Multi-criteria Site Selection and Assessment of Ports in the Northwestern Coast of Egypt: A Remote Sensing and GIS Approach

Salwa F. Elbeih, Sameh B. Elkafrawy, and Wael Attia

Abstract—**Coastal zones represent vital international issues for environmental and sustainable development. Most coastal developing countries mainly depend on the limited coastal resources for their economic development. The promising region of the Northwestern coast of Egypt has attracted massive investments. The main objectives of this present research are: selection of most suitable sites for constructing ports in this area based on a number of environmental criteria and to assess the suitability of the proposed site. Factors used in this study include natural land/marine hazards/factors man-made facilities. Materials used include: multispectral satellite images, digital elevation models, topographic maps, Admiral marine maps, in addition to field survey of the sea depth. Spatial modeling is performed using the spatial analyst module for port site selection and assessment. A total of 62 locations are identified and classified as suitable for positioning a port. All identified areas extend from west of Marsa Matrouh to East of Negeila and record a suitability values from (Good) to unsuitable.**

Index Terms—**Site selection, ports, northwestern coast of Egypt, remote sensing and GIS, land criteria, offshore/inshore criteria.**

I. Introduction

More than 95% of Egypt's population and most of its agricultural lands are mainly concentrated in less than 5% of Egypt's land, along the banks of the Nile River and its delta. On the other hand, the northwestern coast of Egypt extends over 520 km from the border of Libya from the west to the city of Alexandria from the east. A great attention is directed to this area, as one of the promising areas for future expansion. It is under severe pressure due high rates of urbanization, tourism, agriculture, and resource extraction. All these activities have led to negative environmental impacts including; accelerated erosion, marine life destruction, and decrease of biodiversity. Impacts from the predicted climatic changes represent another threat to the coastal ecosystems [1].

The land - sea interface is that part of land affected by its proximity to the sea and vice versa. The coastal area is defined as the border area between land and sea, which can extend in the land and in the direction of the sea to a varying extent based on the objectives and needs of different development programs. The main uses of the coastal zone include coastal engineering installations such as ports and maritime transport (oil and gas, cargo and unloading of goods). The coastal studies of the Egyptian Northwestern Coast have become an urgent need to select the appropriate location for constructing new ports. These studies aim to avoid consequent beaches erosion and the transfer of sediments to other places to drown in the shipping lanes of the ports. Ports are the main ring in the series of multimodal transport, as they are the contact point between land and sea. On the seaside, there is a continuous movement of vessels arriving and leaving the port carrying miscellaneous goods. On the other hand, on the landside, there is movement of goods transportation to and from the port by various ways as roads or railways.

Ports are classified according to their location or function [2]. According to their location, ports are classified as sea ports, inland ports or mixed sea inland ports. For sea ports, they are located in artificially or naturally protected coastal areas, in bays… etc. According to their function, ports are commercial, military, fishing ports… etc. In large commercial ports, shipyards usually offer all kinds of basic ship repair and maintenance services. Port capacity and effectiveness of its operations is governed by several environmental conditions such as wind, waves, swells, tides, fog, storms, ..etc).

Port sites are constrained by different factors including; Maritime access, referring to the site physical capacity to accommodate ship operations; Maritime interface: Indicating amount of space available to support maritime access (in other words amount of shoreline with a good maritime access); Infrastructures and equipment where the site, to be efficiently used, must have infrastructures such as piers, basins, stacking or storage areas, warehouses, and equipment such as cranes; Land access: Access from the port to industrial complexes and markets to insure its growth and importance [3].

When selecting a port location, there are several important points associated with the sea and the land that must be addressed. For the seaside, these points represent the port site with respect to: maritime navigation, competitive ports in the region, the effect of waves' movement, marine currents and the effect of deposition near the coastal region. While on the landside, a number of criteria have to be considered; availability of land area (Backside land) behind the port for various services, and the port location with respect to roads network and railways and the accessibility to port.

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Salwa F. Elbeih and Wael Attia are with Engineering Applications Department, National Authority for Remote Sensing and Space Sciences, Egypt (e-mail: saelbeih@narss.sci.eg, saelbeih@gmail.com, wael.gis@gmail.com).

Sameh B. Elkafrawy is with Marine Sciences Department, National Authority for Remote Sensing and Space Sciences, Egypt (e-mail: s_elkafrawy@yahoo.com; sameh@narss.sci.eg).

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For marine and coastal environment studies, satellite and airborne remote sensing play a main role [4]. In 2015, [5] designed a spatial multi-criteria evaluation (SMCE) model for identifying suitable areas for siting offshore medium size fish farms in the Italian Ligurian Sea. More than 9000 ha were identified with about 40% of this area with high suitability values. Unsuitable areas were discriminated from the suitable ones based on several factors. Sixty five suitable areas were identified from the SMCE for installing offshore fish farms distributed along the Ligurian coast, with some exceptions. An integrated multi-criteria decision-making model was proposed [6] for developing a deep-water sea port in the Klaipeda region considering the economic needs. A combination of Analytic Hierarchy (AHP) and Fuzzy Ratio Assessment (ARAS-F) methods were used to design the model. The model is presented as a form of decision aiding to be implemented for any specific port or a similar site selection.

The main objectives of the present research are to: define the most suitable site/sites for constructing Matrouh Port based on: the guidelines for development of ports, harbors and marinas [7] and assess the proposed / planned site.

II. Materials and Methods

A. Study Area Description

The Northwestern coast development project is one of the three main national development projects in Egypt for Urban Development in 2052. The New Suez Canal is the first one is and the second one is the Golden Triangle for mining in the Eastern Desert. The selected area for investigation is a long, relatively narrow strip of land and sea extending 7.0 km from the coast line in the inshore area of the Mediterranean Sea. It extends towards the south inland until the international coastal road. From the east, it starts from west of Marsa Matrouh city (a city for recreational and touristic activities) and in the west, extends to a distance of about 30 km from one of the planned sites for the port (Fig. 1). The investigated area occupies an area of about 1165 km^2. A commercial sea port is planned to be established in El-Negeila area including maritime berths, industrial zones, commercial areas and other areas on an area of about 2395 acres in the outskirts of the city of Sidi Barani, 110 km west of Marsa Matrouh city with an investment cost estimated to be 1.6 billion Euros.

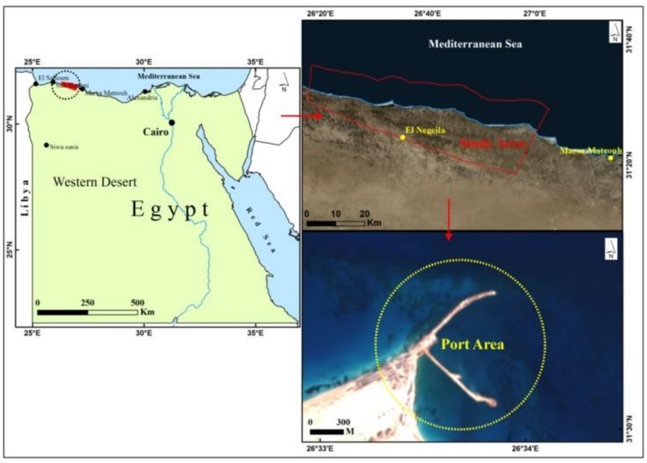


Fig. 1. Location map of the study area.

B. Data and Methods Applied

To fulfill the requirements of the present study, various sources of data have been collected, processed, analysed and integrated into a GIS database followed by the methodology applied for Geo-environmental research. These datasets include:

1) Satellite remote sensing data

- Multispectral Landsat TM, ETM and OLI images were used for:

1) **Delineating land use /cover classes:** Two main land cover classes, urban and cultivated areas, were delineated from a Landsat OLI satellite image dated 2nd of February 2018 (Fig. 2A). The Normalized Difference Vegetation Index (NDVI) was the used method for extracting cultivated areas using the well-known Equation 1. The output of the classification was enhanced using Google Earth images for small cultivated areas. For urban areas, on-screen digitizing was used and the output was enhanced from Sentinel-2 and Google Earth images.

$$NDVI = \frac{(\rho NIR - \rho Red)}{(\rho Red + \rho NIR)} \quad (1)$$

where: ρNIR is the Reflectance in the near infrared band and ρRed is the Reflectance in the red band. The value of this index ranges from -1.0 to 1.0 with the common range for green vegetation of 0.2 to 0.8.

2) **Defining the shore line:** The Normalized Difference Water Index (NDWI) is the used water index for coastline extraction and is a non-linear conversion of both green and near-infrared bands of the Landsat satellite image [8]. Water feature reflects the green band radiation and absorbs in NIR band [9]. NDWI was defined using Equation 2.

$$NDWI = \frac{(\rho Green - \rho NIR)}{(\rho Green + \rho NIR)} \quad (2)$$

where: $\rho Green$ and ρNIR are the reflectance value of Green and NIR band of Landsat image [8]. NDWI image was produced and a threshold value is needed to divide the image into two classes; land and water body using the methodology shown in Fig. 3. The exact shoreline location is shown in Fig. 2B.

3) **Extracting beach characteristics:** In this study, the main surveying devices was high-resolution satellite images integrated with in situ survey. Beach characteristics were extracted from a Landsat 8 satellite image and validated using field investigation. The extracted units included: beach sand, sand dunes, rock area, bare land and sabkhas. Sabkhas are given a minimum weight and sand dunes lie away from the coastal area.

4) **Erosion / Accretion rates**: DSAS (Digital Shoreline Analysis System) was used as a GIS tool to examine past and /or present shoreline positions. Using DSAS in coastal change analysis is useful in computing the rates of change for successive shoreline positions. The end point rate (EPR) is calculated by dividing the

distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline [10], [11]. Erosion and accretion rates are shown in Fig. 2B.

- **Sentinel-2:** A Sentinel-2 image with a spatial resolution of 10 m, acquired in January 2018, was used for:
  1) Defining boundaries of urban areas using on-screen digitizing (Fig. 2A).
  2) Updating and enhancing the roads network of the study area(Fig. 2D)
- **Shuttle Radar Topography Mission (SRTM)** with a 30 m spatial resolution: SRTM data obtains elevation data to generate high-resolution digital topographic database of the earth. The data was processed and classified and was used for:
  1) Defining areas possible to get submerged by a 1.0 m sea level rise (SLR). Using the raster calculator tool (included in ArcGIS 10.1), areas with sub meter elevation were extracted delineating areas under SLR threats (Fig. 2C).
  2) Flash flood analysis by studying the main drainage basins and evaluating the flood hazards at certain pour points along the international coastal road. The major factors influencing the runoff volume and associated peak discharge were described [12]; rainfall duration and intensity, soil types, type of natural or manmade cover on soil, and time of concentration.

Equation 3 is used to estimate surface runoff volume in the study area. The runoff volume for the five main basins along the study area is estimated and shown in Table I.

$$V = R * C * A * P \tag{3}$$

where V: is the surface runoff volume in m^3, R is the reduction factor where R = 1.05-.0053√Area, C is runoff coefficient where $C = [D\sqrt{(9.81 \times p)}/G](1\text{-}S)$, D = drainage density km/km^2, p = the rainfall depth mm, S = the average land surface slope in percent, G = an integer number representing the surface geology where G varies between 1.0 and 9.0; the value 1.0 is assigned to the basement rocks, and 9.0 for the most recent Quaternary deposits, A is the basin area upstream the point of interest.

- ALOS POLSAR 12.5m (2011) was used for obtaining the topography and slope of the study area (Fig. 2C)
- Google Earth maps: used to obtain some updated information for electric power networks (Fig. 2D), secondary roads and defining details in landuse and landcover layer.
- MODIS Data for defining the wave height in the coastal area: A layer is created where stretches of sea from the beaches are drawn in the direction of the predominant wave regime, to visualize the limitation

TABLE I: ESTIMATED RUNOFF VOLUME OF THE MAIN STUDY AREA DRAINAGE BASINS

Basin	A Km^2	D (km/km^2)	P (mm)	S %	G	R	C	V (m^3)
1	70.501	2.24	99.06	0.036	3.00	1.01	20.76	145808.3
2	121.818	2.70	99.06	0.039	3.00	0.99	24.61	294456.8
3	91.751	2.10	99.06	0.048	3.00	1.00	18.80	170710.3
4	156.007	0.79	99.06	0.051	3.00	0.98	7.35	111720.4
5	275.9251	0.34	99.06	0.046	3.00	0.96	3.34	87838.9

2) Maps

- Topographic maps published by the Military survey Authority in 1983 scale 1: (1:50,000), sheets: Marsa Matrouh, Marsa Elasi, Marsa Gargoub, Zayet Shemas and El-Gabgabh. The topographic maps were used to extract the roads, electric power line, railway line, fresh water supply line (Fig. 2).
- Rear Admiral (Jp clarke June 2003 Sheet: Ras AL Muraysah, scale: 1:500,000). These maps were used for obtaining the sea depth for a distance of 7.0 km from the coast. The coastal area, a buffer zone of 0.5 km from the coastal line in both directions, has been categorized into zones based on the depth of sea after a 0.5 km distance from the coastal line (Fig. 2B). This categorization was done to take into account that for locating a deep water port, the sea depth should not be less than 6.0-9.0 m (20-30 feet) at a distance of 500 m from the coast. In addition, field survey of the sea depth was performed.
- Groundwater depth and salinity for both Miocene and Quaternary aquifers were obtained [13] (Fig. 2E). Both aquifers can be utilized for obtaining fresh water for drinking, cooling and maintenance requirements.

3) Other sources of data

- Sea water quality: The water quality parameters in natural water are pH, dissolved oxygen (DO), redox potential, turbidity, salinity, temperature, and stream flow. Laser diffractometric is based on the in-site analysis of the diffraction pattern.
- Coastal habitat: The methodology adopted for this study was a combination of satellite images analysis, interpretation and ground surveying with habitats classified according to standard. Other significant problems included in this category are loss of bottom habitat and fishery resources
- Earthquakes: A survey for historical earthquakes that occurred within the eastern Mediterranean area took place through the USGS Earthquake Catalog [14] in the period from 1800 to 2018. It was found that the magnitude

ranged between 3.8 in 2015 (74km NNW of Rosetta) and 6.2 in 1955 (Eastern Mediterranean Sea). All surveyed points are located outside of the study area extent.

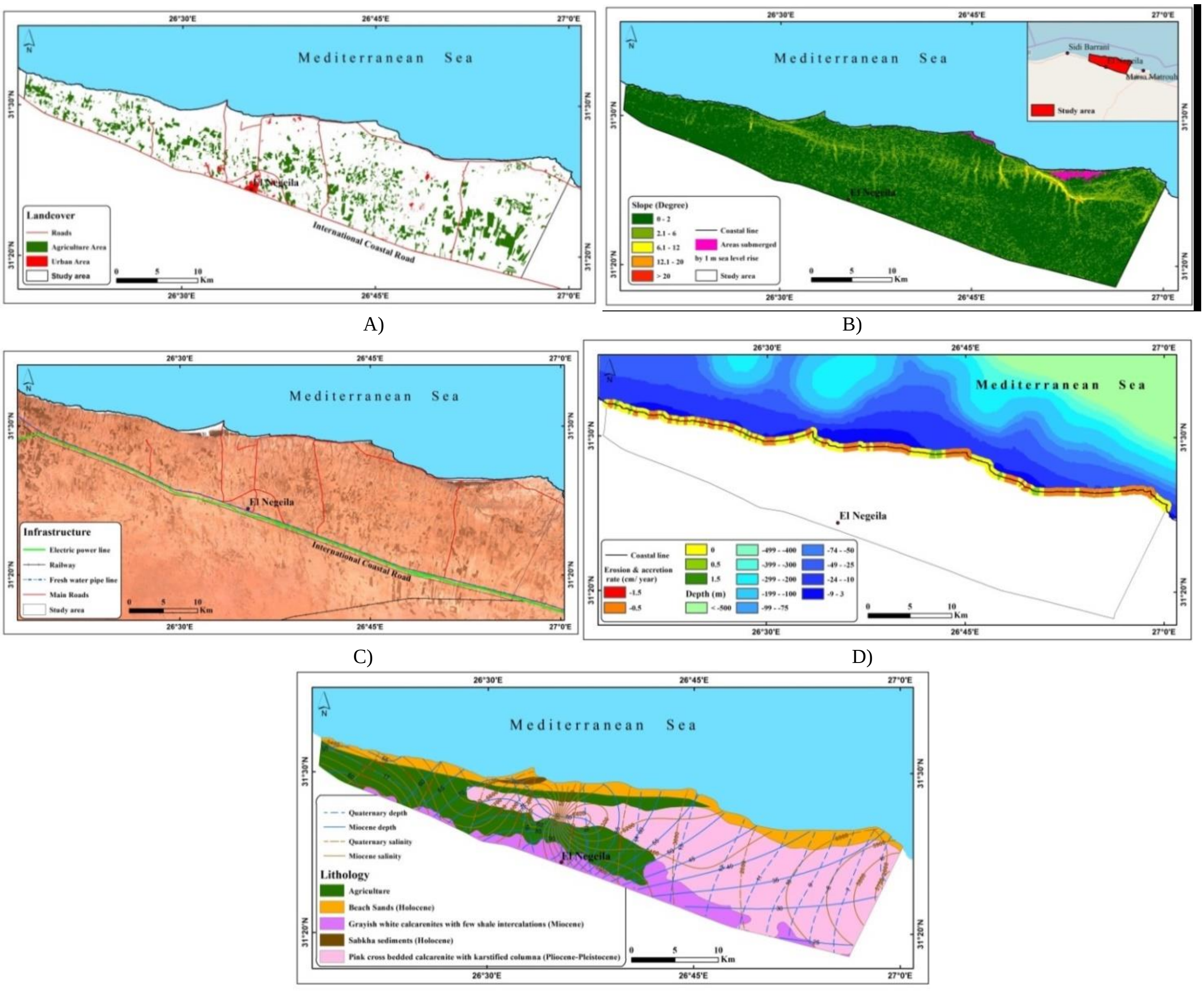


Fig. 2. Summary for model input layers (land and marine criteria); A) Landcover (cultivated and urban areas); B) Slope of the study area and areas expected to be submerged due 1.0 m to SLR; C) Infrastructures; D) Erosion/accretion rates, coastal line and sea depth; E) Lithological layers and groundwater characteristics for Miocene and Quaternary aquifers.

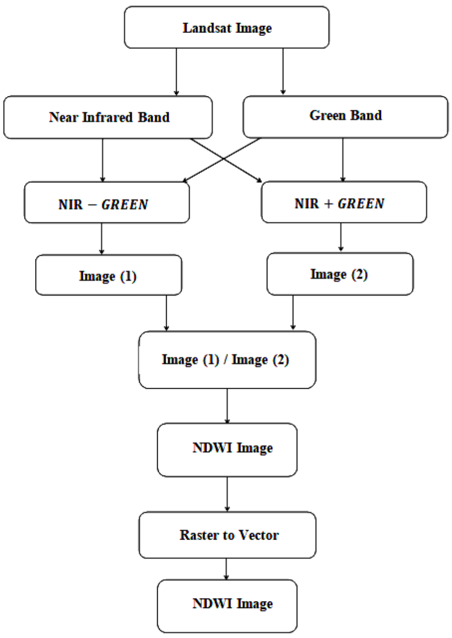


Fig. 3 Shore line extraction using NDWI.

C. SMCE for Site Selection of a Marine Sea Port

A SMCE model has been developed to define best locations for a marine port along the northwestern coast of Egypt. The procedure considers three main factors; marine (inshore/offshore), land (terrestrial) and infrastructures. Six steps have been implemented in the SMCE procedure as follows: 1) factors and hazards affecting the suitability of a site for the port; 2) data elaborated within a GIS platform for obtaining criteria and constraints maps; 3) a model designed to produce the suitability map for a suitable port site taking into account marine factors; 4) a second model designed to produce the suitability map for a suitable port site taking into account land and infrastructures factors; 5) the final suitability map is obtained from the first and second models; 6) The procedure was verified by comparing identified suitable sites with the already planned port location.

Two key MCE methods are employed and used for suitability analysis using GIS; weighted linear combination (WLC) (weighted overlay) [15]-[20] and the simple Boolean method. Constraints and criterion maps are obtained using the Boolean overlay in which factors are combined by logical; intersection and union operators. A common numeric range is used to standardize the criterion maps. These maps are then weighted and combined by WLC, masked by Boolean constraints map, into an overall layer to produce the final result of suitability. The procedure was fulfilled using Arc GIS 10.1 and a complete overview of the procedure is illustrated in Fig. 4.

Two separate model extents were used because for the area under investigation, it was not possible to use one model extent for the three criteria; marine, terrestrial and infrastructures. For that reason, the extent of the marine investigated area was 500 m from both sides of the coastal line. On the other hand, for the land (terrestrial) model, the modeled investigated area started from the coastal line until the international coastal road in the south. The different layers are categorized based on the following ratings: 1 (Best), 2 (Good), 3 (fair) 4 (Poor) and 5 (Worse and Unsuitable).

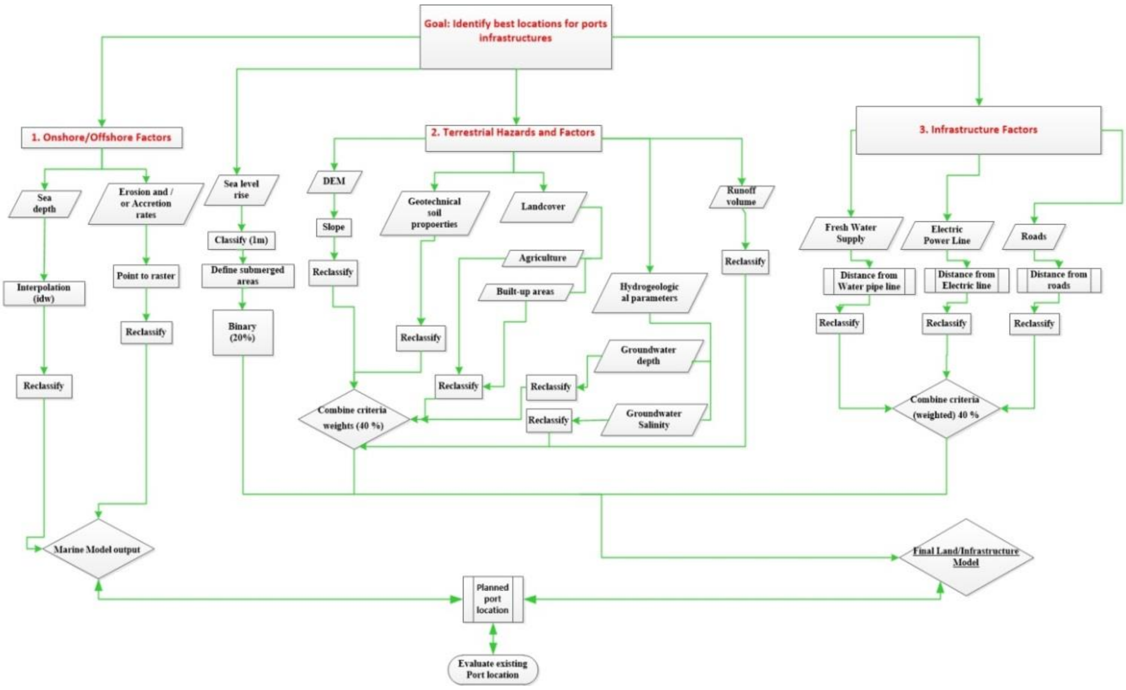


Fig. 4. A detailed flowchart of the weighted overlay model procedure. The onshore/offshore factors, terrestrial hazards and factors and infrastructure factors.

1) Step 1: Defining factors and hazards and collection of data

In order to select the most suitable locations for siting a sea port, first of all, factors and hazards that characterize and influence that selection were identified (Tables II-IV). Choice of factors was done by an extensive research of similar case studies and reports published by EEA [7], and expert judgments. In the process of selection of suitable sites, areas characterized by conflicting activities or areas with high ecological values were excluded.

2) Step 2: Preparing Criterion and Constraints Maps

The factors mentioned in Tables II-IV were classified into constraints and criteria (terrestrial hazards / factors, inshore/offshore hazards/factors and manmade facilities) for identifying suitable sites for ports construction. Constraints and criteria are characterized by eleven factors. For each criterion map an integer standardized score was applied; from 1 (Best) to 5 (not suitable). Standardized scores of 1-4, 1-8, 1-6 were used [21]-[23] but these scores was not suitable for the present case study.

a) 1st criterion: Land hazards / factors

According to the Egyptian Environmental Affairs Agency [7], the land matters considered for selecting an initial site for a sea port in Matrouh are:

1) Water issues: Whether the site is susceptible to flooding and if there are any risks from groundwater pollution due to changes in groundwater table, or proximity to recharge areas, or areas vulnerable to pollution?
2) Geological or soil issues: what is the area behind the beach like (e.g. sand dunes, cliffs, etc.);
3) Operational requirements: if the site provides sufficient land area for present and future requirements?
4) Community issues: Is the proposal likely to affect the heritage found?

The first criterion of land hazards/factors included six factors where an overall weight of **0.40** is assigned to this criterion.

b) 2nd criterion: Inshore/Offshore hazards/factors

According to the Egyptian Environmental Affairs Agency [7], the following are the terrestrial matters considered when selecting an initial site for a sea port in Matrouh:

1) Geological or soil issues: Is bank erosion likely; what is the beach area like (sandy, rocky) and how wide is it?
2) Flora and fauna issues: are any coral reefs present and are they likely to be affected by the project? Are there threatened flora or fauna species?

The second criterion of Inshore/Offshore hazards/factors included two factors.

c) 3rd criterion: Infrastructures

According to the Egyptian Environmental Affairs Agency [7], the following are the infrastructures matters considered when selecting an initial site for a sea port in Matrouh.

1) Water issues: What is the source of fresh water supply?
2) Operational requirements: Can services be efficiently supplied to the site (water, eclectic power) and are there any nearby services?
3) Transport issues: Can the capacity of the road network accommodate traffic likely to be generated by the port?

The third criterion of manmade facilities included four factors as shown in

TABLE . The Euclidean distance spatial analyst tool was used for obtaining three raster layers for roads, electricity line and fresh water pipelines as shown in Fig. 5A. A weight of **0.40** is assigned to this criteria based on a fact that infrastructures can be changed and updated based on the required conditions and status available in the site.

The first and third criteria are modeled together in one single model with an extent different from that of the second criterion as described in section 2.3.

d) Constraints map

Constraints of the study area include all conditions and factors that make an area not suitable for siting a port. So, their mapping allows removing all unsuitable locations and hence helps to avoid conflicts in decision-making: unavailable sites or not completely suitable for ports constructions are excluded. Constraints include: natural protected areas, areas with optimum coastal habitat, areas intersecting with gas and petroleum concession areas. Constraints also include areas with unsuitable sea morphology (depth less than 6.0 m after 500 m from the coast). Excluded areas also include those with erosion/accretion rates greater than 1.5 cm/year and all areas subjected to be submerged due to SLR of 1.0m. Areas submerged due to 1.0 m SLR are located in the east and middle of the study area with a total area of about 1.5 km^2. All areas that are unsuitable for at least one criterion were included in the constraints map (Fig. 5d). Boolean union was used for obtaining the constraints map and is used as an inverse mask for obtaining suitability map, so as to reduce the raster computations. A weight of 0.2 was assigned to areas exposed to 1.0 m SLR and these areas were restricted in the model.

3) Step 3: Design and output of the Inshore/offshore model

The Inshore/offshore model is designed to include two main layers; depth of sea and erosion / accretion rates. To elaborate both layers in the model, a different special extent inside the study area was prepared. This extent is 0.5 km buffer zone from both sides of the coastal line. The depth of the sea at 0.5 km from the coast was interpolated in the 0.5 km buffer zone so that the depth of 0-6.0 m is given a rate of 4 (unsuitable), 6-9 m given a rate of 3, 9-20 m given a rate of 2, and > 20 m given a rate of 1 (Best) as show in Table IV. A similar categorization was applied for erosion/accretion rates. The points when erosion / accretion rates were estimated were converted to a raster file within the same extent. Erosion/accretion rates were categorized as shown in Table IV as: - 0.5- 0.5 cm/year (stable and rated 1),-0.5- -1.50 cm/year (high accretion and rated 2), 0.5-1.50 cm/year (high erosion and rated 3) and >1.50 cm/year (extremely high erosion and rated 5).

A weighted multicriteria overlay model is designed for the two factors with an influence of 50% for each one of them. The equal influence was set because both factors are with the same degree of importance and are dynamic natural factors that cannot be stopped or reduced unless there are other external precautions taken into consideration.

4) Step 4: Design and output of land and infrastructure model

Land and infrastructures model is designed to include layers from both factors together (Tables II and III). Land and infrastructures have the same extent; from the coastal line southwards until the international coastal road. In addition to these two main factors, SLR was included as a third factor with same extent. First of all, areas liable to be submerged by a 1.0 m SLR were extracted and were categorized by Binary overlay (0 or 1).

The straight rank-sum method was applied for obtaining the criteria weights of the land/terrestrial factors. The rank sum method was described [24] and has been used in a number of GIS-multi-criteria decision analysis (MCDA) applications [25]. The first priority rank was assigned to the Runoff volume class, second priority rank assigned to Slope, the third priority rank assigned to the Land cover, the fourth priority rank assigned to Soil, the fifth priority rank assigned to GW Depth and the sixth priority rank assigned to GW salinity. The method was used for weight assignment using Equation 4 [24].

$$wj = (n - rj + 1/SUM\ (n - rk + 1) \quad (4)$$

where wj is the normalized weight for the j th factor, n is the number of factors, rj is the rank position of the factor. Rk is the factor number. Table V, Table VI and Table VII show the weights for infrastructures, terrestrial and marine factors.

5) Step 5: Final Suitability Map

The final suitability map is obtained from the first and second models. After setting the mask from constraints map, criteria map are joined using judgment from experts, representing the weights assigned to each criterion, using a weighted linear combination (WLC), obtaining a final output from suitable locations for a port location. WLC is one of the most used decision methods in GIS [5], [16], [23], [26], [27]. In this study raster format was the main used format for the analysis (even vector format data was converted to raster) because it is easier to implement and better supported by Arc GIS. Hence, criterion and constraints maps were created in a vector format then converted to raster, using a unified spatial resolution of 50 m (the best spatial resolution to give optimum results). The final suitability map has been obtained using the same 50 m resolution. Each criterion and constraints map is composed of I pixels where each pixel is associated with an xij value (representing a standardized score of the *i*–th pixel W.R.T. the *j*-th criterion). The suitability of each pixel was calculated using Equation 5 [28].

$$\text{Ai} = \sum Wjxij \quad (5)$$

where Ai is the suitability of the i-th pixel, Wj is the weight of the j-th criterion with $\sum Wj=1$.

According to literature and national reports [29] for specs of local ports in Egypt (ex. Alexandria, Dekheila,..), in their current design status and future plans, a typical structure for a sea port is considered as follows. Its structure is composed of two main sections; inshore/offshore and terrestrial. The minimum distance along the coastal line is 1.4 km. For the inshore/offshore direction, at least 0.5 km and 1.5 km for terrestrial direction. In other words, an area of 2.1 km^2 (1.5 km × 1.4 km) in the land side and 0.7 km^2(0.5 km × 1.5 km) in the inshore/offshore direction with a total area of 2.8 km^2. Consequently, in the first (marine) model, areas less than 0.7 km^2 and less than 1.4 km in width are excluded from the output. For the second (land and infrastructures model), areas less than 2.1 km^2 and less than 1.4 km in width are excluded from the output.

6) Step 6: Verification

Model verification is a significant phase for data quality and testing outputs of the process [30]. Verification took place by comparing the suitable sites identified and the positions of the planned port at Negilla.

TABLE II: LAND HAZARDS AND FACTORS, ATTRIBUTE VALUES, DESCRIPTION AND RATING

Criteria	Factor	Attribute values	Description	Rating
Terrestrial hazards / Factors (Overall Weight 40 %)				
	Runoff volume (*1000 m^3)	< 120	Best	1
		121-150	Suitable	2
		> 151	Unsuitable	3
	Geotechnical Soil properties	Cross bedded calcarenite with karstified columnar structures at the top	Best	1
		Grayish white calcarenites with few shale intercalations, followed by upwards white limestone	Suitable	2
		Beach Sands	Best	1
		Sabkha sediments	Unsuitable	5
		Agriculture	Unsuitable	5
	Groundwater Salinity (ppm)	< 1200	Best	1
		1200-3000	Water involving a hazard for irrigation	2
		3000-7000	Water can be used for irrigation only with leaching and perfect drainage	3
		> 7000	Unsuitable for both drinking and irrigation	4
	Groundwater Depth (m)	> 20	Very deep	1
		15-20	deep	2
		10 -15	Medium Deep	3
		< 10	Shallow	4
	Slope (degrees)	<1	Level	1
		1-3	Very gentle slope	2
		3-5	Gentle slope	3
		5-10	Moderate slope	4
		>10	Strong slope	5
	Land cover (area in m^2)	Bare Land	Bare Land	1
		< 42000	Small cultivated lands	2
		< 500	Small urban areas	2
		>42000	Main cultivated lands	3
		>500	Main built up areas	3

TABLE III: MANMADE FACILITIES (INFRASTRUCTURES), ATTRIBUTE VALUES, DESCRIPTION AND RATING

Criteria	Factor	Attribute values	Description	Rating
Man Made Facilities (Infrastructures) (Overall Weight = 40 %)				
	Proximity to Fresh Water Supply (m)	< 2500	Very Close	1
		2500-5000	Close	2
		5000-7500	Medium	3
		7500-10000	Far	4
		> 10000	Very far	5
	Distance from Electric Power Line (m)	< 4000	Very Close	1
		4000-8000	Close	2
		8000-12000	Medium	3
		>12000	Far	4
	Distance from Roads (m)	< 1500	Very Close	1
		1500-3000	Close	2
		3000-4500	Medium	3
		4500-6000	Far	4
		>6000	Very far	5

**Sea Level Rise: lands expected to get submerged due to SLR of 1.0 m by the year 2030. (Overall Weight = 20 %)

TABLE IV: INSHORE/OFFSHORE HAZARDS / FACTORS, ATTRIBUTE VALUES, DESCRIPTION AND RATING

Criteria	Factor	Attribute values	Description	Rating
	Depth of Sea (m) within a buffer zone of 0.5 km from coastal line based on the depth after 0.5 km from coast	0-6.0	Unsuitable for regular ports and deep water ports	4
		6.0-9.0	Suitable for regular ports and deep water ports	3
		9.0-20.0		2
		>20.0	Suitable for regular ports and deep water ports	1
	Erosion / Accretion rate (cm/year)	-0.5 – 0.5	Almost stable	1
		-0.5 – -1.50	High accretion	3
		< -1.50	Extremely high accretion	5
		0.5 – 1.50	High erosion	3
		>1.50	Extremely high erosion	5

TABLE V: CRITERIA WEIGHTS FOR THE TERRESTRIAL HAZARDS / FACTORS

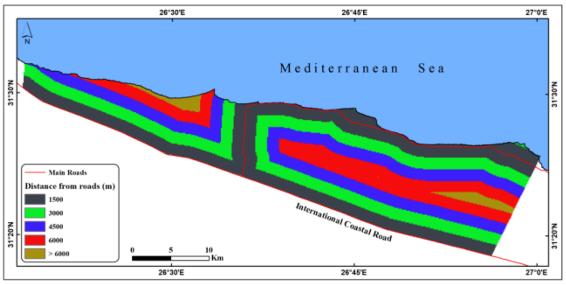
Rank	Criteria	Weight ($n-rj$ +1)	Normalized weight wj
1	Runoff volume	6	0.285
2	Slope degree	5	0.23
3	Land cover	4	0.19
4	Soil	3	0.143
5	GW Depth	2	0.09
6	GW salinity	1	0.05
Sum		21	

TABLE VI: CRITERIA WEIGHTS FOR THE INFRASTRUCTURES FACTORS

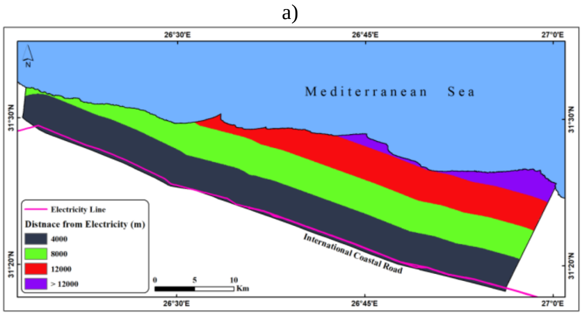
Rank	Criteria	Weight ($n-rj$ + 1)	Normalized weight wj
1	Distance to power line	3	0.5
2	Distance to fresh water facility	2	0.33
3	Distance Roads	1	0.166
Sum		6	

TABLE VII: CRITERIA WEIGHTS FOR THE INSHORE /OFFSHORE FACTORS

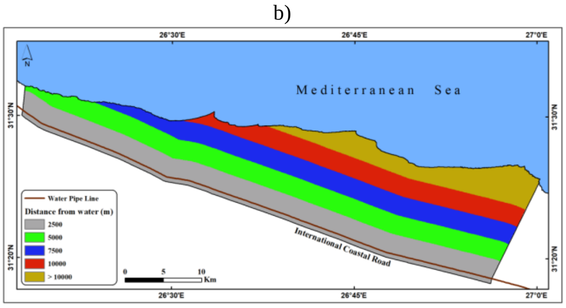
Rank	Criteria	Weight ($n-rj$+1)	Normalized weight wj
1	Depth of sea	1	0.5
2	Erosion/accretion	1	0.5
Sum		2	



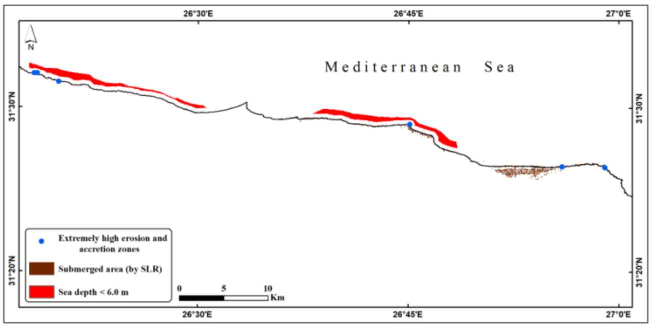
a)



b)



c)



d)

Fig. 5. Criteria maps for: a) Distance to roads, b) Distance to electricity line, c) Distance to freshwater line, d) Map of constraints.

III. RESULTS

The suitability map for favorable ports sites to be constructed, along the northwestern coast of Egypt, is shown in Fig. 6, Fig. 7 and a summary of results is shown in Table VIII. Locations suitable for constructing ports were obtained from two models; the first one for the marine criteria and the second one for land and infrastructures together.

A total of 62 locations are identified and classified as suitable for positioning a port along the northwestern coast (west to Marsa Matrouh), within a total extension of about 70 km in the east west direction. These 62 locations of the marine coastal zone have a suitable morphology in terms of slope (less than 10◦) and depth of sea (more than 6.0 m after the first 500 m from coast).

TABLE VIII: SUMMARY OF SUITABLE AREAS (FROM MARINE MODEL OUTPUT) GROUPED FOR SUITABILITY VALUES, EXPRESSED IN TERMS OF NUMBER OF SUITABLE AREAS AND EXTENSION IN KM^2 AND % WITH RESPECT TO SUITABLE AREAS

Suitability value	Surface area (km^2)	No. of areas	%
1	1.6562	1	2.3
2	19.4694	21	26.6
3	40.7503	30	55.6
4	11.4039	10	15.6
5	0.0051	0	0
Total	73.2798	62	100

The output of the inshore/offshore model, (covering 1.0 km of the coastal zone, 500 m from each side of the coastal line), shows the following results: All identified areas record suitability values from 1 to 5. Only one location, at the far eastern extension of the coast recorded a suitability of 1 (Best) as shown in Fig. 6 and Fig. 7. This location is excluded due to its proximity to a high risk area of terrestrial hazards (flash floods possibility and steep slopes). About 21 of the identified locations (26.6 %) show a rating of 2 (good suitability). About 55.6 % of areas identified show a rating of 3 (fair suitability) counting to 30 locations. 15.6 % of the total number of areas showed a rating of 4 with a total number of 10 areas. Moreover, no areas have obtained a suitability value of 5.

The verification phase of the procedure has shown that the planned port in west Negeila is actually located in suitable areas (rank 2 and 3) (Figs. 7 and 8).

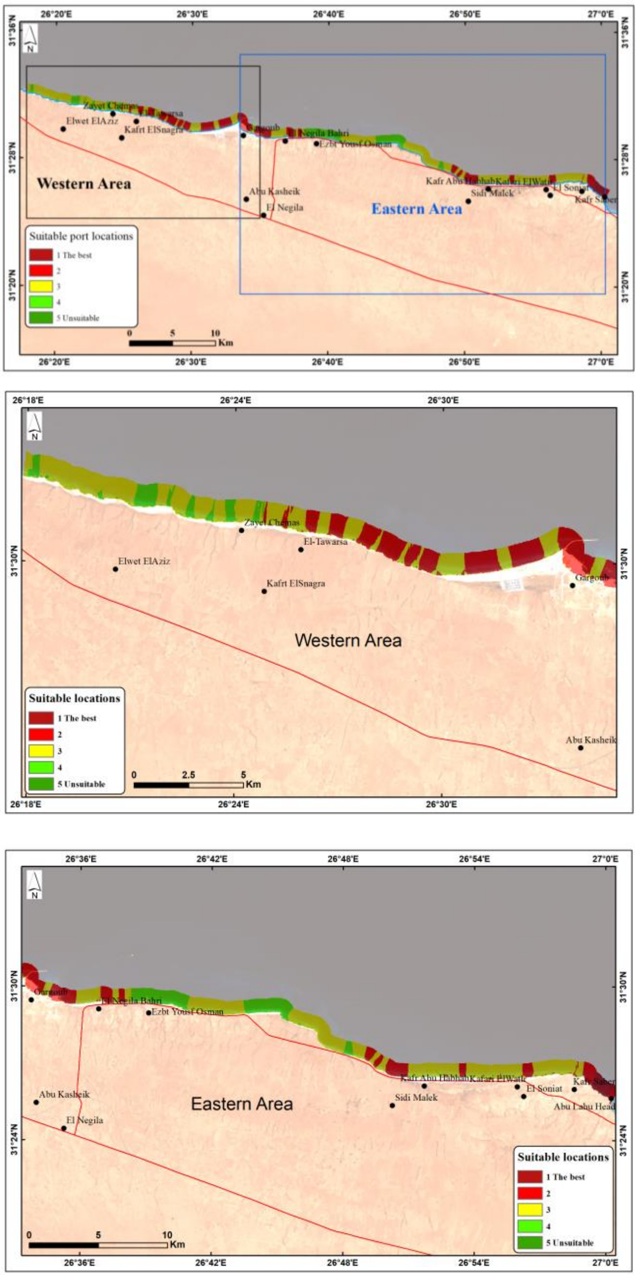


Fig. 6. Suitability map for siting Ports in the northwestern coast: areas classified from best to unsuitable. (Background is a Sentinel -2 satellite image 23 August 2018).

IV. Discussion and Recommendations

The northwestern coast of Egypt is considered to be one of the important coastal networks with the neighboring countries (Mediterranean Sea basin countries). Using ports for importing and / or exporting represents one of the most economic ways of transport between countries and in the same country. Therefore, it is a necessity to designate to this activity suitable sites from terrestrial, inshore , offshore and infrastructures (man-made facilities) points if view.

The northwestern coast of Egypt is a complex system, in which there are many resources / factors / constraints and limitations that contribute together to decide the most suitable location to site a sea port. The problem of spatial planning (a suitable site location) for a certain activity in the coastal zone requires the consideration of several data and information [31]. When starting a new economic/transport activity, different stakeholders have to be involved in the decision-making process. The involvement of stakeholders does not mean that we do not consider the environmental laws of the country [7].

When investigating the dimensions of each classified polygon in the inshore/offshore zone, the following was found: For class 2, extensions of polygons ≥1.4 km on the coastal direction are located immediately east and west to the present port location (Fig. 8). For class 3, most of the locations with a suitable lateral extension are in the eastern side of the study area (Fig. 6)

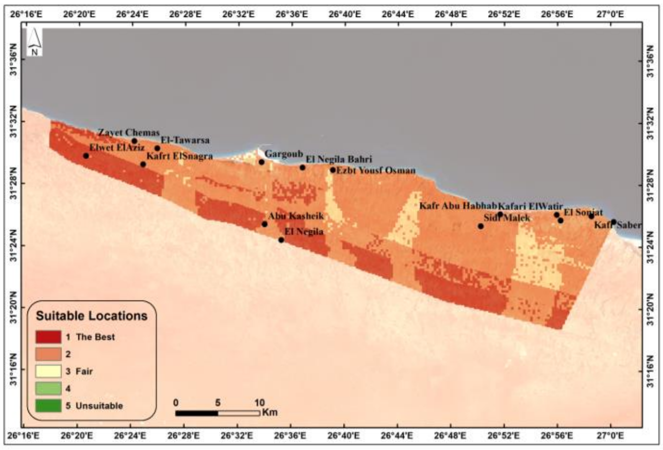


Fig. 7. Suitability map for siting Ports in the northwestern coast with areas classified from best to unsuitable (taking into account the land factors. (Background is a Sentinel-2 satellite image 23 August 2018).

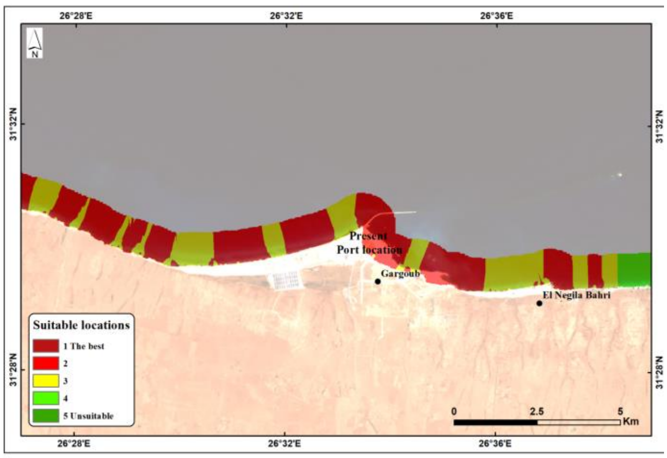


Fig. 8. Comparison map between areas identified using the SMCE model and the present port location at Gargoub. (Background is the Sentinel-2 Image 23 August 2018).

V. Conclusions

The paper presents a procedure developed using the SMCE using ARC GIS modeling for identifying suitable areas to locate new sea ports at the NW coast of Egypt (West to Marsa Matrouh). Due to the different extent for analysis of land and marine factors/criteria, two different extents were used. A spatial resolution of 50 m was applied throughout the whole modeling processes. Identification of suitable areas coincided with the already planned port at Gargoub area (Fig. 8). The present procedure can be enhanced in a way to incorporate all factors in one model. Furthermore, network analysis might be done in GIS to estimate minimum time for reaching the port from adjacent commercial markets

Conflicts of Interest

The authors declare no conflict of interest.

Authors Contributions

This work was carried out in collaboration between all authors. All authors participated equally in the study idea, literature review, data collection and analyses, methodology, statistical analyses, tabulating the data, results validation, writing and revising the whole manuscript-All authors read and approved the final manuscript.

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References

[1] N. F. Soliman *et al*., “Sustainable development of the Northwestern coastal zone of Egypt: economic, social and environmental perspectives,” presented at International Conference on Biotechnology and Environment 2016 (ICBE2016), Institute of Graduate Studies and Research, 2016.

[2] G. Tsinker, *Handbook of Port and Harbor Engineering. Geotechnical and Structural Aspects*, Springer-Science+Business Media, 1997.

[3] J.-P. Rodrigue and T. Notteboom, “The spatial organization of transportation and mobility,” *The Geography of Transport Systems*, 2018.

[4] W. Quellette, “Remote sensing for marine spatial planning and integrated coastal areas management: Achievements, challenges, opportunities and future prospects,” July 2016.

[5] G. Dapueto *et al*., “A spatial multi-criteria evaluation for site selection of offshore marine fish farm in the Ligurian Sea, Italy,” *Ocean & Coastal Management*, vol. 116, 2015, pp. 64-77.

[6] E. K. Zavadskas, Z. Turskis, and V. Bagoˇcius, “Multi-criteria selection of a deep-water port in the Eastern Baltic Sea,” *Applied Soft Computing*, vol. 26, 2015, pp. 180–192.

[7] Egyptian Environmental Affairs Agency (EEAA) (1995 and 2005), “Guidelines for development of ports, harbours and marinas,” *Environmental Impact Assessment*, SEAM Project.

[8] S. McFeeters, “The use of normalized difference water index (NDWI) in the delineation of open water features,” *Int. J. Remote Sens*., vol. 17, pp. 1425–1432, 1996.

[9] S. S. Mitra, D. Mitra, and A. Santra, “Performance testing of selected automated coastline detection techniques applied on multispectral satellite imageries,” *Earth Sci. Inf.*, 2017, vol. 10, pp. 321–330.

[10] M. Crowell *et al*., “On forecasting future US shoreline positions: A test of algorithms,” *Journal of Coastal Research*, vol. 13, no. 4, pp. 1245-1255, 1997.

[11] R. Dolan *et al*., “Temporal analysis of shoreline recession and accretion,” *Journal of Coastal Research*, vol. 7, no. 3, pp. 723-744, 1991.

[12] Y. S. Sherief, “Flash floods and their effects on the development in El-Qaá plain area in south Sinai, Egypt, a study in applied geomorphology using GIS and remote sensing,” Dissertation Zur Erlangung des Grades “Doktor der Naturwissenschaften” im Promotionsfach Geographie. Universität Mainz, 2008.

[13] N. A. Morad *et al*., “Hydrologic factors controlling groundwater salinity in northwestern coastal zone,” *Egypt. J. Earth Syst. Sci*., vol. 123, no. 7, October 2014, pp. 1567–1578.

[14] Earthquake Catalog. (2018). [Online]. Avilable: https://earthquake.usgs.gov/earthquakes/search/

[15] J. R. Eastman *et al*., “Raster procedures for multicriteria multiobjective decisions,” *Photogramm Eng Remote Sens*, vol. 61, no. 5, pp. 539–547, 1995,

[16] R. Eastman, “Multi-criteria evaluation and GIS,” *Geographical Information Systems*, Wiley, New York, pp. 493-502, 1999.

[17] H. Jiang and J. R. Eastman, “Application of fuzzy measures in multi-criteria evaluation in GIS,” *Int. J. Geogr. Inform. Sci*., vol. 14, no. 2, pp. 173-184, 2000.

[18] D. O'Sullivan and D. J. Unwin, *Geographic Information Analysis*, Wiley, Hoboken, NJ, p. 436, 2003.

[19] J. Malczewski and C. Rinner, “Exploring multicriteria decision strategies in GIS with linguistic quantifiers: A case study of residential quality evaluation,” *J. Geogr. Syst*., vol. 7, pp. 249-268, 2005.

[20] J. Malczewski, “Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis,” *Int. J. Appl. Earth Observ. Geoinform*, vol. 8, pp. 270-277, 2006.

[21] J. Aguilar-Manjarrez and L. G. Ross, “Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico,” *Aquac. Int*., vol. 3, pp. 103-115, 1995.

[22] M. A. Salam and L. G. Ross, “Optimising site selection for development of shrimp (Penaeus monodon) and mud crab (Scylla serrata) culture in South-western Bangladesh,” in *Proc. GIS 2000 Conference Proceedings*, March 13-16, Toronto, Canada, 2000.

[23] O. M. Pérez *et al*., “Geographical information systems-based models for offshore floating marine fish cage aquaculture site selection in Tenerife, Canary Islands,” *Aquac. Res*., vol. 36, pp. 946-961, 2005.

[24] J. Malczewski, *GIS and Multicriteria Decision Analysis*, Wiley, New York, 1999.

[25] H. A. Effat and A. El-Zeiny, “Modeling potential zones for solar energy in Fayoum, Egypt, using satellite and spatial data,” *Model. Earth Syst. Environ*., vol. 3, pp. 1529–1542, 2017.

[26] M. L. M. Graymore *et al*., “An index of regional sustainability: A GIS-based multiple criteria analysis decision support system or progressing sustainability,” *Ecol. Complex*, vol. 6, pp. 453-462, 2009.

[27] JICA, T”he study on master plan and rehabilitation scheme of the Greater Alexandria Port in the Arab Republic of Egypt: final report,” 1999.

[28] J. Wang *et al*., “IA-SDSS: A GIS-based land use decision support system with consideration of carbon sequestration,” *Environ. Model. Softw*., vol. 25, pp. 539-553, 2010.

[29] J. Malczewski, “On the use of weighted linear combination method in GIS: common and best practice approaches,” *Trans. GIS*, vol. 4, no. 1, pp. 5-22, 2000.

[30] S. S. Nath, J. P. Bolte *et al*., “Applications of geographical information systems (GIS) for spatial decision support in aquaculture,” *Aquac. Eng*., vol. 23, pp. 233-278, 2000.

[31] P. C. Longdill *et al.*, “An integrated GIS approach for sustainable aquaculture management area site selection,” *Ocean Coast. Manag.*, vol. 51, pp. 612-624, 2008.

Salwa F. Elbeih is an associate professor of civil engineering at the Engineering Applications and Water Division, National Authority for Remote Sensing and Space Sciences (NARSS), Cairo Egypt since May 2014. She has obtained her Ph.D. in civil engineering from Ain Shams University in 2007. She is the acting head of the engineering applications department at NARSS. She participated in several funded national and international cooperation projects including (TEMPUS – Project) 2009-2012, (SUDSOE), FP7 2012-2014, (RDI Programme) 2010 -2012. She is one of the national editors of the Egyptian Journal of Remote Sensing and Space Sciences (EJRS) and a reviewer in more than six international journals. Her research interests comprise: applications of remote sensing and GIS in civil engineering, environmental and geotechnical engineering, the relation between archaeological and water resources conditions. She received a prize from the ministry of water resources and irrigation (2010), best paper in the 6th International Conference on Environmental Hydrology and 2009.

Sameh Bakr El Sayed El Kafrawy is an expert in the field of environmental studies. He is the head of Marine Science Department and Integrated Coastal Zone Management (ICZM) Lab. at National Authority for Remote Sensing and Space Sciences (NARSS). He is an associate professor at NARSS specializing in remote sensing applications in marine and coastal studies. He was been employed at NARSS since 2000. He has been involved and lead in several international projects, WATERMED, ICAMS RAMSES, ALIMAM and MELMARINA, PEGASO Projects and worked on several fields the application of remote sensing and GIS to Environmental studies has been a major interest.

Wael Attia is a GIS & remote sensing analyst in the Engineering Application Department at National Authority for Remote Sensing and Space Sciences (NARSS), Egypt. He was born on the August 6, 1985. He has completed his B.Sc. in Geography Dept. in Faculty of Arts Alexandria University. He had worked in Egyptian General Survey Authority as a GIS specialist. He has more than 12 years of experience in GIS and remote sensing applications, and he got his M.Sc in physical geography using GIS and remote sensing technique in 2018.