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Identifying Geomorphic Features between Ras Gemsha and Safaga, Red Sea Coast, Egypt, Using Remote Sensing Techniques

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Abstract. The dynamic nature of Ras Gemsha-Safaga coastal zone along the Egyptian sector of the Red Sea and its targeting for future development necessitate updating the available information on its geomorphology and on distribution of its landforms and natural habitats. In order to provide information of this kind, a rapid and replicable technique is inquired. The synoptic capability of remote sensing images from Landsat and other similar satellites enable mapping of large sections of coasts at satisfactorily accuracy. In this study, an image from Landsat ETM+ acquired on 9 September 2000 has been processed and results of remote sensing analyses have been combined with field observations and reference data to delineate and describe the main geomorphologic and topographic features of Ras Gemsha-Safaga coast. Principal component analysis (PCA) and false color composite (FCC) were found to be among the most successful remote sensing techniques for mapping of geomorphologic features of the mainland. A combination of bands 3, 2, 1 in a RGB display (*i.e.* true color) was found the best to demonstrate submerged reefs and areas of high density reefs. Following this approach, it was possible to identify most prominent geomorphic units and landforms of the study area. These include fluvial terraces, fossiliferous reefs, alluvial fans, desert wadis, salt pans and sabkhas, spits and sand bars, and submerged reefs.

Keywords: Coastal landforms, geomorphology, Ras Gemsha-Safaga coast, remote sensing, mapping methods.

Introduction

Identification of geomorphologic features and landforms of a certain area can help in deciphering crucial information on the underlying bedrock types as well as, on the past and present physical processes that affect it. Raised coral reefs and beach ridges, as example, can be taken as a geo-indicator of past sea level changes, whereas, fluvial terraces give clues to the previous torrents and floods. In the same manner, seagrass meadows can be used as geoindicator of relatively calm water and sandy sea bed, whereas, occurrence of coral reefs reflects prevalence of hard-type sea bottom. Other useful morphologic indicators include erosional beach scarps or paleo-sea cliffs, coastal dunes, spits and sand barriers, alluvial fans, streams and drainage channels, desert pavements, *etc.* (Morton 2002).

Study the dynamics of coastal landforms and their interrelations to lithology, structures, and other land-cover types can also help in controlling and mitigating natural hazards (*e.g.* storms, torrents and floods) and in improving quality of geotechnical and engineering constructions.

The Red Sea coastal zone between Hurghada and Safaga is one of the most growing areas not only in Egypt but also in the Middle East. Importance and tranquility of this area refer to its intrinsic beauty, diversity of natural resources and spectacular geological and geomorphologic features.

Prior to 1980s, the Egyptian sector of the Red Sea was almost virgin and devoid of any human activities, except for some oil exploration operations (Head 1987). With re-opening the Suez Canal for international navigation, discovery of oil, and resolution of the political and military conflict between Egypt and Israel, the area has been subjected to intensive development *e.g.* tourism and recreation, oil exploration and production, mining and quarrying, and urbanization. However, most of this development was rapid and uncontrolled. Rapid development, in addition to improper human activities, resulted in some annoying environmental problems and degradation *e.g.* loss of habitats, pollution, over-exploitation of natural resources and erosion and accretion of the shoreline, and haphazard urbanization (Hawkins and Roberts 1994a &b, Frihy *et al.*, 1996 and GEF 1997, 1998a & b, Riegl and Piller 2000, El-Gamily *et al.*, 2001 and Dewidar 2002).

Lack of up-to-date information on natural resources and on land-cover types of the study area, played an indirect role in appearance of these problems. Decision makers and other stockholders usually need accurate and up-to-date information on dynamics and status of the prevailing natural resources and land cover types. Scarcity of this kind of information represents one of the biggest constrains for the decision makers to take the proper management action and planning (Chopra & Sharma 1993, Gowda *et al.*, 1995 and Bocco *et al.*, 2001). This, in turn, reflects the urgent need to devote a special effort to map geomorphologic and land cover types of the study area.

In this connection, the present study tries to utilize satellite data from Landsat Enhanced Thematic Mapper Plus (ETM+) for updating the available information on the geomorphology of the study area. The main objective of this study is to precisely define the boundaries between the main landforms of the study area. The study is part of a larger effort to fully understand the physical nature of the area and all geomorphic factors which shape it.

Study Area

The area of interest occupies the coastal strip between latitudes 26°38′05″N and 27°44′05″N (Fig. 1) on the NW part of the Red Sea coast (~ 5 km north of Ras Gemsha and ~ 15 km south of Safaga town).

Prominent geomorphic features of the study area include crystalline escarpments and sedimentary formations, fringing and submerged reefs, raised fossilliferous reefs, fluvial terraces, coastline headlands and embayments, and offshore islands.

Human and developmental activities in the study area include tourism and recreation, coastal development and urbanization, oil exploration and production, mining and quarrying activities, shipping and harboring. Increased coastal tourism has led to increased coastal urbanization. Quarrying for construction material has been developed at some sites nearby to Hurghada and Safaga to meet the ever increasing needs of coastal development and urbanizations. Light mining is practiced at small scale, particularly in near Safaga.

Expansion of these activities in time and space together with the effects of some natural factors like intermittent torrents and heavy rains, involved in a widespread change in physiography and geomorphology of the study area.

Tourism and recreation is the fastest most-growing industry in the study area. Resort development along the coast, particularly, between Hurghada and Safaga expanded rapidly during the last two decades with the result that the coastline beginning from north of Hurghada to Safaga has been transformed from pristine coast into ‘concrete’ strip of tourist hotels and recreational facilities (Hawkins and Roberts 1994b).

Source of Data

The approach which has been used here to describe the geomorphologic characteristics of the study area is based on a combination of remote sensing data analysis and field observation in some key areas.

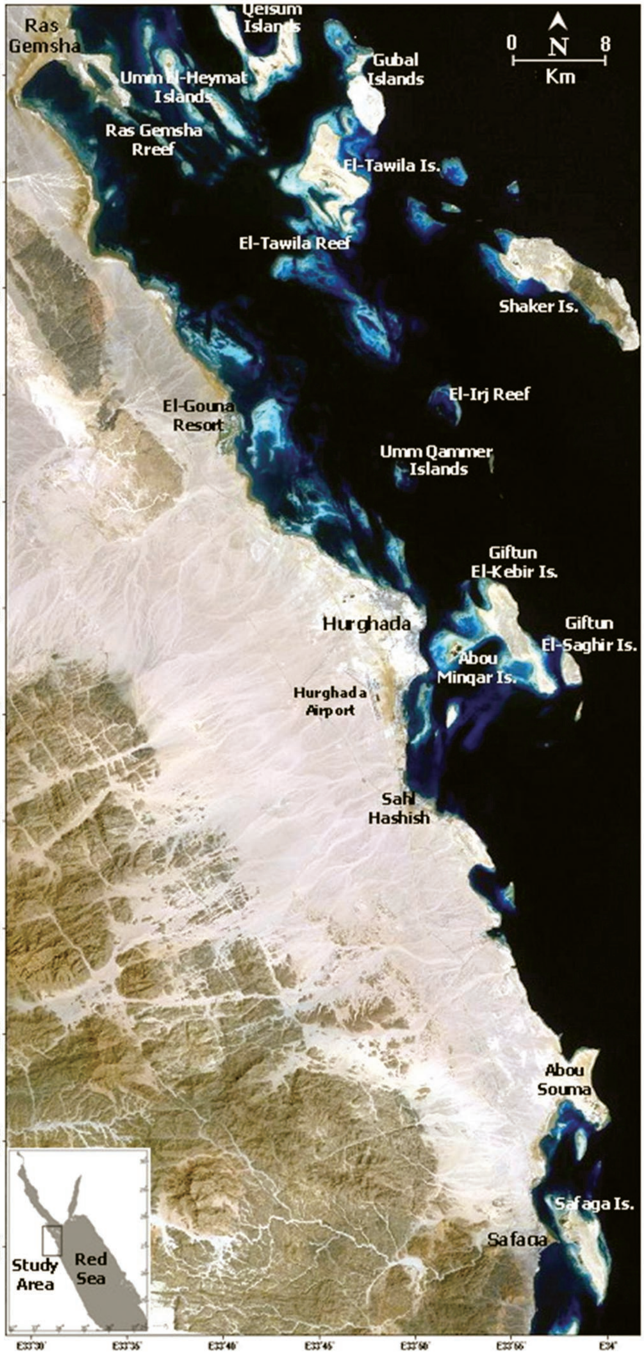

Fig. 1. Landsat ETM+ in true color acquired on 10 September 2000 for the study area.

Remote Sensing and Collateral Data

An image from Landsat ETM+ that corresponds to the WRS-2 path 174, row 41, acquired on 10 September 2000 was utilized for this study. The image is of good quality and contains no effective haze or clouds. The sun elevation at time of acquisition (~ 58º) is suitable for study of geology and geomorphology in such tropical area. Figure 1 demonstrates a true color combination (visible bands 3, 2, 1 in a RGB display) of the Landsat ETM+ image utilized in this study. In addition to this, different forms of collateral data were utilized for this study. These include 1:50,000 scale topographic maps (Egyptian General Survey Authority, 1989) and 1:500,000 and 1:250,000 scale geologic maps (Geological Survey of Egypt, 1984 and 1992, respectively).

The Landsat ETM+ is the seventh generation (L7) in a series of satellites launched by NASA beginning from early 1970s. The ETM+ sensor which is carried onboard has the same essential multispectral spectral bands and the same spatial resolution (30 m) as its predecessor; the Thematic Mapper (TM). These include band 1 (B1), band 2 (B2), and band 3 (B3) in the visible spectrum, band 4 (B4) in the near infra-red, band 5 (B5) and band 7 (B7) in the mid infra-red. One of the most significant improvements of this generation is the addition of an 8th panchromatic broad band (PAN) operating in the 0.50-0.90 um range (visible and near infra-red) with a spatial resolution of 15 m. The spatial resolution of band 6 (thermal infrared) has also improved to 60 m resolution instead of 120 m as in the TM sensor. Furthermore, high and low gain settings have been used with this band to adapt imaging of high and low reflection areas (Landsat-7 Science Data Users Handbook).

Field Data

To interpret image features and verify indistinct elements, a field trip to key locations within the study area took place during January 2001. Collection of data and locating visited sites were carried out using Global Positioning System (GPS) receiver (Magellan GPS NAV 5000 Pro). Also, interviews with inhabitants or specialists were conducted when needed to retrieve historical information or facts about specific element. True and false color composite reprints of the scene in various scale (1:100,000 to 1:35,000) were accompanied in the field to be used for locating and verifying the checked remotely sensed elements. In addition, other base-line information and observations collected during a field visit in October 1997, in context of participation of the authors in a research project for establishing a sensitivity map for the NW Egyptian Red Sea coast, were also used in this study.

Remote Sensing Data Processing and Techniques

All image processing was performed using ER Mapper (version 5.5 under Windows), which is one of the most popular image processing tools (Earth Resources Mapping 1996).

Image Pre-Processing

Geometric correction and geo-referencing (Transverse Mercator Projection and Helmert 1906 spheroid) was done by using points of precisely known geographic positions, *i.e*. Ground Control Points (GCPs). At first, the panchromatic band was selected as a base for the image to map registration process. The reason is that it offers better spatial details and enhanced resolution than the other multispectral bands. Geometric correction was achieved by using 32 well distributed GCPs extracted from 14 base topographic maps of scale 1:50,000 (Egyptian General Survey Authority, 1989) and a second-order polynomial transformation at root mean square (rms) error of 0.9 pixel (*i.e.* 14 m) and using the nearest neighbor sampling algorithm.

Next, this band was used as a reference in image to image registration process. Co-registration to the multispectral dataset was achieved by using 42 GCPs and a 1^{st} order polynomial transformation with an rms error of 0.25 pixels. The nearest neighbor method of sampling was used to maintain the original pixel brightness values and to resample the pixels at a spacing of 30 m in both directions. Evaluation of results of geometric correction and co-registration was carried out using another set of GCPs and also by overlapping each dataset over another to ensure that these sub-images cover an identical ground area.

Image Analysis

In an effort to accurately delineate rock units and to efficiently identify the geomorphological characteristics of the study area, many merging techniques were employed to merge the grayscale panchromatic band (15 m) with the other multispectral bands (30 m). The product is a composite between the two input data type, *i.e.* an enhanced multispectral images that offer better spatial details (15 m resolution) and more capabilities than the original. Of all merging techniques, merging by Principal Component Analysis and overlying of panchromatic band as Intensity Layer over the Red-Green-Blue (RGB) display (*cf.* ER Mapper 5.5, Earth Resources Mapping 1996) were found the most effective techniques.

In another separate effort, a binary mask or gray-level thresholding (Lillesand and Kiefer 2000) was applied so as to segment the image into two main sections; land and water. The masking effect has the advantage of stretching a specific dynamic range into the maximum possible scale (0-255) yielding an image of more details and much better contrast and hence better interpretability, comparing to the original non-masked image (Fig. 2).

Next, some of the most effective image processing techniques were applied to this product so as to enhance its appearance and embedded information. Among other techniques, the False Color Composite (FCC) and Principal Component Analysis (PCA), were found to be the most effective for identifying and mapping of landforms and geomorphologic features of the study area. On each product, landforms, rock units and natural habitats have been recognized mainly by their distinctive spectral signatures, color, tone, texture, pattern, size and shape. Ambiguity between similar elements was resolved mainly by field check.

False Color Composite (FCC)

An FCC product is by no means the most potential way of visual interpretation of multispectral image (Novak and Soulakellis 2000). A water-masked FCC of bands 7, 4, 1 in RGB display (Fig. 2), was found very useful for discrimination of lithology and rock units of the study area. Bands used in this composite reflect variations caused by ferric and ferrous iron (Band1), iron oxides and hydroxides (Band 4) versus OH-bearing minerals, clays and layered silicates (Band 7) (Crippen 1989 and Kenea 1997). This composite was found useful also for delineation of other landforms like sabkhas, salt pans, alluvial fans, coralline and fluvial terraces (Fig. 2). Addition of PAN as an 'intensity layer' over this composite gave image of almost the same spectral appearance but with much improved spatial details. Disadvantages of this addition include lowering the overall contrast of the image, in addition to, limitation of this product to display purposes only.

A water-masked composite of band ratios B5/B1 in red display, B4/B1 in green and blue (single) band in blue, was found the best and most potential product for mapping lithology, landforms, and wadi vegetation (Fig. 3A). Band rationing technique is very effective for lithological discrimination as it removes shadows and topographic effects, particularly in mountainous areas.

Principal Component Analysis (PCA)

The PCA is one of the most popular multivariate analysis that removes the redundancy in image bands and reduce them into meaningful ones without effective loss of the original information. It might be performed in either a selective manner, *i.e.* some bands are selected only for the analysis rather than all bands or in a collective manner, whereby all bands are entered for PCA analysis (Singh 1989).

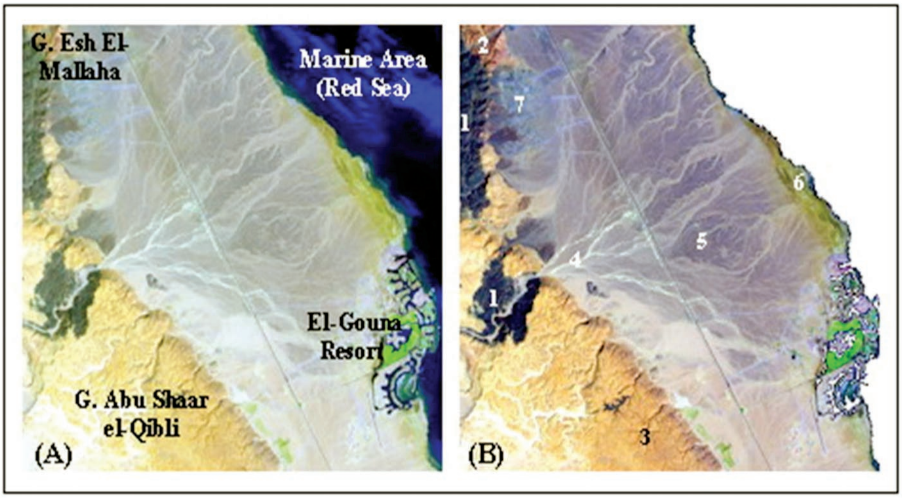

Fig. 2. Effect of binary masking on image appearance and interpretability. Image (A) shows a FCC of bands 7, 4, and 1 in RGB display without masking, whereas image (B) shows the same area after binary masking of water. Numbers in image (B) denote: (1) Mafic metamorphic rocks, (2) Younger granites, (3) Miocene coralline facies, (4) Flood streams, (5) Fluvial terraces, (6) Semi-wet sabkha, (7) Quarrying area.

In the PCA image, spectral differences between materials usually become more apparent than in individual bands. The best results were given by a composite of correlated principal components (PCs) 4, 2, 1 (Fig. 3B) and PCs 6, 2, 1 in a RGB display.

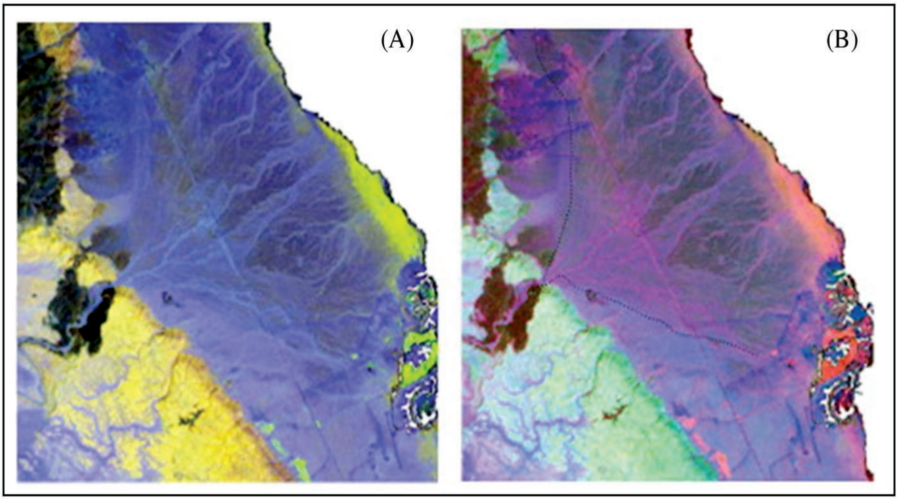

Fig. 3. Image (A) is a composite of B1, B4/B1, and B5/B1, B4/B1 and B1; and image (B) is a composite of PCs 4, 2, 1 (in RGB display).

Results and Discussion

The following is a general description to the main geomorphological features and landforms of the study area, as revealed by integration of remote sensing and field observations:

Basement and Sedimentary Hills

They form one of the most prominent features of the whole Red Sea coast. They run on the mainland more or less parallel to the coastline leaving a relatively narrow coastal plain of about 15 km wide in average before encountering the marine area. The area north of Hurghada is the only exception to this, as the coastal plain extends for more than 35 km before it slopes up to a resistant basement and sedimentary heights. These hills consist of uplifted crystalline and high-relief sedimentary rocks of variable height and composition (Plate 1A). The highest mountain in the area is Shayeb el-Banat. It is located at about 40 km SW of Hurghada and rises up to 2187 m (Said 1962). The Red Sea hills in the study area are dissected occasionally by wadis and fluvial channels which are activated sporadically during flood and rain periods. These tributaries run mostly in NEE-SWW and W-E directions and supply the adjacent basins, by alluvial sediments.

The basement rocks dominate the study area, whereas, the sedimentary formations are concentrated only to the north of Hurghada town. Effect of erosion and faulting is more pronounced at the basement hills to the SW of Hurghada. Erosion by floods, weathering effects together with faulting and other structural activities, have rendered the large massive basement shield in this area into discrete blocks, some of which are sub-rectangular in form (see Fig. 1). In the northern and southern parts of the study area the joint/fault system is less pronounced. This may explain why the basement range at these parts is more coherent and massive than the central area.

Coastal Plain

The coastal plain forms a flat, narrow and irregular strip between the basement relief and the fringing reef and water area. It rarely exceeds 15 km in width and almost disappears at Safaga. However, the area north of Hurghada has a vast coastal plain where it attains about 35 km in width before it meets a very rugged hilly terrain. The peneplained surface of the coastal area (Plate 1B) is interrupted occasionally by either salt-encrusted depressions/salinas, gently inclined fans and fan deltas, small dunes low hills or by fluvial and coralline terraces (see Fig. 1).

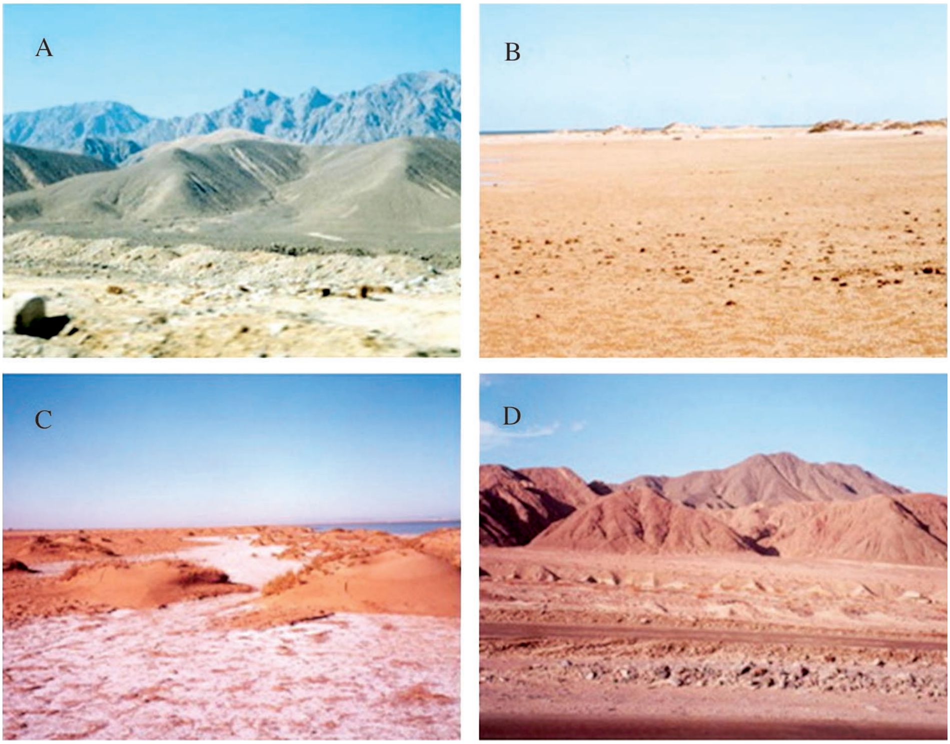

Plate 1. Field photos show the following geomorpholocial features: (A) Sedimentary hills and basement shield (in the background), (B) Wide coastal plain with coastal dunes (at the left), (C) Vegetated micro-dunes with salt deposits, (D) Alluvial fan east of El-Esh mountain.

Extensive parts of the coastal plain are covered by desert pavements which derived from the adjacent basement rocks. Dense desert pavements are identified by their dark tone on FCC image (Fig. 2B). In other localities, fluvial terraces are covered by thin veneer of coral fragments. Arvidson *et al.* (1994) ascribed occurrence of this veneer to effect of storms which tend to disrupt coral fragments from fossil coral reefs to be transported elsewhere. The coralline veneer appears on FCC image in the form of whitish patches similar in spectral signature to Late Pliestocene coralline limestone terraces (Fig. 4).

Coastal and Inland Dunes

Coastal and inland dunes, in the study area are not widespread or well developed. The coastal dunes are concentrated mainly in the backshore zone, mostly in the form of 'nebkhas' (low height dunes or sand hills fixed by halophytic vegetation or other rooted plants) (Plate 1C). Inland dunes are limited to wadis and escarpment slopes and appear in the form of climbing dunes and cliff-top dunes. Being under the minimum mapping unit (15 m) together with their similarity to the surrounding deposits, makes it difficult to identify these dunes on the utilized satellite image.

Alluvial Fans and Fan Deltas

Alluvial fans are formed in the piedmont slope and around outflow points of the drainage network to the coastal plain. Fan initiation is due to drastic reduction in gradient between the eroded wadi and the receiving basin that lead to sudden lowering in velocity of floods and therefore deposition of its load (Miliaresis and Argialas 2000). Fan deltas are formed by a similar mechanism when the transport potential of a wadi is being high enough to deliver part or most of its sediment load into the nearshore water area.

The study area is characterized by a set of coalescing alluvial fans of Quaternary age (Purser 1985). These fans slope out from the Precambrian escarpments and spread in fan shape toward the coast (see Plate 1D and Fig. 3). Alluvial fans are well developed in the northern parts especially in the undulating area below Esh Mellaha block. This may be ascribed to the fact that wadis of this area are relatively narrow and steep. In effect, extensive quantities of clastic sediments are delivered at time of floods and heavy rains to the low lying piedmont plain, to eventually form extensive and coalescing alluvial fans.

According to Braithwaite (1987), most of these fans were formed during periods of heavy rains (Pliocene to Pliestocene) when wadis were very active and able to deliver and spread huge quantities of weathering products to the receiving basin. Most of these fans are covered by thin veneer of desert varnish and relict rock fragments (Fig. 4). In some other parts of the study area, alluvial fans comprise essentially pink granitic clasts and therefore appear in the field in a distinctive pink color.

Fluvial and Coralline Terraces

They form a significant landform along the coastal plain as they extend in the form of series of reefal or fluvial terraces on the shore area notably between Hurghada and Abu Souma. Reefal terraces, remarkably, form most of the rocky shores in this area and locally, extend up to 8 km inland. Fluvial terraces are more frequent landward and often slope gently seaward (Plate 2A). They can be clearly demonstrated in wadis and flood channels, whereby walls of wadis often expose alluvium interbedded with coralline limestones. Coralline terraces are situated close to the coastline and may rise up to 30 m in height (Plates 2B and 2C). The reefal and fluvial terraces are of Early to Late Pleistocene in age (Braithwaite 1987). Interbedding of reefs and alluvial deposits suggests a

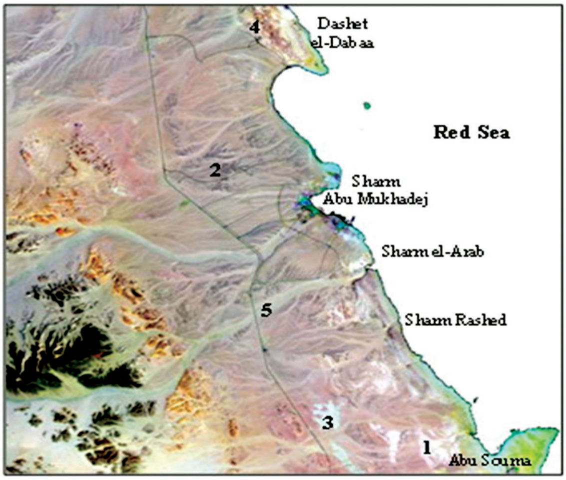

Fig. 4. Water-masked FCC of band combinations 7,4 and 1. Numbers denote some of most prominent features of the study area. These include (1) Fluvial terraces covered by a thin veneer of reworked coral fragments, (2) Quaternary fluvial terraces covered by desert pavement, (3) Quaternary evaporites, (4) Late Pleistocene coralline terraces, and (5) Wadi channel.

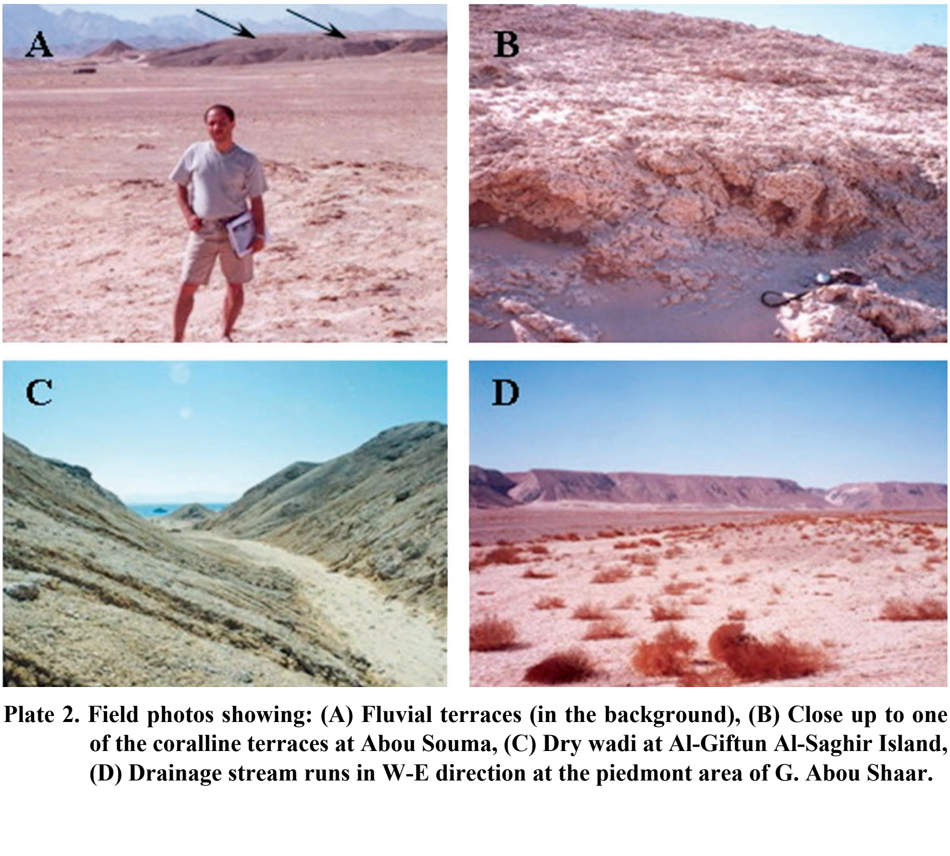

Plate 2. Field photos showing: (A) Fluvial terraces (in the background), (B) Close up to one of the coralline terraces at Abou Souma, (C) Dry wadi at Al-Giftun Al-Saghir Island, (D) Drainage stream runs in W-E direction at the piedmont area of G. Abou Shaar.

general glacial-interglacial rhythmicity and therefore, reflect fluctuation of the Pliestocene climate and eustatic sea level (Ezzat *et al.*, 1993, Freytet *et al.*, 1993, El-Moursi *et al.*, 1994 and Plaziat *et al.*, 1995 and 1998). According to Arvidson *et al.* (1994), coralline limestones formed during sea level highstands when sediment was trapped upstream. During lowstands, wadis cut into sedimentary deposits and generated fluvial terraces. Outcrops of coralline limestone and terraces appear as white areas on FCC 741 product (Fig. 4).

Wadis and Drainage Channels

The sea coast of the study area is dissected by several major wadis. These include Wadi Esh el-Mellaha, Bali, Falq el-Waar, Falq el-Sahl, Abu Mukhadej, Sharm el-Arab, el-Falij and wadi Abu Assala. All of these wadis cut through the basement and sedimentary rocks and trend, mostly in NEE-SWW and W-E (Plate 2C).

In the past, especially during the pluvial period, these wadis were much more active than today. They played, therefore, a major role in development of alluvial features on the coast, *e.g.* alluvial fans, fan deltas, alluvial plain and also in controlling reef growth. Today, rains and hence sediment flux to the coast became more limited due to aridity of the weather and consequently, the erosional effects became restricted to the present day occasional floods (Plaziat *et al.*, 1998).

Results of image analysis show that the drainage in the southern parts has a dendritic pattern and coarse texture, whereas, it becomes sub-rectangular at the central area, as well as, at the basement rocks of the northern parts. Drainage at the coralline limestone platform of G. Abu Shaar is dendritic and fine in texture (Fig. 4).

Close to the coastal plain, the drainage systems turn to parallel or sub-parallel and become weakly expressed as they dissipate throughout the peneplained alluvium. In the northern parts, recent stream activity is apparent and resulted in series of flow streams (Plate 2D). Pathways of these streams were very apparent in the field, as well as on, the image. These streams can be recognized on FCC 741 by their bright whitish color and by their specific course which emerge from an inland wadis and head towards the sea in a fan form (see Fig. 2 and 5).

Sabkhas and Salt Pans

Sabkha is an Arabic term means 'salt-enriched flat areas'. They are developed under arid to hyper-arid conditions on supratidal and intertidal surfaces by progressive evaporation of the standing high water or interstitial water (Purser 1985) that may be derived by underground infiltration. The salt may be clearly visible in form of crystals or as white patches of thin salt crust on the surface (Plate 3A). Presence of salts is manifested by appearance of moisture which, in turn, makes the host soil very dark in color (brown to brownish black). Even when a sabkha become a dry, the moist appearance is retained (Bahafzallah *et al.*, 1993, Sabtan *et al.*, 1995 and Al-Saifi and Qari 1996).

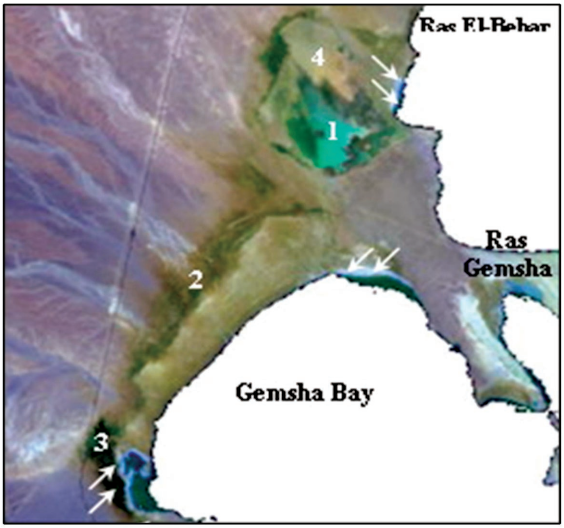

Fig. 5. Another example from the last image product (water-masked FCC of band combinations 7, 4 and 1) showing differentiation in sabkha phases and soil moisture: (1) Salt pan or wet sabkha, (2) Semi-wet sabkha, (3) Vegetated sabkha, and (4) Dry sabkha. Arrows point to the supratidal salt crusts which are being formed by evaporation.

Sabkhas in the study area form a prominent feature as they occupy very long tracts of the mainland coast. They are best developed at the northern extremity of the study area, definitely at Ras El-Behar; north of Ras Gemsha, where they extend southwards, as far as north of Hurghada (Fig. 5). Sabkhas of this area vary between wet and semi-wet types. The coastal strip to the south of Hurghada hosts also long tracts of sabkhas of the semi-dry type.

In the field, sabkhas are distinguished by their mottled brown to buffy surface and are marked by embryonic dunes, nabkhas, halophytic plants (zygophyllum) and by sporadic occurrence of isolated thin salt crusts (Plate 3A). Small lenses of light colored dry wind-blown sand deposited, occasionally, over the salty soil and hence, interrupt continuity of sabkha surface (Plate 3B). This type of sabkhas coincide with the incipient type (zone 1) given by Bahafzallah *et al.* (1993) and Sabtan *et al.* (1995) in their work on Dahban, north of Jeddah, Saudi Arabia.

On a FCC of band combinations 741 (or on true color image (3,2,1 in RGB display)), sabkhas can be identified by irregular brown tracts on the backshore zone (Fig. 5). Tracts which are inhabited by halophytic vegetation appear in greenish brown color whereas those encrusted by gypsum or halite appear in white patches very similar to that of playa streams deposits of flood streams.

Coastline Landforms

The coastline between Ras Gemsha and Safaga exhibits some of the most conspicuous geomorphologic features of the region. These include sand spits, sand bars, sandy and rocky beaches, intertidal sand- and mud-flats. They are best displayed on a false color composite of bands 7, 5, 4.

Two prominent spits can be identified in the study area. The first is developed in the intertidal area south of Hurghada. It emerges above the sea level most times and extends for about 550 m inside the sea during low tide, whereas, it become submerged during the high tide condition (Plate 3C). The second prominent spit is located south Abu Souma Bay and is little bit longer (600 m) than the northern spit (see Fig. 6). Sand bars are well developed in the northern part at Esh Mellaha and el-Gouna foreshore areas and also in the southern part.

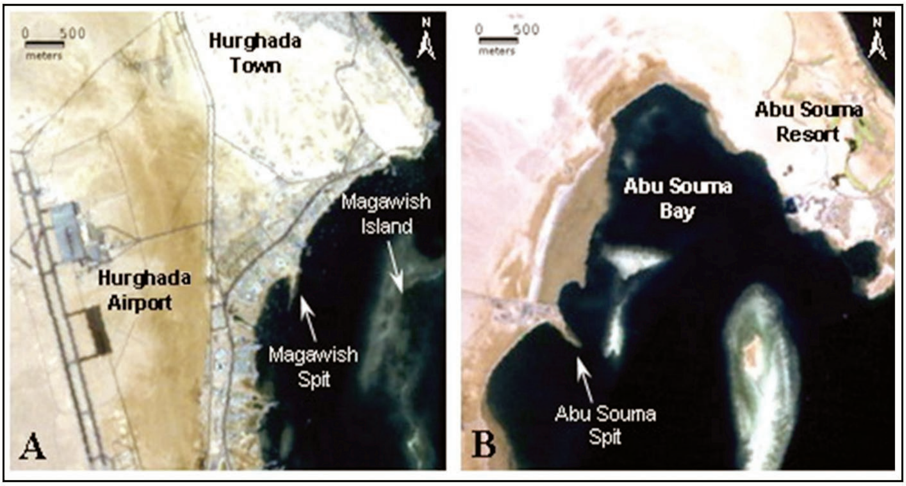

Fig. 6. Two of the most prominent sand spits of the study area as displayed by a true color image. (A) The sand spit south of Hurghada and (B) The sand spit south of Abu Souma.

Rocky beaches occur only at areas where the coastline is fringed by the Pleistocene reefal terraces at Hurghada, Dasshet el-Dabaa and Ras Abu Souma. In some locations, fossil terraces may rise few meters high above the beach and therefore, form cliffy beaches. Sandy beaches are well developed north of Hurghada, Abou Souma Bay, and south of Safaga (Plate 3D). The sandy beach at Abou Souma Bay represents one of the most spectacular sand beaches along the entire Egyptian Red Sea coast.

Similarly, vast intertidal sand-flats are normally developed at wadi mouths and bays that are fronted by wide reefal flats and receive sheet floods intermittently. Terrigenous sediments carried by flood streams find its way to the intertidal area where it is reworked by the prevailing currents. Firstly, silt and fine grains drifted away offshore whereas the heavier coarse to fine sand rest on the reef flat to form spectacular fine to muddy sand blanket (Plate 3E). Mudflats develop mainly in sheltered areas of mangrove stands particularly at Abu Menqar and Safaga islands. The subaerial roots of mangroves form a reticulate network under water and therefore act as screen for the influx fluvial sediments which ultimately blocked and deposited to form soft muddy substrate.

Reef Flat

The reef flat of the Red Sea constitutes a stable intertidal 'platform' at the front of the coastline. It is made up of old reef platform (dead coral pavement) that is favorable for growth of modern reef and gradually inclines to low water (Plate 3F). It is rarely found bare especially in the back-reef zone (*cf.* Dullo and Montaggoini 1998) where sand or mud blanket cover the substrate of this zone.

The reef flat in the study area in general, is irregular and frequently is interrupted at wadi mouths whereby it forms 'sharms' (*e.g.*, Sharm Abu Makhadej, Sharm el-Arab, Sharm el-Naqa, Sharm el-Tahtani). Interruption of the reef flat and absence of any build up in 'sharms' may be explained by the effect of water run-off and by input of clastic sediments from wadis (Dullo and Montaggioni 1998). The width of the reef flat varies markedly along the coast of the study area from few tens of meters up to ~ 2 km width as in the southwestern coastline of el-Tawila island and south of Gemsha Bay. It is to be noted that the reef flat is almost absent or very limited in width along most of the NW-SE coasts of offshore islands (*e.g.*, Shaker, Giftun el-Saghir & el-Kebir islands and at Sharm el-Arab, Dashet el-Dabaa, and southward of Safaga).

Locally, the reef flat is eroded to form lagoons (in case of large scale erosion) or spur and groove structures (Plate 3F). The latter, are probably related to relict wadi channels formed when the sea level was 120 m lower than the present (Coleman 1993). Seawards, the reef flat develops to a steep drop-off known as reef slope and characterized by abundant modern reef growth.

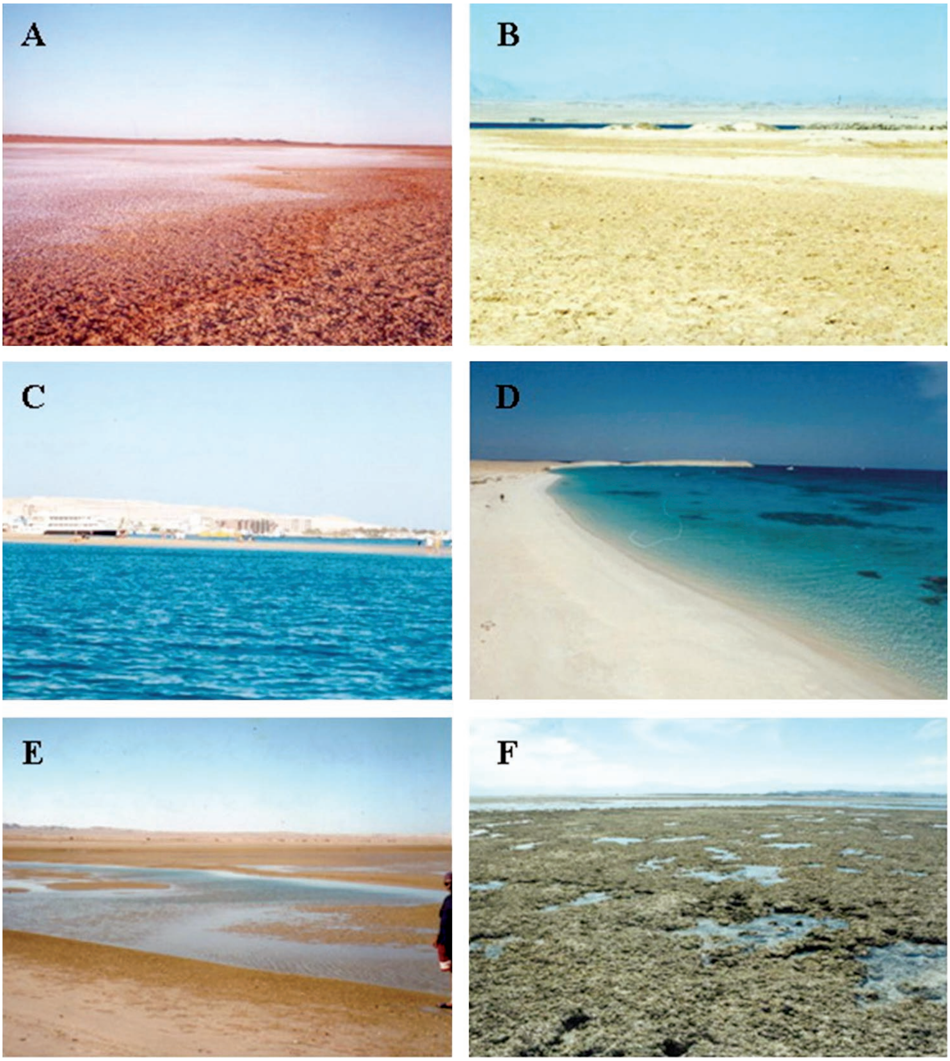

Plate 3. Field photos showing: (A) Sabkha as it looks like in its semi-wet state, (B) Sabkha as it looks like in its semi-dry state, (C) Sand spit south of Hurghada, (D) Extensive sandy beach at Gubal Al-Saghir Island, (E) Tidal sand flat south of Safaga, (F) Reef flat east of Abu Minqar Island.

Offshore Features: Islands and Submerged Reefs

The study area hosts the largest number of offshore islands of the Egyptian Red Sea coast. About 25 islands occur scattered in the marine area between Ras el-Behar and Safaga. They are located in the offshore area at distance of 30 km from to the nearest mainland coastline.

Islands near Hurghada have the highest marine diversity and therefore, are known as popular diving site. Vegetation is sparse in most islands except in el-Tawila and Safaga islands where they host dense patches of *Zygophyllum* sp. and also in Qeisum South, Abu Minqar, and Safaga islands which contain dense local stands of black mangrove.

The northeastern coast of most islands offers very narrow or absent reef flat because of the open marine conditions. Conversely, the western shores are more protected and therefore, offer comparatively wide and extended reef flats. Except for Shedwan and Gubal Kebir islands, surface rocks of all other islands are made mainly of Late Pliestocene reefs. Shedwan and Gubal Kebir islands are more rugged and have outcrops of Late Miocene evaporites and Middle Miocene coralline carbonates in addition to the Quaternary fossil reef.

Large number of submerged reefs or sha'abs (*Arabic word for barrier or submerged reefs*) are scattered all over the offshore zone of the study area, especially in the northern parts. They consist of limited reef barriers or platforms which submerged at least 3-5 m beneath sea water at low tide. The most extensive and diverse sha'ab is shaa'ab Abu Sha'ar which runs in NW-SW direction off el-Gouna, north of Hurghada.

Reef flat areas as well as submerged reefs are best displayed on Landsat image by combination of the first three visible bands (*i.e.*, bands 3, 2, 1) in RGB, as they are most capable bands for penetrating shallow water areas and revealing, in this way, submerged reefs and other benthic habitats. Lithology and rock units of offshore island, on the other hand, are best displayed by combination of bands 7, 4, 1 and bands 7, 5, 4, respectively.

Result of image analysis together with vectors obtained through careful manual on screen digitization were combined in one product to ultimately yield a generalized geomorphological map of the study area (Fig. 7).

Summary and Conclusions

This study provides an example for utilization of remote sensing data for identifying of geomorphic characteristics of highly dynamic zone, like Hurghada-Safaga coast. The spatial resolution of the Landsat ETM+ sensor in its multispectral mode (30 m) is fairly enough to map most geomorphic features and

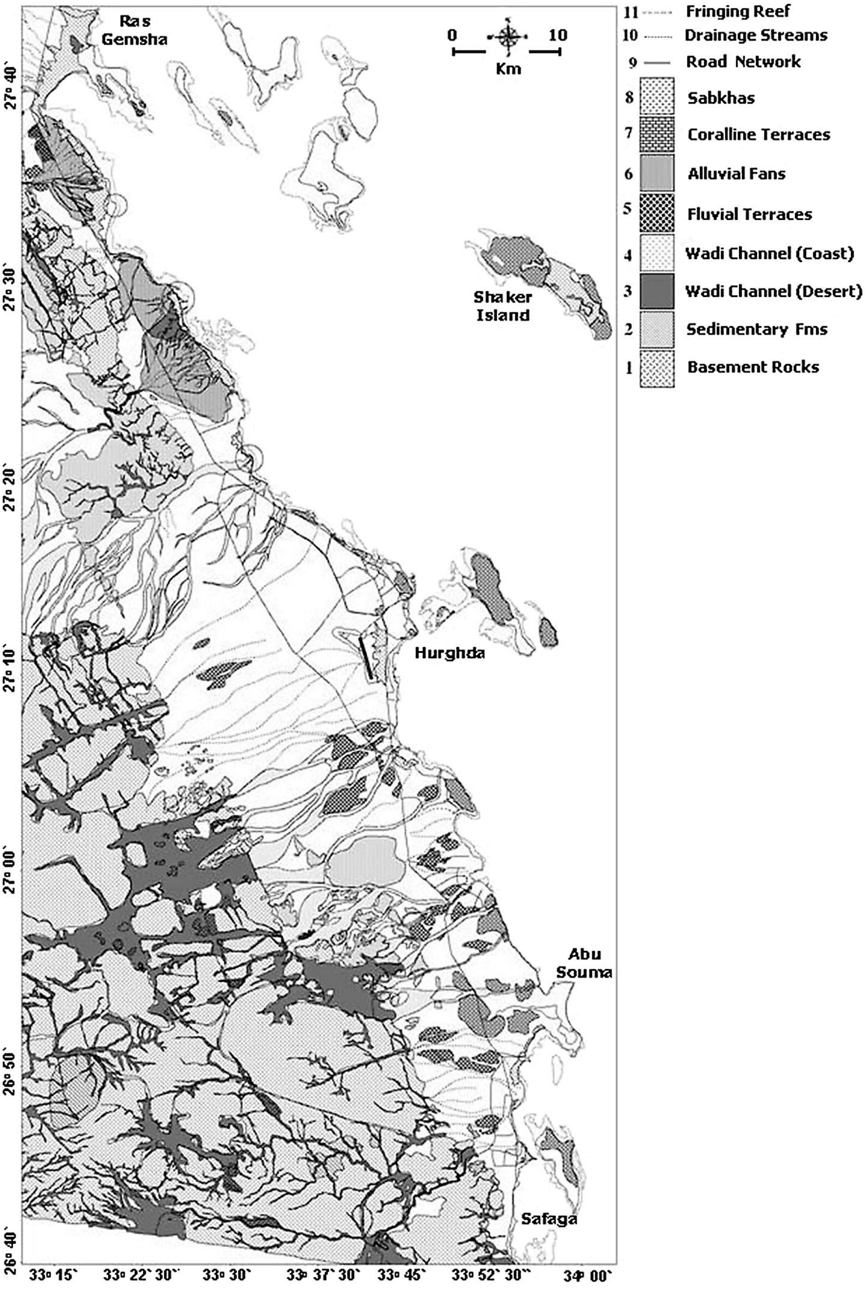

Fig. 7. Generalized geomorphological map of the study area.

landforms within the study area. Incorporation of the 15 m resolution panchromatic band improved mapping accuracy and visual interpretability of Landsat image. Principal component analysis and false color composite were among the most successful techniques for this purpose. Ground truthing of image and field check were very helpful, as well. Most prominent geomorphic features of the study area include fluvial terraces, fossiliferous reefs, alluvial fans, basement shield rocks, sedimentary hills, coastal and inland dunes, sand spits and sand bars, submerged reefs and offshore islands.

In conclusion, anthropogenic activities and development in the study area are ever-increasing and hence, expected to impose wide-scale changes in both landscape and coverage pattern. It is of paramount importance, therefore, to update the available maps on its descriptive characteristics. This is a very important and essential prerequisite for proper future land use planning and management of the area.

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استخـدام تقنيات الاستشعار من بعد في التعرف على الملامح الجيومورفولوجية لساحل البحر الأحمر فيما بين رأس جمشة وسفاجة بمصر

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المستخلص. تتطلب الطبيعة الديناميكية لساحل المنطقة الواقعة بين رأس جمشة وسفاجة على القطاع المصري من البحر الأحمر، إضافة لاستهداف هذه المنطقة للتنمية المستقبلية، ضرورة تحديث المعلومات المتاحة على مميزاتها ومعالمها الجيومورفولوجية. ولكي يمكن تقديم معلومات من هذه النوعية، يجب توافر تقنية سريعة ، ويمكن كذلك تكرارها وإعادة تطبيقها. وفي هذا الإطار فإن النظرة الكونية لصور الاستشعار من بعد الملتقطة بواسطة القمر لاندسات، والأقمار الشبيهة الأخرى تتيح عمل ترسيم مفصل لقطاعات عريضة من السواحل وبقدر كبير من الدقة.

لقد تم في هذه الدراسة استخدام وتحليل صورة فضائية ملتقطة في ٩ سبتمبر ٢٠٠٠ بواسطة المستشعر ETM+ المحمول على القمر لاندسات، ومن واقع نتائج هذا التحليل، إضافة إلى الملاحظات الحقلية والبيانات المرجعية الأخرى، أمكن عمل ترسيم ووصف المحددات الجيومورفولوجية والطوبوغرافية الأساسية في منطقة الدراسة. وفي هذا الإطار فقد أثبت تحليل المكون الرئيسي (PCA) وكذلك تركيبة الألوان غير الحقيقية (FCC) أنهما من أنجح تقنيات الاستشعار من بعد وأكثرها فاعلية في إظهار المعالم الجيومورفولوجية الموجودة قبالة الساحل. وفي المقابل فقد وجد أن استخدام تركيبة الألوان الحقيقية (True Color) هي الأكثر فاعلية في إظهار الشعب المرجانية المغمورة ، وأيضًا تلك المناطق الغنية بالشعاب المرجانية

وقد أفاد الأسلوب الذي تم اتباعه في هذا البحث، في التعرف على أبرز المظاهر الجيومورفولوجية للمنطقة وفي تحديث المعلومات المتوافرة عنها. وبحسب ما توصل إليه البحث، فإن أبرز المظاهر الجيومورفولوجية في المنطقة تتضمن المصاطب النهرية والمصاطب المرجانية القديمة، والمراوح النهرية، والوديان الصحراوية، والسبخات والبرك الملحية، والألسنة الرملية البحرية، وأخيراً الشعاب المرجانية المغمورة.

الكلمات الدالة: التكوينات الأرضية، المظاهر الجيومورفولوجية، ساحل البحر الأحمر، الاستشعار من بعد، طرق الترسيم.