EGYPTIAN JOURNAL OF AQUATIC RESEARCH **ISSN: 1687-4285**
VOL. 33 NO. 3, 2007: 24-38

SURFACE CHARACTERISTICS AND COVERAGE PATTERN OF THE NEW DAMIETTA PORT AREA, AS MAPPED BY HIGH RESOLUTION REMOTE SENSING

WAHID M. MOUFADDAL

National Institute of Oceanography & Fisheries (NIOF)
wahid_moufaddal@gawab.com

Keywords: Damietta port area, satellite imagery, land-use mapping, future planning.

ABSTRACT

The New Damietta port area has been subjected to large landscape changes and reformations since construction of the port in early 1980s. The area still under development and is expected to experience some more changes during the next few years. This reveals the urgent need for assessment of the present coverage pattern and land-uses of the port area. The present study attempts to determine details of land cover and land use information of the New Damietta port and surrounding area using high resolution remote sensing in conjunction with results of the ground survey and field observations. A recent image from QuickBird has been used for this purpose. Land cover types and surface characteristics were described and their areas estimated and mapped using the standard remote sensing methods. Results of this study show that the landscape of the New Damietta port area is dominated by man-made cover types and infrastructures, rather than natural land cover types. The most prominent surface features of the study area include: port area, bare land, water bodies, road and rail network, built-up area, and sand dunes. The area includes also various types of land use e.g. commercial and industrial, agriculture and mixed crops, residential fabrics and dump sites.

1. INTRODUCTION

The New Damietta port is located on the northeastern part of the Nile delta along the Egyptian Mediterranean coast, about 37 km west of Port-Said and about 9 km of Damietta city (Fig. 1). The port has been established in early 1980s and began its operation in July 1987 for the purpose of improving trade facilities and fostering flow of trade-traffic across the Mediterranean coast of Egypt. It handles export of agricultural products, fertilizers, and furniture and receipt imported goods such as petrochemicals, cement, grains, flour, and general cargo with a total capacity of about 5.6 million tons annually.

The port occupies an area of about 13 km^2 and is subdivided into two main parts; the shipping area, which is an inland section containing 16 berths and quays, and the water area which is composed of an access channel connecting the shipping area with the Mediterranean Sea and the main basin. In order to facilitate access to inland navigation, the port's basin has been connected to the Rosetta branch of the River Nile through a man-made barge canal of 4.5 km long and 5 m depth. There are some ambitious plans for development of the port and improving its trade facilities. In this respect, the Port Authority is planning to make a new extension south of the existing grain berth (Fig. 1). This is part of the third phase of development of the port which is expected to be completed by year 2010.

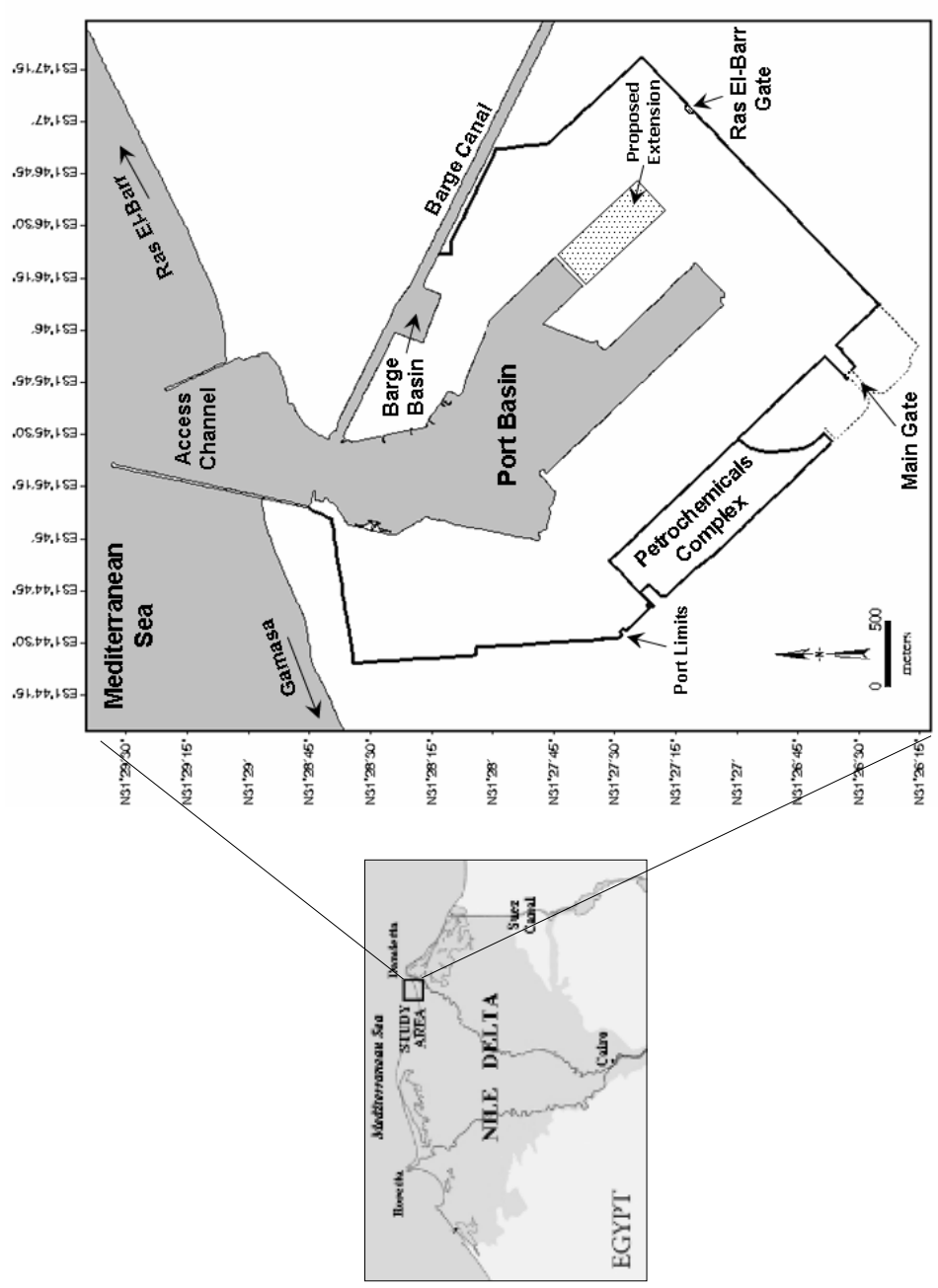

Fig. (1): Generalized map showing limits of the New Damietta port and location of the new proposed extension.

The primary purpose of this study is to asses the environmental condition in regard with the existing land uses, coverage patterns and surface characteristics of the port area using high spatial resolution remote sensing. This has been achieved through visual interpretation of remote sensing data and on-screen raster-to-vector digitization of the image features. A recent satellite image from QuickBird has been used for this purpose.

To the author's knowledge there is no published remote sensing study on land use or/and land cover types of the port area or its vicinity. Literature review reveals that most remote sensing studies carried out on the study area were focused mainly on coastal changes and shoreline erosion and accretion during the short timescale of 1984 to 1991. These include studies of Klemas and Abdel Kader (1982), Frihy (1988), Smith and Abdel Kader (1988), Blodget *et al.* (1991), Frihy *et al.* (1998), El-Raey *et al.* (1999), White & El-Asmar (1999), El-Asmar (2002), and El-Asmar and White (2002).

Importance of this study arises from the fact that the port area is still under development and is likely to be subjected to further spatial changes and reformation during the next few years. Mapping of the existing land cover types therefore is of paramount importance for documentation of the present situation, as well as, for assessment of future changes. Assessment of the present surface characteristics is also very important for the future development and land-use planning of the area.

2. MATERIALS AND METHODS

2.1. Data acquisition and collection

The primary data used in this study was satellite imagery. There are a variety of imagery types can be used and, normally, images with higher spatial and/or spectral resolutions are preferred for coastal land-use and land-cover mapping. For this purpose, a high resolution image from QuickBird was utilized for study of the port and its vicinity area. The QuickBird spacecraft, owned and operated by Digital Globe^{TM} Inc., collects the highest resolution imagery commercially available (Volpe 2004, Digital Globe 2006). It acquires images in 4 multispectral bands of 2.44 m resolution and one panchromatic band (pan) of 61 cm resolution.

The selected QuickBird image covers an area of 38 km^2 and acquired on 4 December 2005. The image was delivered in GeoTIFF 8-bit enhanced standard format and geo-referenced to the Universal Transverse Mercator (UTM) Zone 36 as projection and WGS 84 as datum. In addition to satellite data, a 3-days field visit to the port and surrounding area was conducted during 24 to 26 July 2006 in order to acquaint with prevailing important cover types and land-uses. During this visit, not less than 40 sites were checked and described. Prominent surface characteristics and other important information relevant to land uses and activities were also described in the field so as to aid the process of image and remote sensing interpretation.

Other supplementary information utilized for this study included: (1) generalized land-use map produced by the Port Authority showing the main features and amenities of the port, and (2) topographic map of scale 1:25 000 covering the study area.

2.2. Image preprocessing and analysis

The image processing steps which applied in this study included: preparation of the satellite data for viewing and analysis, merging multispectral bands (2.4 m) with the pan band (0.6 m) to enhance spatial details while preserving the spectral information, determination of the classification scheme, visuals interpretation and digitization, editing of the image classes and categories, and finally producing spatial map for the study area.

Initially, the image was subjected to enhancement and information extraction

procedures through standard remote sensing techniques e.g. false color composite, principal component analysis, unsupervised classification. Ground truth information which collected from ground survey, and collateral maps was also combined to results of remote sensing analysis for evaluation of the descriptive characteristics of the port area and its vicinity. All of the digital image processing and subsequent mapping of remotely sensed data was performed using ER Mapper 7.1. Vector layers produced through remote sensing mapping have been gathered and edited using ArcView GIS.

2.3. Classification scheme design

Due to some logistics and financial limitations, classification of the land-cover and land-use types of the study area was based essentially on visual interpretation and digitization of the QuickBird image. Computer assisted classification (unsupervised) was conducted in some cases, as necessary.

A modified version of CORINE classification scheme (European Community, 1993) was developed specifically to tune with purposes of this study. In this context, the land cover in the study area was classified at two hierarchical levels. The level I classification scheme contained six categories; built up area, waste lands, bare lands, water bodies, vegetation, and sand dunes. Subsequently, each class has been subcategorized in level II classification into number of discrete classes depending on importance of the land cover and spatial details of the image.

3. RESULTS AND DISCUSSION

Through application of methods of image interpretation and raster-to-vector representation together with other information collected from field survey, it was possible to describe the main coverage pattern and land uses of the study area. Results of this step show that the most prominent surface features of the area include: port area, bare land, waste lands, water bodies, built-up area, agriculture and mixed crops (corn, green leafy, bananas, etc.), and sand dunes.

3.1. Surface characteristics of the port and surrounding area

3.1.1. Physiographic setting

The port and surrounding area is flat in general, as it is part of the coastal plain of the northeastern part of the Nile Delta. Elevation varies between 0.2 m near the coastline but it increases to 3 m above mean sea level (MSL) at the southern and eastern limits of the port.

The Port was constructed in a coastal embayment some distance inland in order to be protected from winter storms and hence, can be used year-round and avoid shipping delays (El-Asmar & White 2002). The port entrance from the seaside is protected against the littoral drift by two jetties (breakwaters); the western jetty is 1640 m long and the eastern jetty is 760 m (Fig. 1). The total area of the port now is 12.88 km^2, of which 3.8 km^2 is water, and the rest area is land.

The port can be broadly subdivided into 5 main divisions (Fig. 2). These include the Petrochemicals and Liquefied Natural Gas (LNG) complexes at the west and the industrial free zone at the east, this in addition to the water area (port basin) and the surrounding platforms and berths. The southern parts contain most amenities and services of the port e.g. administration buildings, fire station, water pumping station, agricultural quarantine and accommodation houses. Berths and quays of the port occupy the central area and include the containership and general cargo berths to the west and the bunkering and grain berths to the east.

The port area was originally a large field of fertile agriculture land backed by a wide zone of coastal sand dunes. Establishment of the port necessitated clearing and dredging all

of vegetation habitats and land-uses which used to occur in the area. This resulted in huge quantities of dredging materials. Excavation works for the port's access channel only resulted in not less than 5 million m^3 of dredged sediments (Frihy *et al.*, 1991).

The area surrounding the port is comprised of agriculture land that is cultivated with seasonal crops and fruit farms, with exception of the northeastern parts which comprised of abandoned land put under development and planned for some industrial and tourism activities (Fig. 2).

3.1.2. Land-cover and land-use types

The final land cover map produced by remote sensing analysis and GIS is demonstrated in Fig. (3). It is comprised of six level II land cover classes, in addition to some important landmarks of the area. Description of theses classes is given as follows:

3.1.2.1. Built up area

3.1.2.1.1. Port area

The port itself is a built up area established in the region through reclamation and clearing of the coastal dunes and agriculture which used to occur in the area before the port. More than two thirds of the total port area is comprised of a built-up land, whereas the rest area is water (see Figs. 1 and 2).

Coverage patterns prevailing in the land section of the port include administrative and commercial buildings, industrial units, horticulture and natural vegetation, services and emergency facilities, residential buildings and accommodation houses, road and rail network, undeveloped land, storage tanks and bins, storage open yards, waste lands and dump sites.

3.1.2.1.2. Residential fabrics

Except of Damietta city which is located far about 9 km far from the port, other residential fabrics in the port area are very limited both in size and population, in general. Only three discontinuous residential communities were reported in the port area and its immediate vicinity. These include one residential area inside the port itself, definitely at the middle of its southern side. It comprises about 35 residential houses that are being used for residence and accommodation of the workers and technicians of the Port Authority. The total area occupied by this fabric is about 74,000 m^2.

The other two residential areas are located outside the port area and composed of two small villages inhabited by local people and farmers of the area. The first village is located very close to the port, definitely at a place facing its southern fence-wall. It is composed of a small village (namely "Izbaet Nasr Allah") of a total area of 10,560 m^2 and lies on the outer port road far about 1.5 km from Ras El-Barr gate. The second residential area is composed also of a small village, namely "Izbaet Khamsa", of an area of 34,300 m^2, and lies west of the port area about 3.5 km far from the port's main gate. In addition to this, there are some other discrete living- and farm-houses scattered randomly throughout the agricultural land around the port area.

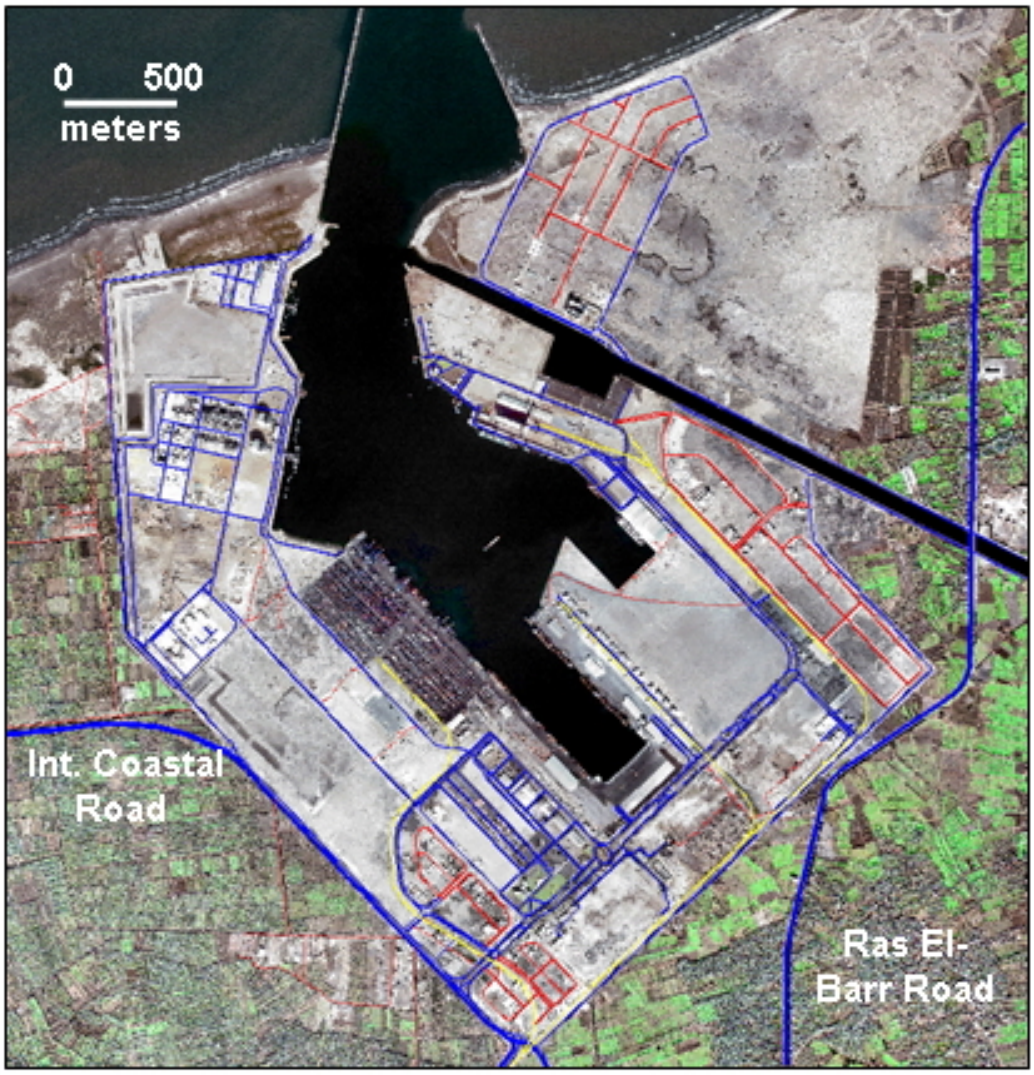

Fig. (2): Road and railway network of the port area. Vectors in blue = main (asphalted) roads, red = unpaved roads/tracks, yellow = railway lines.

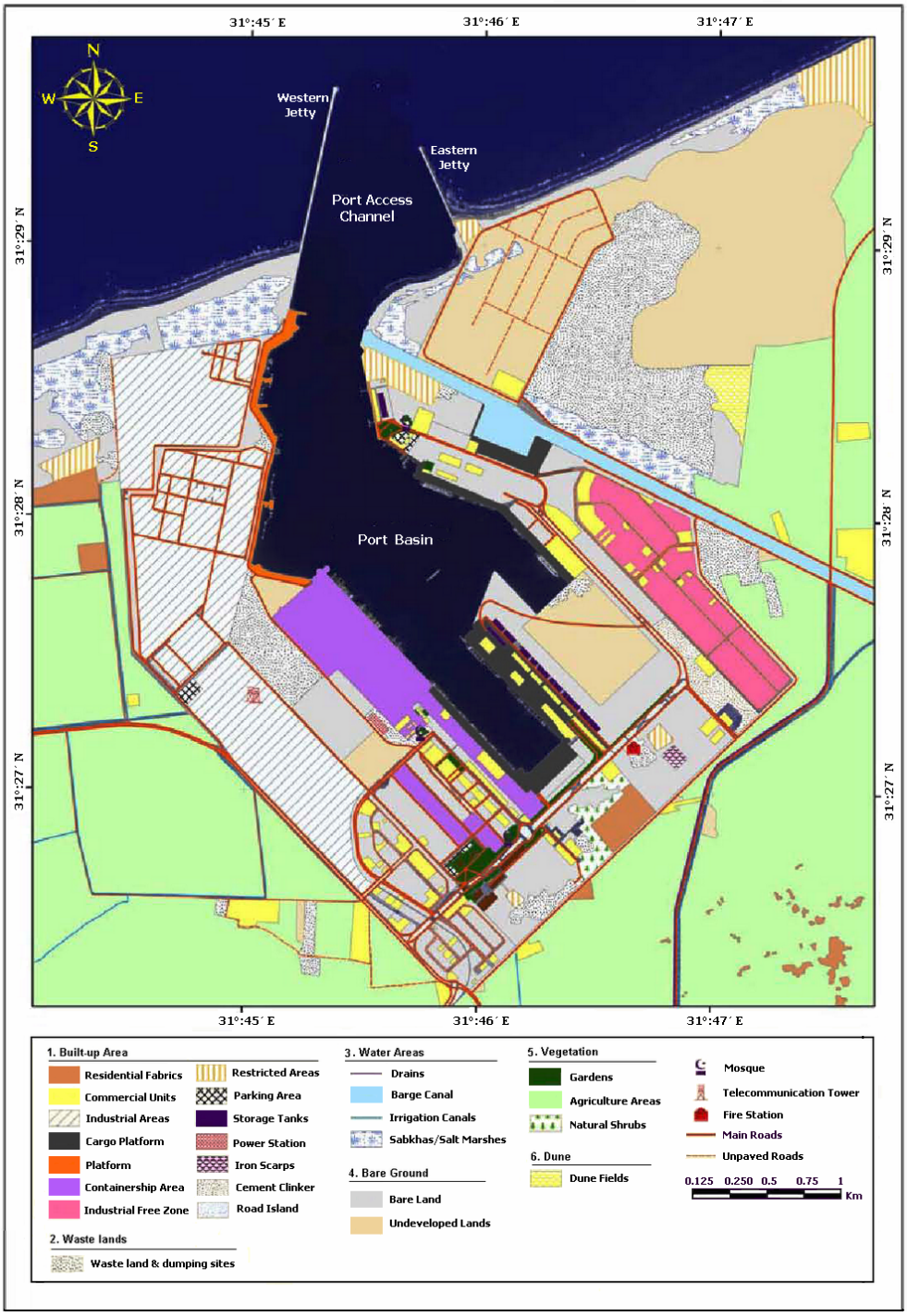

Fig. (3): Land use and cover types of the study area as resulted from manual digitization and computer-assisted classification methods.

3.1.2.1.3. Industrial and commercial units

Industrial and commercial units form the second largest land uses in the study area after agriculture and cultivation. Industrial activities inside the port are restricted to the petrochemical and LNG complexes, which lie at the western side of the port. Outside the port, the industrial activities are very limited. It is of note that no one industrial activity was observed in the immediate vicinity of the port.

On the other hand, most of the commercial activities outside the port are concentrated near the main gate. Large number of timber-yards, open and roofed storage sites are widespread at this area. Associated with these activities some other services and activities such as artisanal food stores, trade of construction materials, etc.

Inside the port, storage facilities such as storage sites, bins, tanks and compartments are the most dominant commercial coverage pattern throughout the port area. Storage oil and gas tanks and compartments are more concentrated at the northwestern part of the port. In addition to these facilities, there are some other open sites being used for storage of other by-products and general cargos.

3.1.2.1.4. Road and rail network

The port is served by a very good road network. Inside the port area, there are different types of roads serving the port amenities and connecting between the different platforms and activities inside it. These include the main arterial road which connects the port's main Gate and Ras El-Barr Gate with the other parts of the port. The route of this road begin from the main gate where it runs in E-W direction across the port before it branches to the right where it ends at Ras El-Barr Gate and to the left where it ends at the barge Canal. This 2-lanes road has a total width of 55 m in average.

The road network inside the port includes also some secondary roads which connect the different terminals and berths of the port with its main road. Secondary roads normally are less in width than the main road and composed of only one lane.

Unpaved tracks are widespread also in the port, as well as in the surrounding area. They are more common in the undeveloped and waste lands and usually used as short-cuts for accessing villages and other places.

Outside the port, the area is being also served by a good road network. This network is comprised of three main roads in addition to indefinite number of secondary roads and unpaved tracks to serve the residential and commercial units which are scattered around the port land. The main roads are represented by Ras El-Barr Road which passes near the port in NNE-SWW route before its deflection at Ras El-Barr Gate towards the northeast and again at the southeastern corner then towards the north where it is heading to Ras El-Barr resort. The second main road is the international coastal road which approaches the port at its western side, then it runs after that parallel to western side of the port before it branches at the southwestern corner of the port into two branches. The port and its associated units and activities are being served by a third asphalt road. This road passes parallel to the fence walls where it is connected to the port road network at gates and entrances of the port amenities and units.

In addition to these motor-roads, the port area is served also by a good rail network. This network is composed of the main railway which runs parallel to the southern side of the port in a NE-SW direction. The main railway branches at almost equal distances to three perpendicular sub-lanes running in NW-SE route and serving the different cargo berths of the port.

3.1.2.2. Dumping sites and waste lands

Dumping is a widespread activity inside the port as well as throughout the surrounding area. Therefore, it is not surprising that the dumping sites and waste lands constitute one

of the most frequent and widespread classes in the study area, in general. Not less than 14 dumping sites could be delineated in the study area, both inside and outside the port (Fig. 4).

Inside the port, most of undeveloped bare land is currently being used for dumping of solid wastes and demolition materials. The largest of them occur at the western part of the port, behind the containership area (DS-8 in Fig. 4). It occupies an area of about 210 000 m^2 and accommodate solid wastes of building demolitions, marble boulders, and large stones.

The most extensive dump site in the study area is located outside the port north of the barge canal (DS-1 in Fig. 4). It occupies an area of about one million square meters and is being used for disposal of dredged sediments and subsurface soil excavated during construction of the barge canal.

Other dump sites outside the port include two localized dump sites (DS-2 and DS-3) at the western bank of the barge canal behind the industrial free zone, and another site northwest of the port and west of the water treatment facility of the LNG complex (DS-7). All of these sites are also being used for disposal of dredged materials. In addition to this, there are some other limited dump sites distributed randomly throughout the port area e.g. DS-5, DS-6, DS-9 (Fig. 4).

Outside the port, most prominent dumping sites are located southeast of the port near the entrance of its main gate (DS-13 and DS-14). Field check revealed that they accommodate subsurface soil and dredged material which seem to be excavated during construction of some commercial buildings and houses in the nearby area. Table 1 lists locations of all delineated waste lands along with their areas.

3.1.2.3. Water bodies

The water class of the study area is comprised of the open seawater, the navigation canal and basin of the port. The water areas in the port area and its vicinity can be sub-classified into the following categories:

3.1.2.3.1. Marine area

This includes the nearshore water area outside the port. The nearshore and offshore waters off the port's coast is part of the Mediterranean Sea and hence, should be affected by the east-trending longshore current which dominates the whole southeastern Mediterranean.

3.1.2.3.2. Port basin

This includes the water area inside the port basin beginning from limits of the entrance channel to limits of the General Cargo berth. This basin has a total area of 3.81 km^2 and is being used for berthing and mooring of commercial ships (Fig. 2).

3.1.2.3.3. Barge canal

A man-made barge canal has been established in the port area so as to connect the port with the Damietta branch of the River Nile. The idea beyond this is to reduce cost of transportation through navigation by barges and small ships. The barge canal extends in NW-SE direction for about 4.5 km east of the port. The canal has a width of 90 m and water depth of 5 m. The length of its main basin is about 400 m, whereas its width varies between 150 to 220 m to make it wide enough to receipt barges and navigation ships of small to medium-size vessels (Fig. 2).

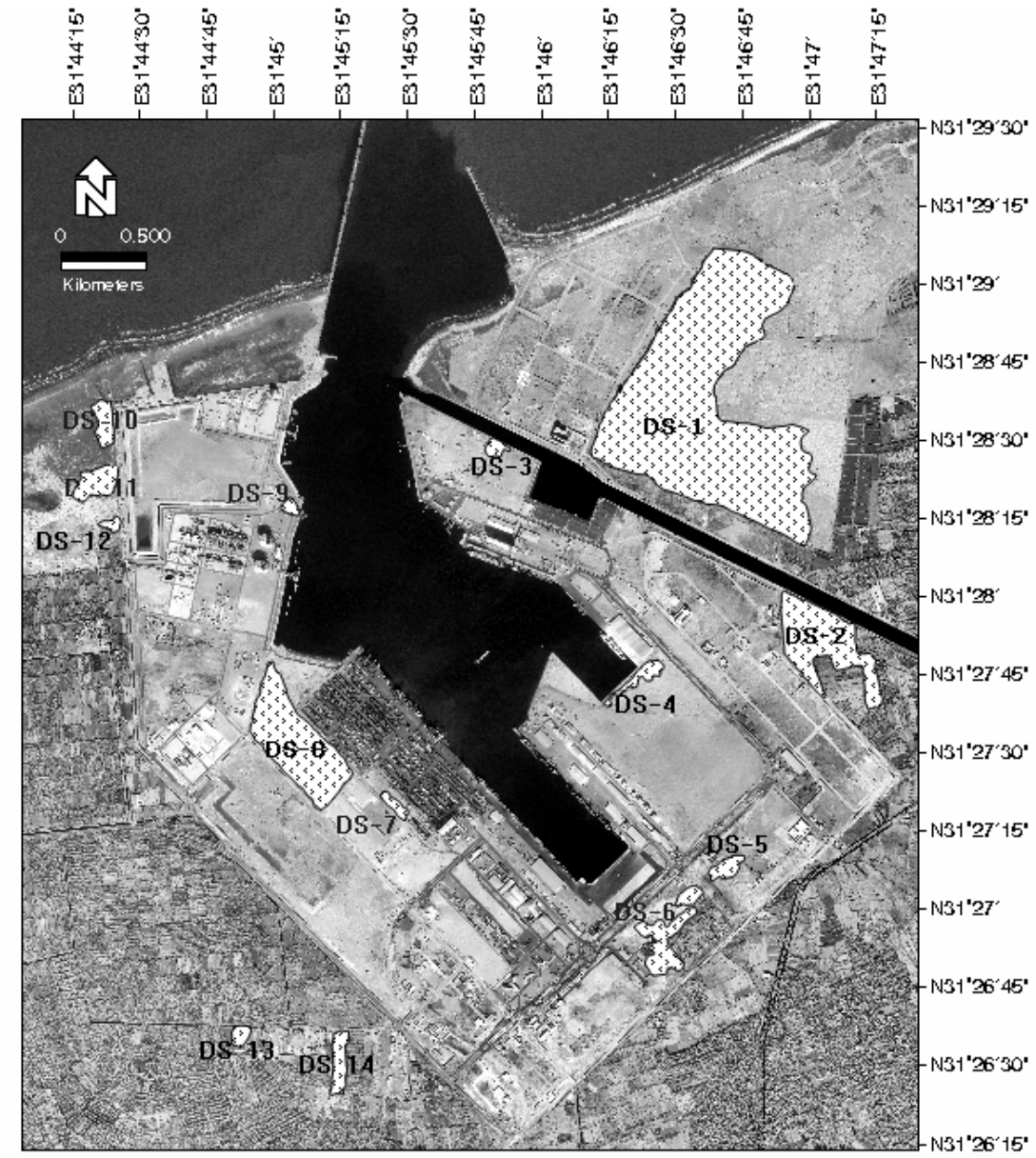

Fig (4). Location and distribution of the waste lands and dumping sites throughout the study area.

Table (1): Locations and areas of waste lands of the study area, as given in Fig. (4).

Waste Land	Location	Area (m^2)
DS-1	31:28:38N / 31:46:33 E	1,011,502
DS-2	31:27:53N / 31:47:03 E	158,205
DS-3	31:28:27N / 31:45:50 E	7,622
DS-4	31:27:41N / 31:46:19 E	13,584
DS-5	31:27:08N / 31:46:44 E	12,672
DS-6	31:26:56N / 31:46:27 E	50,036
DS-7	31:27:19N / 31:45:29 E	8,021
DS-8	31:27:30N / 31:45:09 E	209,680
DS-9	31:28:16N / 31:45:05 E	6,128
DS-10	31:28:32N / 31:44:24 E	25,314
DS-11	31:28:20N / 31:44:23 E	30,889
DS-12	31:28:13N / 31:44:26 E	4,767
DS-13	31:26:35N / 31:44:55 E	8,374
DS-14	31:26:35N / 31:45:18 E	26,873

3.1.2.3.4. Irrigation canals & drains

With exception of the newly constructed navigation canal which connects the port area with the Damietta branch, there is no any another drainage or navigation waterway inside the port. Outside the port, the cultivated land around the port is being served by a good drainage system and large number of agricultural canals and drains. The most prominent and the closest of them to the port is the Sayalla Canal which lies south of the port and runs with Ras El-Barr Road in a NNE-SSW route before it deflects at the southeastern corner of the port towards the north.

3.1.2.4. Bare land

Barren lands comprise these lands which either devoid of any activity or still untouched such as beaches and backshore areas. Most barren lands are concentrated outside the port area near the coast and mostly composed of abandoned or undeveloped land. Outside the port, the barren lands are very limited and composed of abandoned land that used to be cultivated for agricultural crops. The bare land of the study area can be sub-categorized as following:

3.1.2.4.1. Undeveloped land

This consists of the areas devoid of any activity or even any characteristic land cover. This class includes therefore the clear-cuts and transactional lands that are likely to change or be converted to other uses in the near future.

3.1.2.4.2. Coastal plain and beaches

The coastal plains and beaches north of the port are still undeveloped and devoid of any land use or human activity. The coastline of the study area is sandy, gently curved with a general NNE-SSW orientation. The width of the coastal plain ranges from 0.2 to 2.0 km. However, large tracts of the beach especially west of the eastern jetty and east of the western jetty are embanked with stones and sea-blocks for giving them further protection against hazards of erosion and storm waves. It is of note that the coastal plain at the northwestern part of the study area is inundated by seawater due to overtopping of the incoming waves or through infiltration at sabkha areas.

3.1.2.5. Vegetation

The vegetation class represents one of the major and most widespread classes throughout the study area. Vegetation of the area can be broadly categorized into:

3.1.2.5.1. Natural vegetation

This includes the perennial shrubs and bushes which grow up sparsely distributed throughout the study area. They in general have no environmental value and grow randomly without a definite pattern or alignment. Natural vegetation within the port is restricted to basically undeveloped areas and bare ground. Most abundant natural vegetation cover in the study area occurs outside the port on the eastern bank of the artificial barge canal mostly in form of saltmarsh shrubs. Sparse halophytes and sabkha shrubs were also observed throughout the backshore area of the western jetty.

3.1.2.5.2. Agriculture

This subclass is very widespread in the vicinity of the port area but it is almost absent inside the port. The cultivated fields in the area surrounding the port, especially from the south, form a continuous fabric of characteristic pattern. Vegetation inside the port appears as discontinuous parcels around some administrative buildings as well as along both sides of the main road inside the port. It is composed mostly of horticulture plants, palm trees, and grassland.

Outside the port, most of the land is arable and cultivated with annual and permanent crops e.g. rice, corn, wheat, fruit trees (mainly banana), palm trees, etc. Non-irrigated arable land and garden zones around administrative pastures are included also in this subclass. It is of note that rice cultivation and banana fields are the most dominant agricultural activities in the study area.

3.1.2.6. Sand dunes

3.1.2.6.1. Nabkhas/embryo dunes

Nabkhas are common small sand dunes formed around plants. Wind blown sands begin to accumulate and rise up when it is obstructed by plants (shrubs or trees) or any similar obstacle. Individual plants must reach 10 - 15 cm in height before they can effectively trap sand. Despite being stabilized, they change their orientation with change direction of the winds.

Nabkha dunes were observed only in the undeveloped land south of the Grain berth inside the port. Their heights don't exceed 50 cm despite their widths may extend up to 3 meters. Ground survey showed that they are composed preliminary of well sorted fine- to medium-grained sand.

3.1.2.6.2. Barchan dunes

Barchan or crescent-shaped dunes form where wind primarily blows from one direction and where there is little or no vegetation present. A small field of crescent sand dunes was reported outside the port, definitely east of the navigation channel. Remote sensing measurements show that this field occupies a triangular area of about 550 x 450 x 250 m dimension and lies about 1800

m northeast of the project site on the eastern bank of the barge canal. Barchan dunes at this area can be as wide as 28 m, and as long as 15 m and up to 4 m in height but they vary in general between 18 and 25 in width, 10 and 15 m in length, and 3 and 5 m in height.

4. SUMMARY AND CONCLUSIONS

Land-uses and cover types of the New Damietta port area has been investigated using high resolution recent image from the QuickBird satellite (0.6 to 2.4 m resolution), in conjunction with field observations and ground survey. Application of the standard image interpretation techniques and classification methods was of much help for mapping and description of the main classes and features of the study area.

Results of image analysis show that the port area is dominated by built-up area and man-made cover types, rather than natural land covers. Prominent surface features of the area include: port area, bare land, water bodies, road and rail network, vegetation and sand dunes. The area includes also various types of land use e.g., commercial and industrial, agriculture and mixed crops (corn, rice, green leafy, bananas, etc.), residential fabrics and dumping sites.

Importance of this study refers to the fact that the port area is a fast-growing area and therefore, is expected to experience wide scale changes in its landscape, terrain uses during the next decade. Assessment of the present surface characteristics and coverage pattern in this area therefore, is essential and critical for future land-use planning, as well as, for proper management of the area, in general. In view of this, it is recommended to update the information on land-uses and land cover types of the port area every on regular basis.

ACKNOWLEDGEMENTS

The author wish to thank Dr Mohamed El-Saraway and the Watanyia Environmental Services (WES) Co for providing the satellite image and some logistics during the field work. The author is also thankful to Drs Amr El-Sammak and Hesham Mansour for their help and support during the preparation for this work.

REFERENCES

Blodget, H.W., Taylor, P.T., Roark, J.H.: 1991, Shoreline changes along the Rosetta–Nile promontory: Monitoring with satellite observations, *Marine Geology*, **99**: 67–77.

Digital Globe Inc.: 2006, *QuickBird Imagery Products: Product Guide* (Revision 4.7.1), 77 pp.

El-Asmar, H. and White, K.: 2002, Changes in coastal sediment transport processes due to construction of New Damietta Harbour, Nile Delta, Egypt, *Coastal Engineering*, **46**: 127–138.

El-Asmar, H.: 2002, Short -term coastal changes along Damietta-Port Said coast Northeast of The Nile Delta, Egypt, *J. of Coastal Research*, **18 (3)**: 433–441.

El-Raey, M., Sharaf El-Din. S. H., Khafagy, A. A., and Abo Zed, A. I.: 1999, Remote sensing of beach erosion/ accretion patterns along Damietta - Port Said shoreline, Egypt, *Int. J. Remote Sensing*, **20 (6)**: 1087-1106.

European Community: 1993, CORINE Land cover-Guide technique, Office des Publications Officielles des Communautés Européennes.

Frihy O. E.: 1988, Nile Delta shoreline changes: aerial photographic study of a 28-year period, *J. of Coastal Research*, **4**:597–606.

Frihy, O.E., Fanos, A.M., Khafagy, and A., Komar, P.D.: 1991, Patterns of nearshore sediment transport along the Nile Delta,

Egypt, *Coastal Engineering*, **15**: 409–429.

Frihy, O., Dewidar, M. Kh., Nasr, S., and El Raey, M.: 1998, Change detection of the northeastern Nile Delta of Egypt: shoreline changes, spit evolution, margin changes of Manzala lagoon and its islands, *Int. J of Remote Sensing*, **19**: 1901–1912.

Klemas V., and Abdel Kader A. M.: 1982, Remote sensing of coastal processes with emphasis on the Nile delta. *In: Proc. Int. Symp. on Remote Sensing of Environments*, Cairo, 27 pp

Smith, E. S, and Abdel Kader, A.: 1988, Coastal erosion along the Egyptian Delta, *J. of Coastal Research*, **4**:245–255

Volpe, F.: 2004, Use of QuickBird satellite data for urban environments, *Urban data management symposium*, Chioggia (Italy).

White, K and El-Asmar, H.: 1999, Monitoring changing position of coastlines using Thematic Mapper imagery, an example from the Nile Delta, *Geomorphology*, 29: 93–105.