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RESEARCH PAPER

Change detection and restoration alternatives for the Egyptian Lake Maryut

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Risk assessment;
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Abstract This paper analyzes all changes that occurred to the Egyptian Lake Maryut in order to identify the best strategy for restoring it. Four scenes were used for change detection; three LANDSAT images (dated 15th of March 1991, 2nd of May 2004, and 22nd of May 2013), and the fourth scene was a SPOT-HRV image dated 16th of August 1995. Maximum likelihood classification (MLC) algorithm was used to classify the images. The next step used was to focus on land cover changes by using change detection comparison (pixel by pixel) and the cross tabulation technique to analyze changes for the four supervised classification images. The results indicated that severe land cover changes occurred in different land covers especially in the last few years that may be due to political and socio-economic problems. Finally, a modern method based on the Delphi technique was used to select the best restoration alternative for restoring the Lake Maryut. Results indicate that severe land cover changes have occurred. In addition, the most suitable restoration alternatives are pollution control for the eastern part of the lake and reopening closed parts in its western part.

1. Introduction

In Egypt, the pressure of population on land and its limited resources for producing more food, fodder, and fuel represent a major factor affecting sustainable development. During the last few years, and due to political changes and the absence of tight monitoring procedures, land use/land cover changes are taking place at high rates that make this environment prone to degradation. Planners, resource managers, and decision-makers need a reliable mechanism to evaluate the problem and give alternatives for land restoration including lakes' rehabilitation.

The Governorate of Alexandria hosts about 40% of the Egyptian industrial activities. Most of these activities are dependent on using Lake Maryut, which is located to the south of Alexandria City, either in the cooling process or as a liquid waste dumpsite. In addition, agricultural drainage water (at least six million m^3/day), carrying agro-chemicals and trace metals together with industrial wastes and untreated domestic waste were discharged into the lake (Sestini, 1993). Due to this strong human impact on the lake, many changes occurred to this environment both physical (i.e. changes in land cover/land use and water quality) and biological (i.e. changes in fish catch from 7767 tons in 1962, to 3847 in 1972, to less than 1000 tons in the 808 s) as reported by Halim, 1983. Increased eutrophication and emission of H_2S gas from the lake and salinity have

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also exacerbated the problem. These negative effects together with socioeconomic changes facing the country have put a tremendous pressure on Lake Maryut.

The objective of this study is to identify and assess the changes that occurred in the lake's ecosystem over the past two decades. All the different impacts on the lake are also listed and categorized, and results are used to identify options for restoration and sustainable development of the lake.

2. Study area

The present Lake Maryut represents a small portion of a larger lake that was known during the Roman era by Lake Mariutus. It extended for 80 km parallel to the north coast and 30 km south of Alexandria city, as shown in Fig. 1.

3. Data

The data used in this study could be classified into two groups. The first data group is the remote sensing images. Four scenes were used; LANDSAT-TM dated 15th of March 1991; SPOT-HRV dated 16th of August 1995, LANDSAT ETM + dated 2nd of May 2004; and LANDSAT ETM + Dated 22nd of May 2013. Fig. 2 represents the most recent image taken, as an example of those images.

The second data group used in this study is the GIS information with the field surveys' data used in building the geographic information system, like topographic maps, field survey databases, classified satellite images, and statistical data.

4. Image classification

The hybrid classification technique done through the ERDAS software was carried out for all available satellite images using MLC algorithm (Paola and Schowengerdt, 1995). Only 14 themes were found separable, as shown in Fig. 3. These are:

- Deep, shallow, and turbid water classes (representing 3 water bodies classes);
- Wet vegetation class (representing water hyacinths in the lake);
- Vegetation (two classes; annual crops and complex vegetation);
- Barren land (represents those agricultural areas with no vegetation cover);
- Wet land (on the margin of the lake and some logged areas);
- Orchards (mainly fig trees and some palm trees);
- Bare soil, Calcareous bare soil (two classes);
- Urban and Build up areas (one class includes roads and tracks);
- Calcareous sediments (represent those unconsolidated, high calcium carbonate content soil); and
- Limestone (and highly calcareous consolidated soils).

4.1. Post-classification (accuracy assessment)

An equal number of random points was chosen for each class in the supervised classification images for accuracy assessment. This is equal to (n + 1), where "n" is the number of obtained classes (i.e. equal to 15 points). Then, around each created random point, a polygon of size 9×9 pixels was created for testing. Thus, the total number of points used for each class is equal to 1215 ($9 \times 9 \times 15$) points. Results obtained indicated that the overall classification accuracy for LANDSAT TM scene taken in 1991 was 98.0%; for SPOT–HRV scene taken in 1995 was 98.6%. On the other hand, the accuracy percentage was 96.7% for the LANDSAT–ETM image taken in 2004, while it was 98.9% for the LANDSAT–ETM scene for the year 2013.

Figure 1 Location of the study area.

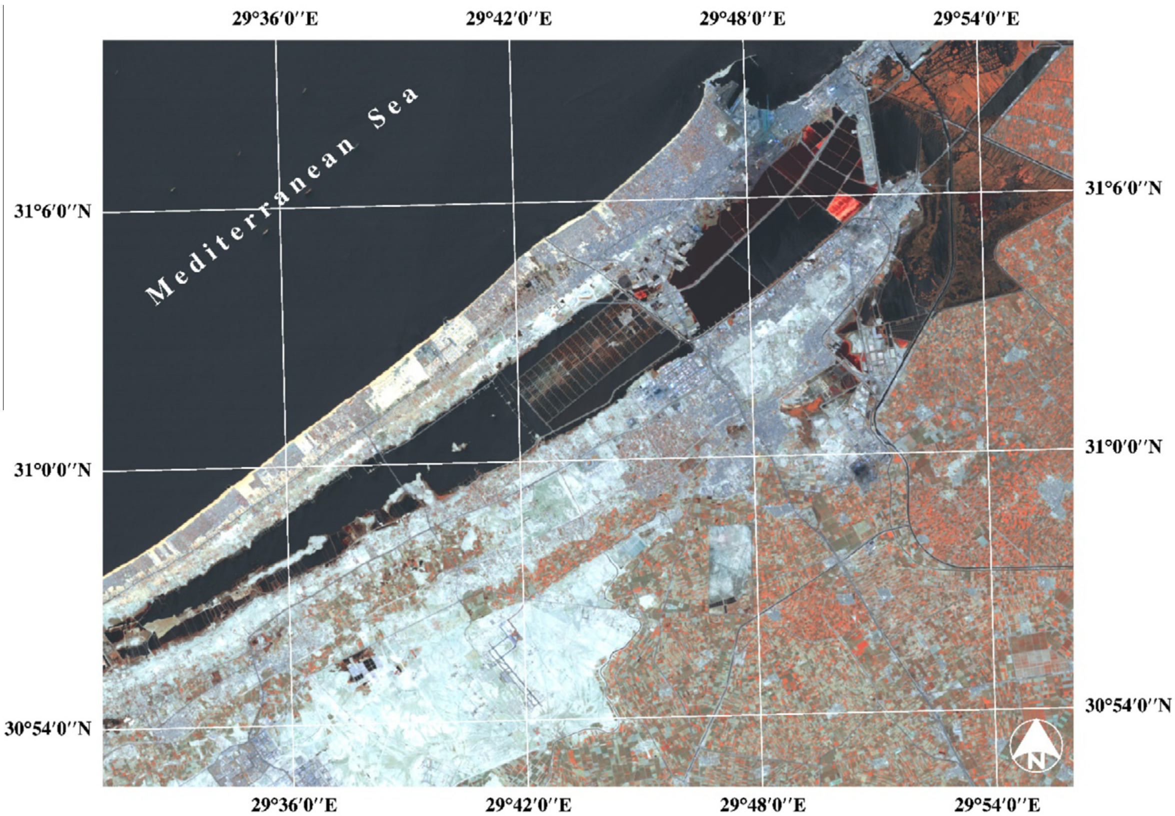

Figure 2 False color composite image, LANDSAT–ETM+, 2013.

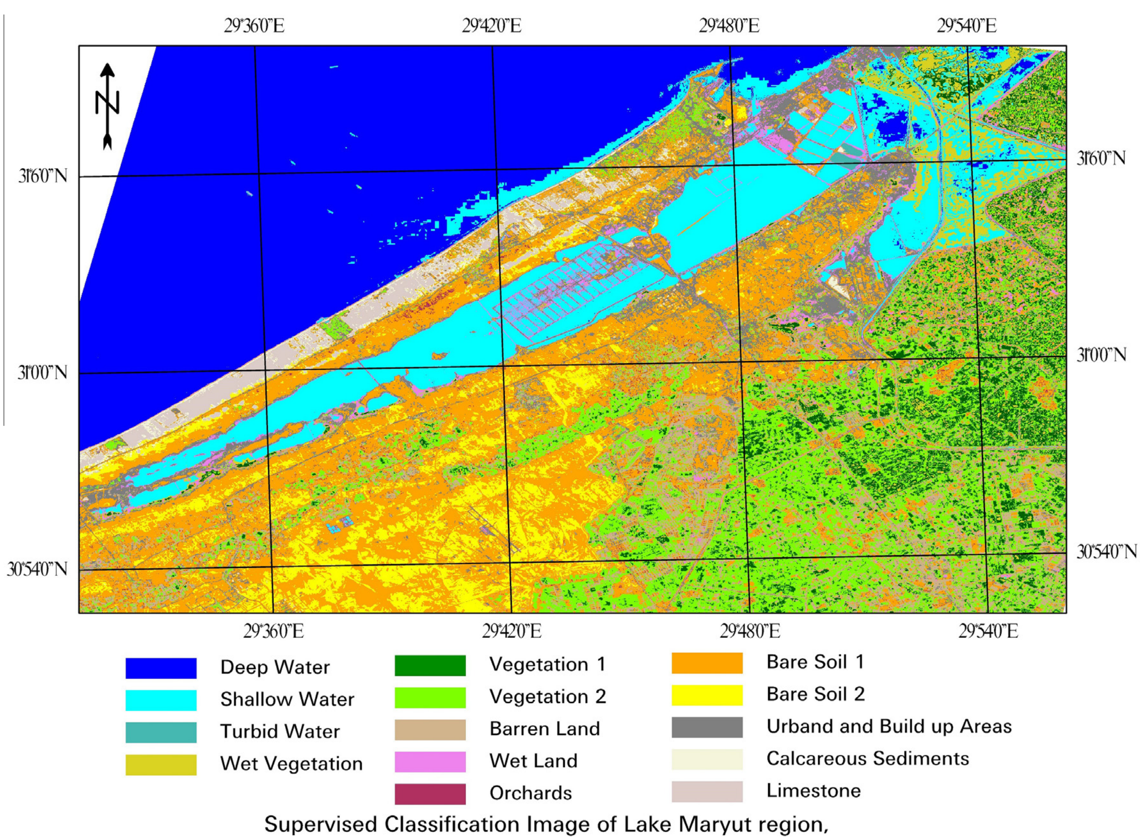

Figure 3 Supervised classification image of year 1995.

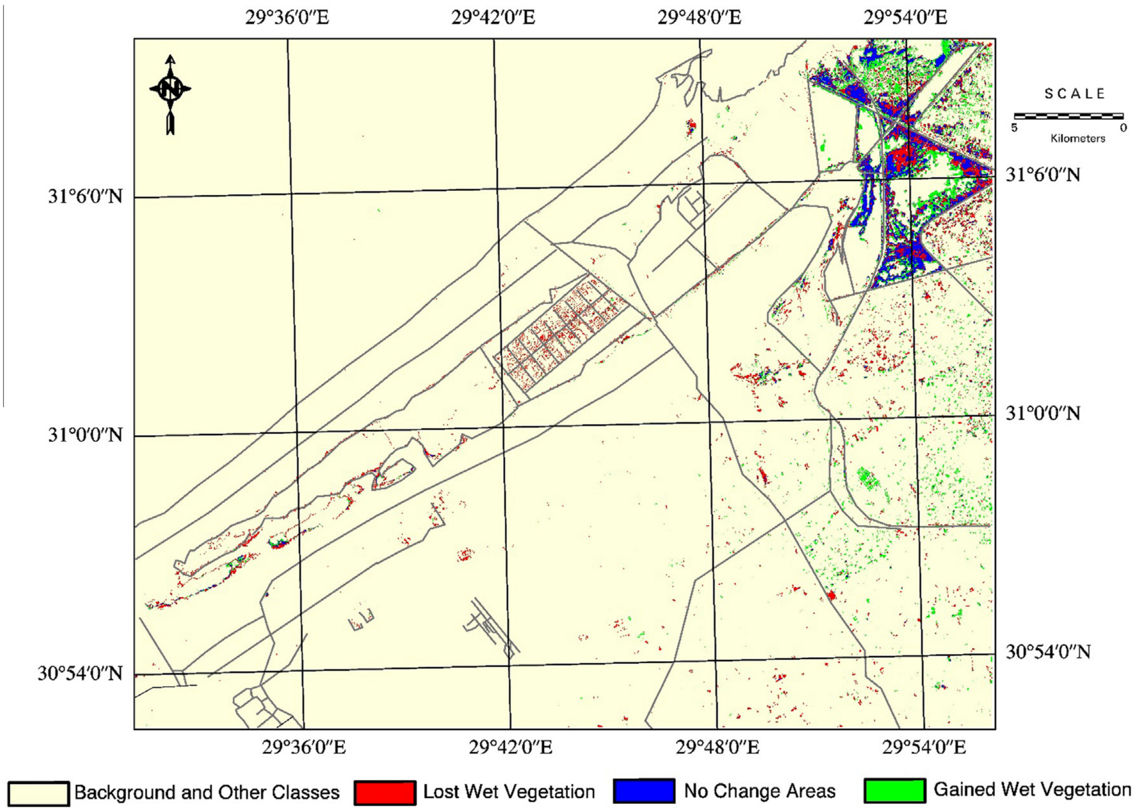

Figure 4 Changes in ''Wet-Vegetation'' land cover class.

5. Change detection in the area of Lake Maryut

The cross tabulation technique was used to identify changes that occurred in the area of Maryut Lake covering three different time spans; (i) 1991–1995, (ii) 1995–2004 and (iii) 2004–2013. Separate images were created for the changes of each land cover class during these three time spans (i.e. 14 images for each time span). Fig. 4 illustrates one of these created images. All the statistics of these are presented in Table 1.

6. Restoration of Lake Maryut

In order to achieve sustainable development of Lake Maryut and its surroundings, it was essential to find a scientific way to improve its conditions and to restore its nature and function. From the analysis undertaken, the main problems facing the restoration of Lake Maryut would be pollution (i.e. water, air, soil, and visual pollution), high eutrophication, accumulation of contaminated heavy metal sediments, increase of water hyacinths, and urban encroachment (i.e. shrinking of water body volume). A number of alternatives could be proposed based on the information derived from both remote sensing and GIS. According to the nature of the Lake and main activities surrounding it; it could be separated into two ecosystems. Hence, the alternatives could be also split into two main groups. The first group would be concerned with the eastern part of the Lake (high pollution rates and higher population), while the second group would be concerned with the western part (high shrinking rates). Both eastern and western groups may have three alternatives. All of these alternatives are presented in the following sections.

6.1. Eastern part alternatives

6.1.1. No action alternative

This alternative represents the current situation, with all human impacts (especially the different types of pollutants, like industrial, agricultural, and domestic wastes) on the lake and without having any restoration process. Contamination is expected to have serious negative cumulative and irreversible impacts.

6.1.2. Pollution control projects

This alternative needs a great deal of studies, efforts and funds. It has two main objectives; the first is to stop – or at least minimize-pollution from its sources, while the second objective is to launch pollution control projects to remove the accumulated effects of pollutants on the lake.

6.1.3. Encourage tourism activity in Maryut ridge

There are large areas around the lake that are suitable for tourism. The southeastern zone, which lies near ''King Maryut and Burg El-Arab'' areas, which are characterized by dry weather (low humidity) and moderate temperatures all over the year round, could be excellent for winter tourism. The northeastern zone, especially Maryut ridge, is characterized by high elevation and moderate temperature especially in summer. In fact, many winter and summer resorts already exist on the southern

Table 1 Significant Lake Maryut region changes in scene percentage.

Class	Changes (1991–1995)	Changes (1995–2004)	Changes (2004–2013)
Deep water	No significant changes	No significant changes	No significant changes
Shallow water	Nearly stable	No significant changes	81.7% has no change
Turbid water	+2.6% over shallow water	+3.7% over wet land +1.1% over urban and built-up	50.2% has no change +39.7% over shallow water
Wet vegetation	62.65% has no change +5% over shallow water +14.8% over turbid water +9.3% over "Annual Crops"	93.21% has no change +2.1% over shallow water +2.7% over turbid water +1.0% over "Complex Vegetation"	91.3% has no change +5.1% over shallow water +2.7% over Turbid water +1.9% over deep water
Annual crops	64.8% has no change +16.9% over "complex vegetation" +8.0% over barren land +3.7% over bare soil	82.2% has no change +10.77% over "complex vegetation" +5.0% over barren land +0.6% over bare soil	88.4% has no change +1.32% over "complex vegetation" +2.0% over barren land +0.6% over bare soil
Complex vegetation	49.0% has no change +18.8% over "Annual Crops" +4.4% over barren land +17.4% over bare soil	57.6% has no change +3.3% over "Annual Crops" +6.0% over calc. bare soil +24.3% over bare soil	43.8% has no change +41.3% over "Annual Crops" +6.8% over Calc. bare soil +8.1% over bare soil
Wet Land	51.4% has no change +24.0% over shallow water +7.6% over turbid water +12.6% over wet vegetation	73.6% has no change +4.2% over shallow water +5.5% over turbid water +6.5% over barren land and bare soil	84.5% has no change +6.3% over shallow water +0.4% over turbid water +8.8% over barren land and bare soil
Bare soil	60%–76% has no change	66%–92% has no change	74% has no change
Urban & built-up	56.5% has no change +32.2% over bare soil +4.3% over vegetation classes +1.3% over barren land	77.6% has no change +10.6% over bare soil +2.8% over vegetation classes +2.9% over barren land and wet veg.	48.7% has no change +18.1% over bare soil +11.2% over Limestone +3.6% over barren land and wetVeg +18.3% over Shallow water
Limestone	91.1% has no change +4.7% over calcareous sediments +2.4% over bare soil	93.6% has no change +3.5% over calcareous sediments +2.1% over cal. bare soil	88.3% has no change

and northern zone. This activity is likely to help the lake restore its environment due to the work to be done through tourism investments.

6.2. Western part alternative

6.2.1. No action alternative

It represents current situation, with all activities such as quarrying and urban encroachment, and other human impacts on the lake and without having any restoration process.

6.2.2. Drying the western parts (High Saline Parts) of the Lake

That alternative deals with urban extensions over the western parts after land filling by sands and gravels. Those western parts (as mentioned earlier) are almost dead with rare evidence of fish, planktons or water plants. The proposed urban extension will be of low cost and would be ideal to serve youth and others of low incomes.

6.2.3. Re-open closed parts of the Lake

That alternative is based on an optimistic idea of reopening closed parts of the lake (mostly the western parts) without destroying the infrastructures made in the area. Most of the human-made barriers that isolate parts from the main lake body are roads. So, that alternative stresses on reconnecting the isolated parts of the lake to the main lake water body, and helps water currents to move through it. That could be done by placing suitable diameter pipes under those barriers.

In order to opt for the most suitable alternatives, an accurate computerized method should be used with select specific analysis methods. The *Interaction Matrix* method is therefore applied through modern software called the *Rapid Impact Assessment Matrix* "***RIAM***" (Pastakia, 1998). The RIAM is an analysis and presentation tool for Environmental Impact Assessment (EIA), which allows EIA reports to be completely transparent and easily understood.

All potential direct and indirect impacts and a detailed interaction matrix analysis based on the Delphi technique were carried out (Linstone and Turoff, 1975). Matrices are used not only for the identification of possible impacts but also for evaluating those impacts by entering numbers into matrices that represent subjective estimates of the significance of the relevant impacts. Summary of such impacts in matrices is used to compare environmental significance of those alternatives.

Four main parameter groups for each of the alternatives or proposed scenarios were identified. The parameters include the following: (i) Physical and Chemical (PC) parameters representing the natural, non-organic environmental changes; (ii) Biological and Ecological (BC) parameters containing the

Table 2 Different impacts for different environmental parameters.

Physical and chemical components		*Socio-cultural components*	
PC1	Air quality	SC1	Tourism
PC2	Esthetic view	SC2	Socio-cultural conservation
PC3	Surface water	SC3	Public image
PC4	Ground water quality	SC4	Social equity
PC5	Water logging		
PC6	Landscape	*Economic and operational components*	
PC7	Accessibility	EO1	Employment
PC8	Infrastructures	EO2	National income
Biological and health components		EO3	Business opportunities
BE1	Fauna and flora	EO4	Land prices
BE2	Biodiversity (bird, plankton, and fish)	EO5	ICZM plan
BE3	Lake productivity	EO6	Coast
BE4	Public health		

habitats, food chain, and species that make up the natural and domesticated flora and fauna that may be affected; (iii) Socio-Cultural (SC) parameters representing the human environment, and the cultural heritage of the societies in the study area; and finally (iv) Economic and Operational (EO) parameters representing the economic aspects of development and the operational complexities that will guarantee, or hinder, sustainability of the development of the area in future. Each parameter is estimated according to the magnitude, duration, reversibility, and cumulative effects and is given a score based on the experts' judgment, Table 2. The experts' judgment was obtained through several seminars and brainstorming sessions in either university or non-governmental organizations like Friends of the Environment Association in Alexandria.

The scale used to evaluate impacts for environmental parameters in Impact Matrix is completely different. It ranges from 0 to 4 in importance, −3 to +3 in magnitudes, and 1 to 3 in permanence, reversibility, and cumulative components. The positive sign indicates positive beneficial impact, the negative sign indicates negative adverse impact, and zero indicates an insignificant impact. Three diagrams were obtained for each part of the lake after completing the impact matrix. By overlaying the three diagrams, summary diagrams were obtained (Figs. 5 and 6). In these histograms the horizontal axis represents the levels of negative and positive (or neutral, *N*) impacts, ascending in value from A until E while the vertical axis represents the magnitude of contribution of each group of environmental components according to the length of the specific representative color.

Results of the analysis of impact matrix indicated that the *no action* option in both parts of Lake Maryut involves mostly negative components of varying magnitudes.

In the eastern part, the remaining two alternatives *encourage tourism* and *pollution control projects*; have significant

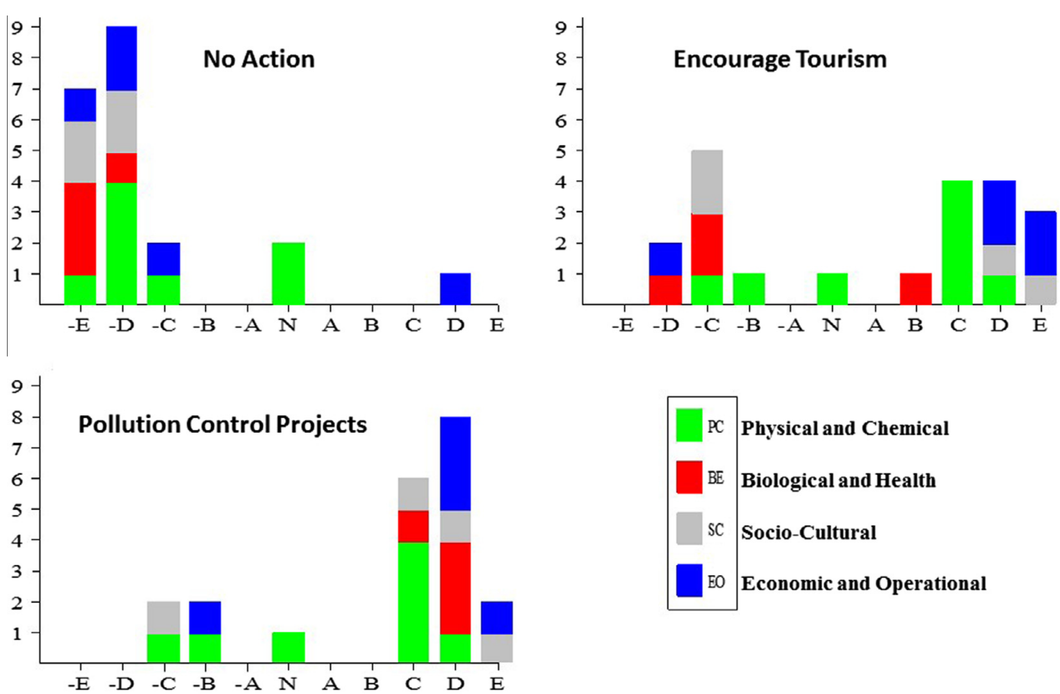

Figure 5 Option summary of the three proposed alternatives in the eastern site of the Lake.

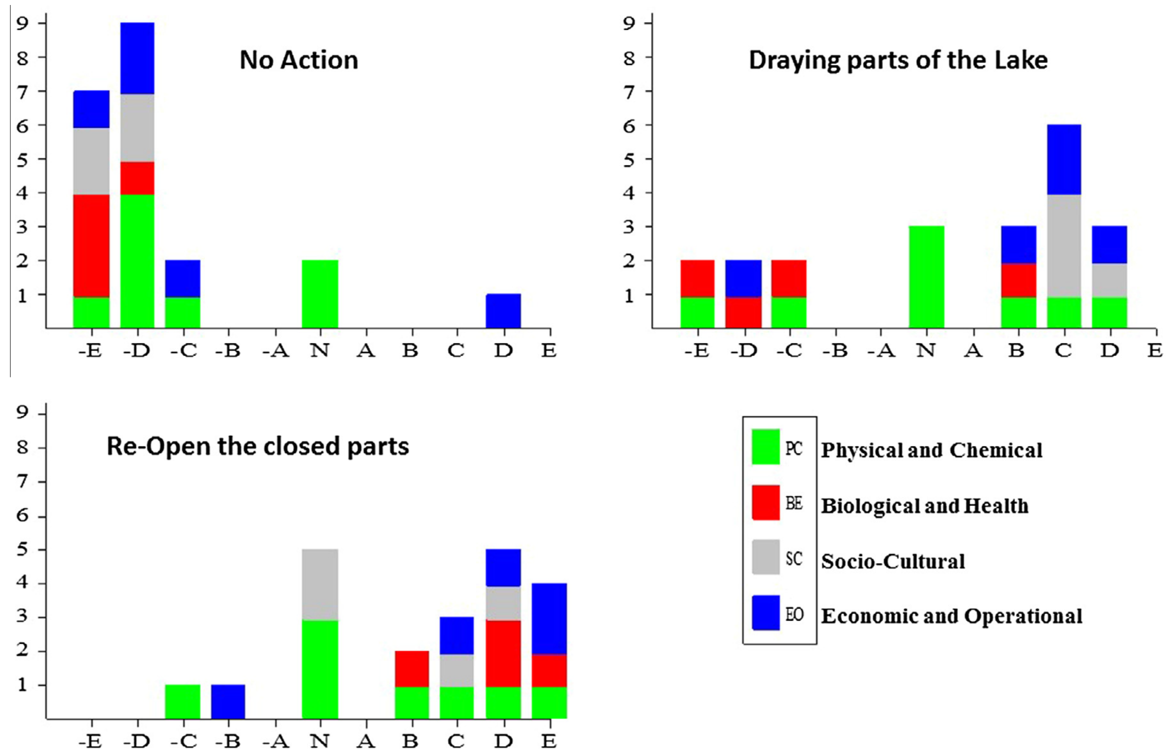

Figure 6 Option summary of the three proposed alternatives in the western site of the Lake.

positive impacts on the surrounding environment, with some negative impacts that could be mitigated. The *pollution control projects* option has the highest positive impact and, at the same time, the lowest negative impact.

In the western part, the two options *drying parts of the lake and reopening the closed parts* have also significant positive impacts on the surrounding environment, with some negative impacts that could be mitigated. However, the option *drying parts of the lake* has higher negative impacts, thus the *reopening the closed parts* option with its lower negative impacts and higher positive impacts is the best solution for that part.

7. Conclusions and recommendations

The main result of processing of satellite images is a recent land cover/land use image for study areas that can help in change detection and consideration of restoration alternatives. Change detection results of the study of the Egyptian Lake Maryut identified environmental conditions, status of natural resources and rate of changes which make the management of the lake in future easier, applicable, and sustainable. It could be concluded from the study that:

1. Lake Maryut water body could be classified into three classes; shallow water, turbid water, and wet vegetation. By analyzing changes of the three water classes in relation to the terrestrial classes, approximate total changes that occurred to the lake were obtained. The accumulated area of change, in the three classes, is estimated at 24 km^2.
2. Another remarkable change that was identified in the Lake Maryut region is that turbid water increased by about 2.6%. This means that there is still pollution input, which does not only influence the lake, but it also increases in level as well.
3. New settlements surrounding the lake increased by about 32.2% (24 km^2) over bare soil. There is also urban encroachment over cultivated land (vegetation and barren land classes) by about 4.3% and 1.3% (3.2 km^2 and 1.0 km^2) and that represents a great loss in spite of the presence of Egyptian Environmental Law, which prohibits that and the land filling process too.
4. Results indicate that the most suitable alternatives are *pollution control* for the eastern part of the lake, and *reopening closed parts* in the western part with some mitigation measures.
5. The alternative of *drying the western part of the lake* is not environmentally acceptable because it affects severely the water balance of the whole region. Water logging problems in other areas could result from drying parts of the lake. Based on the above results, it is recommended that the following would be done:

1. Building a complete geographic information system (GIS) for the area has a great importance for identifying changes and decision-making. The data resulting from GIS should be updated regularly.
2. It is recommended to use the Speckle Techniques in addition to the techniques used in this study to monitor large areas. Those techniques include White light Speckle Photography, Laser Speckle Photography, Sunlight Speckle Photography, Speckle Metrology, etc. Those modern techniques could use the sun as a light source with high resolution camera to study the movement or distortions in large areas.
3. A repetitive monitoring of the whole northwestern Egyptian coast by satellite images is necessary for monitoring

and assessing large-scale land use changes and/or human impacts that occur in the region.

4. Compliance testing of plans of Alexandria between 2017 and 2024 must be carried out.
5. With the current rates of drying projects of Lake Maryut, the lake is shrinking dramatically. It is necessary to develop an integrated coastal zone management plan for the development of the lake as soon as possible.
6. More effective programs of pollution control should be exercised in the industrial areas, which dump its wastes in Lake Maryut.
7. The huge limestone quarries, present along the Alexandria-Matrouh road, should be controlled and activities should comply with environmental regulations.
8. A natural resources management program should be applied and no human interference should be allowed without an environmental impact assessment as required by Egyptian law.

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