarse sands characterized by mega-ripples and sand waves, commonly occurring in wedge shaped sets on the shoreface and bounded by a low angle surface of truncation (Fig. 8e). This represents swash cross stratifications on the boundary of the upper shoreface. The lower shoreface on the other hand characterized by ripple laminated boiturbated sands with mud intercalations (Fig. 8e).

Sustainable development

In the framework of sustainable development, the government of Egypt is decided to include the Tineh Plain in the mega project "Suez Canal Corridor" as phase "A" of the project "East Port Said Phase" (GAFI 2014) (Fig. 10). To achieve the integrated development of East Port Said, an extension for the eastern harbor will establish on 17.130 acres with expected investment of 20 billion LE. An industrial and transit trade area south of the harbor intended to construct on 10.000 acres with expected investment of 120 billion LE, and will comprise a full range of export of heavy, medium and light industries such as chemical industries, electronic, basic construction materials, glass, food, metal, textile, car, and business district. The area will include research and studies center, logistic zone and an exhibition's area. An urban residential city (Port Said New City) is expected to build on 13.650 acres and receives 1.5 million people in Tineh Plain near the City of Pelusium with investments of 75 billion LE through phases. In addition to free trade zone, tunnel, electric train and other recreational facilities for about 10 billion LE. In the Tineh Plain 12.000 acres have been allocated for fish breeding farms and 36.000 acres for reclamation and cultivation. The area of fish breeding farms was allocated on the expense of the stored stiff sticky clayey dredged materials accumulated in alternation with thick salt beds during excavation of the old Suez Canal, while that of sands were used for reclamation and

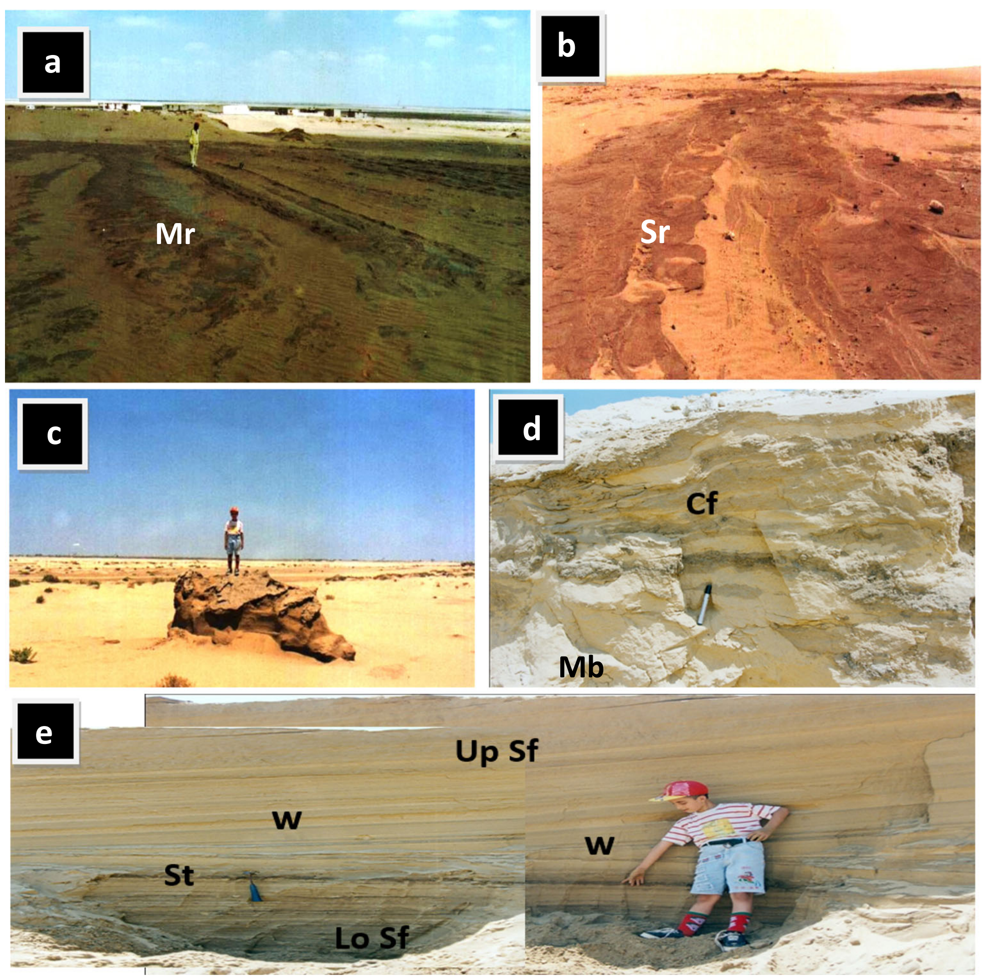


Fig. 8 Geomorphology and field Geology of the Tineh plain: (**a**) Accreted beach ridges of mega ripples "Mr" 1.5-2 m apart and about 60cm height a characteristic feature of mid-tidal (mixed) flat, (**b**) superimposed small ripples "Sr" at some ridges. (**c**) Small yardang represent part of accreted ridge subjected to wind erosion. (**d**) The mouth bar "Mb" structure less bottom of coarse to medium sands and distributary channel fill "Cf" of intercalated mud with sands forming bifurcated flaser and/or wavy bedding. (**e**) The deltaic plain surface composed of sands of upper shore face "Up Sf" with the characteristic low angle cross stratification at the contact of the lower tidal flat and swash subparallel to base of wedge shaped sets "W" bounded by surface of truncation "St", the lower shore face "LoSf" with the characteristic rippled bioturbated sands intercalated with thin mud laminae

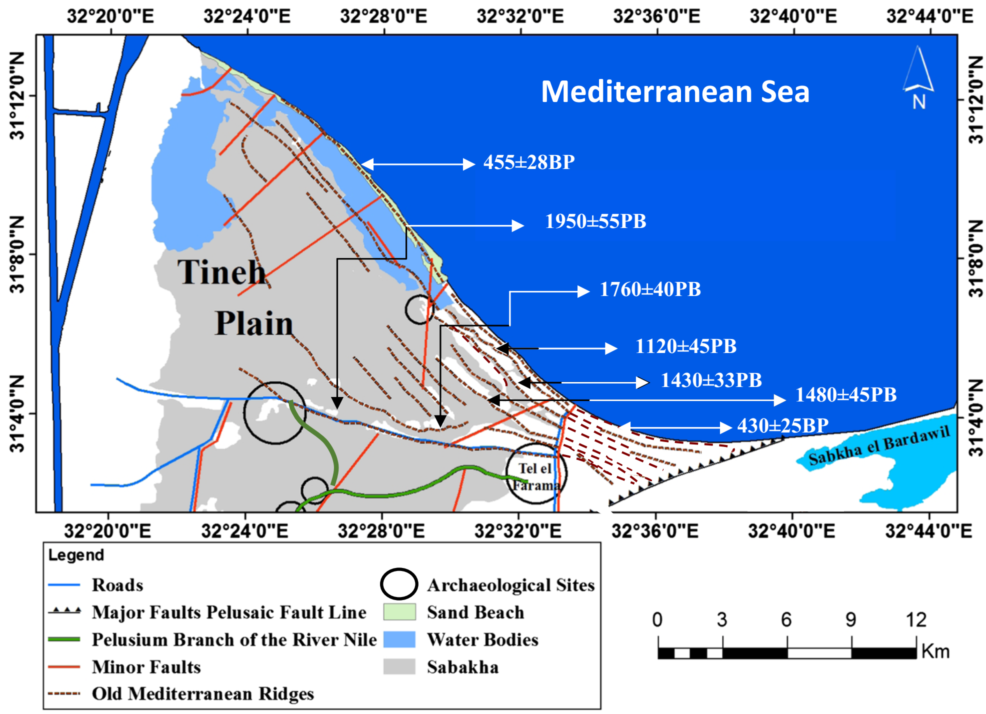


Fig. 9 Structural elements and accreted beach ridges with ages along the Tineh plain (modified after Stanley et al. 2008; El Gammal 2013)

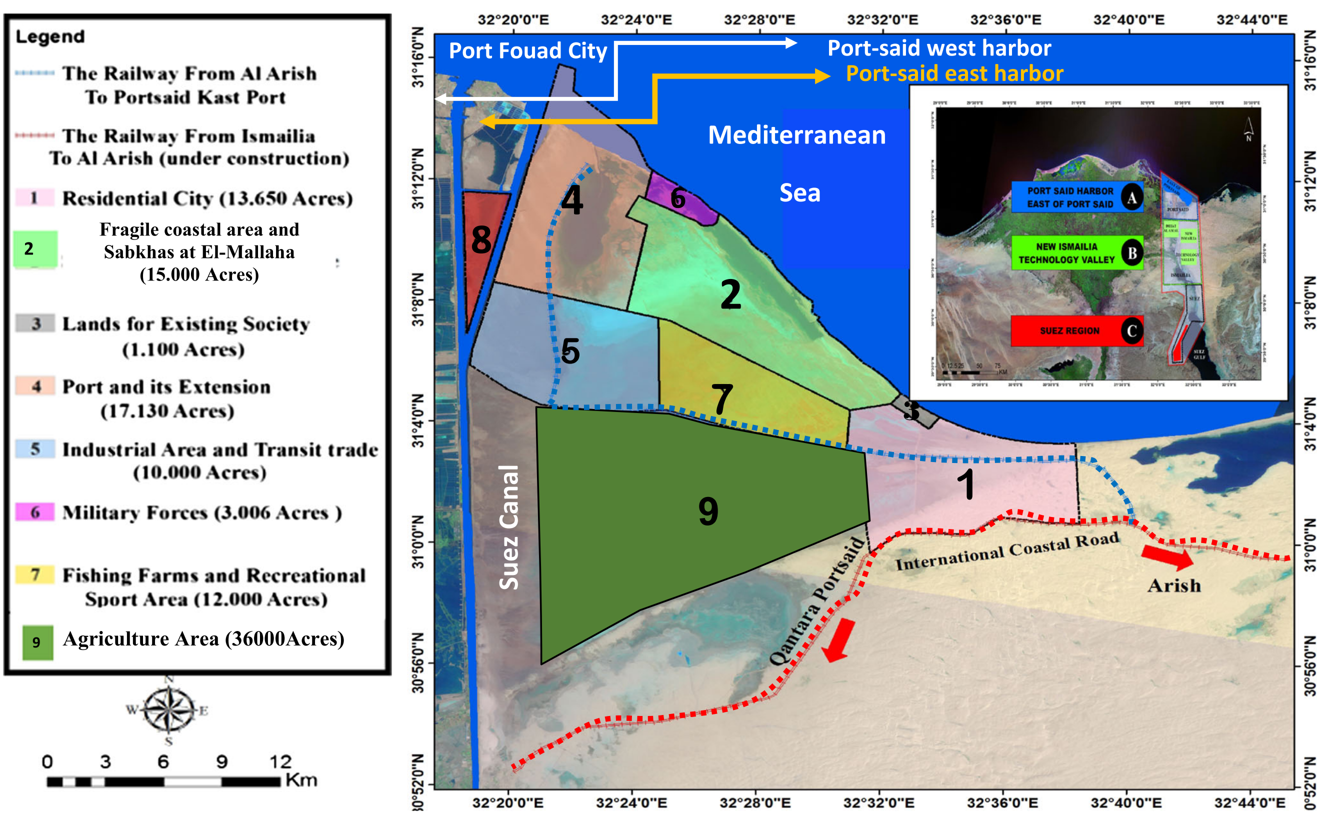


Fig. 10 The Mega project "Suez Canal Corridor" Stage A "East Port-Said" showing the main activities expected at the Tineh Plain (modified from GAFI 2014)

cultivation reflecting how sedimentary lithofacies characteristics controlled human development activities. The Suez Canal Corridor ambitious project forget the rehabilitation and restoration of the fortifications of Tineh Plain at Qalat Um Mefarih, Tell El-Luli, Tell El-Farama and other sites, and to put them on touristic agenda of the project. Although we acknowledge the consideration of fragile coastal area and Sabkhas at El-Mallaha (15.000 Acres) for aquaculture area, we warning from the stress on this soft fragile sediments, especially in the presence of such evident tectonism and human activities for fish breeding and reclamation with consequent water uses,, which may represent hazardous problems that may threaten the archeological sites .

Conclusions

The present study is an attempt to demonstrate how geologic processes of a region greatly contribute in carving its topography, reflected on its geomorphology, and control the development activities. To achieve this study, satellite data acquired for years 1984, 2000, 2006, 2008 and 2010. In addition, several field verification, lithofacies description, unit sampling and photographing were conducted.

This study clearly show three geomorphic units: the beach, the strand plain, and the deltaic plain. The beach is flat with concavo (accreted) –convex (eroded) shoreline. The strand plain made of accreted beach ridges of very low bundles, set at slight mutual angles, which sometimes truncate one another. These were tens of centimeters height and spaced 10–30 m, their width vary from 5 to 30 m, composed mainly of medium to fine sands with accumulations of shell debris, and characterized by several sets of planar tabular cross laminations. The deltaic plain surface composed of intercalations of sand and mud of shoreface, mouth bar, and distributary channel fill. The accreted ridges representing four paleoshorelines related to Late Holocene and dated back to 400–500BP, 1100–1200BP, 1400–1500BP, and 1700–1900BP. They may explain the history of Late Holocene sea level coupled with the history of River Nile flood and active tectonics.

Change detection of LU/LC show six classes; the beach, the wetland (El-Mallaha lagoon), sabkhas or salt marshes, urban, agriculture, and fish breeding farms. In 1984, the beach (4.2 km^2), El-Mallaha lagoon (26.4 km^2), sabkhas or salt marches (236.7 km^2) were reduced due to expansion of agriculture (120.3 $km^{2)}$, fish breeding farms (35.7 km^2), and to a lower extent the urbanization.

The present study illustrates the impact of geology on most development activities. To the north of El-Salam Canal, the increased salinity in the strand plain and sabkhas limits the development activities and forced rural and bedouin to construct fish breeding farms in order to overcome high salinity and help in washing sediments. Such circumstances is completely different south of El-Salam Canal, where sediments are mainly deltaic and dune sands, most activities oriented to reclamation and cultivation. The expansion of activities of fish breading farms appears threatening the archaeological sits at Tell El-Farama and neighbors, and may represent future hazardous problem.

This study clearly demonstrates the important to consult geology before establishing hub projects, and raise alarm of constructing heavy industries and other logistics related to shipping in Tineh Plain in the framework of Suez Canal Corridor Mega Project due to active tectonism, the characteristic of sediments, and related wet, soft fragile environments. The activities related to agriculture, fish breeding, and salt industries are recommended in the framework of sustainable development. It is important to include the master plan of the Suez Canal Corridor Project a chapter on the processes to save the ruins of fortifications of Tineh Plain. These are not only Egyptian heritage but also a world one record the history from the Persian invasions of Egypt about 6th or 7th Century B.C. through, the Byzantines in 859–860, the Greeks in 954–955, the Arabic Conquest, and the Crusaders in the 12th Century. Efforts of the international organization such as UNESCO should be implemented in this concern.

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