Change Detection of Inland Water Bodies Using Remote Sensing Techniques. A Case Study: Lake Maryuit, Egypt

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Abstract:

Lake Maryuit is one of the northern Egyptian lakes, located in the north western coast of Egypt. The lake contributes to fish production, serves as a drainage basin for the adjacent cultivated land, and adjusts the climate of Alexandria city. Also, the lake has great potentials for recreational and tourism activities. Moreover, the lake is considered as an ecosystem, which provides a habitat for various species. Nevertheless, the lake has been suffering from a wide range of stresses including high levels of pollution in addition to land filling activities to acquire land for urban expansion, which led to a significant decline in the lake area over the past decades. Such stresses, consequently, restricts the services provided by the lake. This, in turn, highlights the need for continuous monitoring of the changes in the area of the lake and analyzing the main reasons underlying the decline in the lake area.

The main objective of this paper is to detect changes in the area of Lake Maryuit through remote sensing techniques over the period 1984 - 2002. In this study, Post-classification technique was employed, using Landsat Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) data to detect such changes. It was found that the lake area has declined about 4.63% over the stated period. Most of the reduction in the lake area was concentrated in the eastern and northern parts of the lake, due to land filling activities and urban encroachment on the lake as well as the construction of new highways. This study could support the monitoring and management of natural resources in the case of Lake Maryuit and similar cases as it provides an accurate quantitative analysis of the development of the lake area.

Keywords: Remote sensing, inland water bodies, change detection.

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1. Introduction:

Lake Maryuit is one of the northern lakes in Egypt, located south west of Alexandria city. The lake extends between 31° 01´ 48˝ and 31° 10´ 30˝ North and 29° 49´ 48˝ and 29° 57´ 00˝ East[1]. It is artificially divided, by Alexandria Cairo Desert Road, El-Umum Drain and Nubaria Navigation Canal, into four basins namely; Main Basin, Aquaculture Basin, Northwest Basin, and Southwest Basin (Figure 1) (El-Sharkawi, 1999). Each of these basins has different characteristics in terms of depth, vegetation cover and even water quality.

The present Lake represents a small portion of a much larger lake that was known during the Roman era as "Lake Mariutus", which was connected by a branch of the River Nile called Kanobi Branch through small canals (El-Sharkawi, 1999; Malti, 1960). Furthermore, the Lake has experienced, during the 20th century, a significant decline in its surface area from 273 km^2 (67 459.8 Acres) in 1913 to 67.2 km2 (16 605.5 Acres) in 1985 (Figure 2). This means that during seven decades the area of the lake has declined more than 70% of its original area (Abo El-Enin, 2002).

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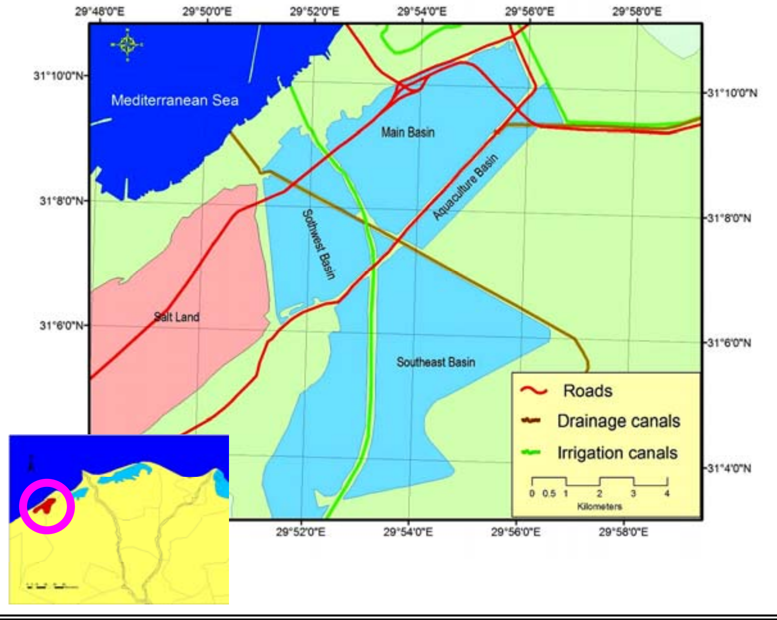
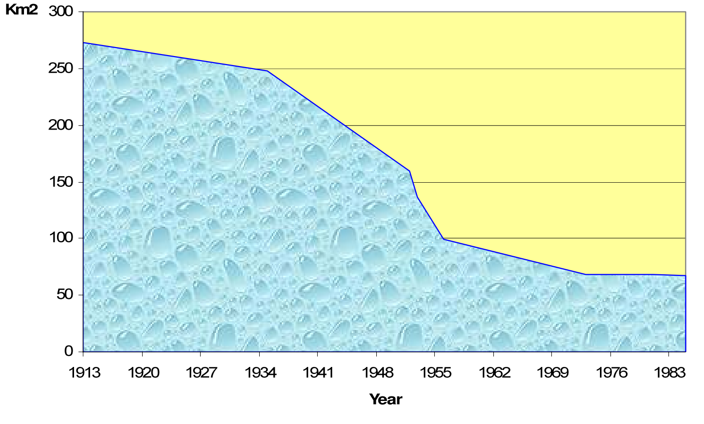
[1] Contrary to other northern lakes in Egypt, the lake is not naturally connected to Mediterranean Sea. Yet, Lake Maryuit is artificially connected to the sea through El Max pumping station, which discharges the overflow from the lake directly into the Mediterranean Sea via El Ummum Drain.

Figure (1): Main basins of Lake Maryuit



Source: Done by the researcher based on topographic map scale 1 : 50 000

Figure (2): Change of Lake Maryuit Area During 20th Century



Source: Abo El-Enin, 2002.

The sediments of the lake indicated that it used to receive both sea water and freshwater in the course of its history as they consists of fluvial deltaic formations and brackish lagoon mud (Aboul Ezz and Abdel Aziz, 1999). It seems that marine sediments were deposited during periods of high sea level when sea water invaded the lake depressions (Aboul Ezz and Abdel Aziz, 1999; Malti, 1960).

The average water depth in the lake is about 120 cm. The bottom elevation varies between 3.7 to 4.0 meters below sea level (El-sharkawi, 1999). The main sources of feeding water include El Qallaa Drain, El Ummum Drain and Nubaria Canal. Also, there are a number of outfalls that discharge sewage water after primary treatment, and untreated industrial wastewater into the lake (Kassim, 2005). It should be noted that the main basin is heavily polluted, at present, due to the different types of pollutants discharged into it (El-Bestawy, et al., 1999).

The lake, meanwhile, plays a crucial role in producing fish, preventing intrusion of salt water into surrounding agricultural land and adjusting the climate of Alexandria city. Also, the lake has great potentials for recreational and tourism activities and from an environmental perspective, it is considered to be an important ecosystem, which provides habitat for various species including migratory birds[1].

Wide areas of the lake, reaching as much as 60% of the total area of the main basin, are covered by vegetative masses principally Phragmites and Hyacinths. Furthermore, the bottom of some parts of main basin is covered by submerged aquatic vegetation (Kassim, 2005). Such vegetation cover, it should be noted, may accelerate sedimentation and thus providing more opportunities for land filling activities, especially if located near or on the borders of the basins. Sedimentation may also restrict water circulation in the lake in such a way that would reduce BoD and CoD in the water[2]. This in turn may, particularly when accompanied with various water pollutants existing in the lake, adversely affect fish stocks in the lake and ultimately limit fish production in the lake[3]. Consequently, large proportion of the fishermen working in the lake had either accepted lower income levels or abandoned fishing altogether, seeking other unskilled

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[1] Most of these functions are significantly affected by the current state of the lake and the decline in its area.

[2] For the purpose of economic production of fish, it was recommended that the vegetation cover should not exceed 30% of the basin surface area (Abo El-Enin, 2002).

[3] In this respect it was estimated that fish production from Lake Maryuit has decreased from 11 365 tons in 1981 to 4 861 tons in 2003 and the share of fish production from Lake Maryuit has declined from 8.2% to 1.1% of the total fish production in Egypt during the same period (CAPMAS, 1983 and Ministry of Agriculture, 2003). Futhermore, these conditions led to the disappearance of some types of fish including for instance, Mullets (Mugil), eals and cat fish (El-Sharkawi,1999).

employment opportunities; e.g. garbage sorting or manual labour.

Concerning the legal and institutional contexts surrounding water bodies' management in Egypt, according to Law 124 of 1983, which organises the fishing activities in the Egyptian lakes, the General Authority of Fisheries, Ministry of Agriculture, is considered to be the main agency responsible for managing the lakes (Article 2). The law also prohibits discharging any industrial wastewater, pesticides or similar toxic or radioactive compounds into the water (Article 15). Also, it is forbidden, according to this law, to fill in or drying any parts of the lakes (Article 20) (General Authority for Official Print Affairs, 1993).

Moreover, Law 4 of 1994 assigns the responsibility of protecting the environment and monitoring the discharges of various activities into the environment to the Ministry of State for Environmental Affairs. This is typically done, for the lakes, with the support of the Environment and Water bodies Police Force. In addition to these bodies, other governmental bodies involved, whether directly or indirectly, include the Ministry of Public Works and Irrigation; Ministry of Housing and Reconstruction; the governorate and Alexandria Sewage Company.

However, these legalisations and their implementing agencies have not managed to control land filling activities in the case of Lake Maryuit, which led to continual decline in lake area over the last period.

The main objective of this paper is to detect changes in the area of Lake Maryuit over the period 1984 – 2002, using remote sensing technique. Moreover, the study intends to analyze the main reasons underlying changes in the area of Lake Maryuit.

2. Change Detection Techniques:

Change detection is usually employed in a wide range of applications such as monitoring land use and land cover changes, deforestation, desertification, coastal changes, urban sprawl and other cumulative changes. In this context, remote sensing data at different time intervals offers considerable promise for monitoring land cover changes (Elnazir et.al, 2004; Tachizuka et al., 2002). It helps in analyzing the rate of change as well as the casual factors or drivers of changes (Ramachandra and Kumar, 2004). Moreover, remote sensing data may, it was argued, provide an efficient tool for monitoring land-cover changes in an area of interest in the past using time series satellite data (Tachizuka, et al., 2002).

The basic assumption underlying change detection techniques is that changes in land cover result in changes in radiance values[1] recorded by the sensors (Acharya, 2002). Accordingly, such changes in radiance could be used to indicate changes in land cover.

Currently, extracting land cover from remotely sensed imagery is probably one of the most commonly performed tasks in remote sensing. Generally, there is a wide range of approaches for detecting the changes in land cover. Image differencing, post-classification, multi-date visual composite and visual interpretation are examples for a wide range of approaches that are employed to detect such changes.

Generally, the various approaches for change detection can be classified into two main broad categories; the first includes those techniques that aim at detecting changes directly from radiometry such as image differencing and date multi-date visual composite. The second category, meanwhile, includes those techniques that aim at detecting changes from independently produced manipulated images such as post-classification and visual interpretation (Elnazir, et.al, 2004). The

[1] Usually, changes in radiance due to land cover changes are larger and more considerable than radiance changes caused by other factors such as difference in atmospheric condition, difference in sensors calibration, moisture condition, illumination conditions and difference in sun angles.

most commonly used change detection techniques may include image differencing, multi-temporal composite image post-classification and Independent visual interpretation techniques.

Image differencing, which is probably the most widely applied method, involves subtracting one date of imagery from a second date that has been precisely registered to the first (Acharya, 2002). According to this method, the changes can detected through subtracting the digital number value for a given band of one image acquired on a certain date from the digital number value of the same pixel for the same band of another image acquired on another date. Image differencing seems to be an effective method to identify the area immediately where the change has occurred and provide lower errors relative to other methods (Tardie and Russell, undated). Yet, to ensure accurate results from image differencing technique the data of the two images should be acquired at the same period possibly the same season (Acharya, 2002).

Multi-temporal composite image technique provides a simple mechanism to display changes between two dates of imagery. According to this technique, to display the changes in a land cover a new image with a combination of three bands of two different points of time was created (Tardie and Russell, undated). The selection of the three bands should be based on the spectral behavior of the target land covers. Multi-temporal composite technique seems to be promising when the analyses is needed to be done for a regular time interval (Acharya, 2002).

According to post-classification technique, two or more images from different dates are independently classified. To ensure accurate results from post classification technique, adequate signatures should be selected and reliable ground data should be readily available (Acharya, 2002).

Independent visual interpretation technique implies comparison between two or more images from different dates, which are independently visually interpreted. To distinguish various land covers, the spectral behavior of land covers should be well understood in different wavelengths and accordingly the appropriate color composite will be selected to display clearly the different land covers in interest. Based on visual interpretation of the image, vector layers for different land covers would be created through on-screen manual digitizing.

However, it should be noted that the selection of the appropriate technique is based on physical and biological characteristics of the study area as well as available knowledge about the area.

It is worth mentioning that, the use of remote sensing imagery in mapping and monitoring various land features was necessitated, in many cases, by the lack of up-to-date maps and inaccessible areas. In such cases, remote sensing techniques provide a valuable alternative for continuous mapping and monitoring.

Furthermore, in a pressured environmentally-sensitive and ecologically important regions, there is an urgent need for continuous monitoring that can provide up-to-date and accurate land cover information for proper management of such regions. Such a task could entail high costs if undertaken using aerial photography or traditional mapping. Instead, multi-spectral remote sensing imagery, which are available at a relatively low cost, makes it more suited for the continuous generation of information required for monitoring these regions.

3. Change Detection Analysis:

In order to detect the changes in the area of Lake Maryuit, post- classification technique was adopted, in which a comparison between two independently classified images of different dates was carried out. The selection of this technique was due to the fact, as mentioned before, that some parts of Lake Maryuit are covered by vegetation masses having similar spectral behavior of cultivated land surrounding the lake. This meant that using any of change detection techniques that aim at detecting of changes directly from radiometry such as image differencing would be inappropriate as those areas of with vegetative cover, would wrongly be identified as cultivated land.

To monitor change in the area of the lake two LANDSAT satellite images for Maryuit Lake were obtained. Ancillary data such as topographic map scale 1:50 000 for the study area was also used in the analysis and in result validation. The first image used was TM image with a spatial resolution of 30 meter dated 11/09/1984, while the second was ETM+ image with a spatial resolution of 15 meter dated 17/06/2002. As the acquisition dates of images were in summer months, seasonal variation could be ignored.

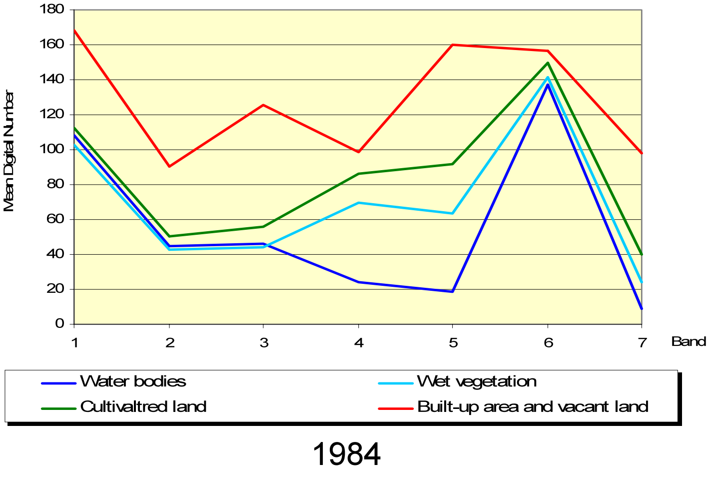
The two images have already been rectified to a common UTM (Universal Transverse Mercator) coordinate system. Using Erdas Imagine 8.5, the two images were enhanced through histogram-equalized stretch to increase the volume of visible information. Thereafter, each image was classified (supervised classification), in the same manner, with a maximum likelihood algorithm. During the classification process a large number of training areas (classes) were initially generated in each image. Training areas (classes) with spectral similarities were merged (aggregated) to represent a land cover. According to dominant land cover and land uses in the area of Lake Maryuit and its surroundings, it was decided to classify the images into 4 land covers including water bodies, wet vegetation, cultivated land, and built-up area and vacant land.

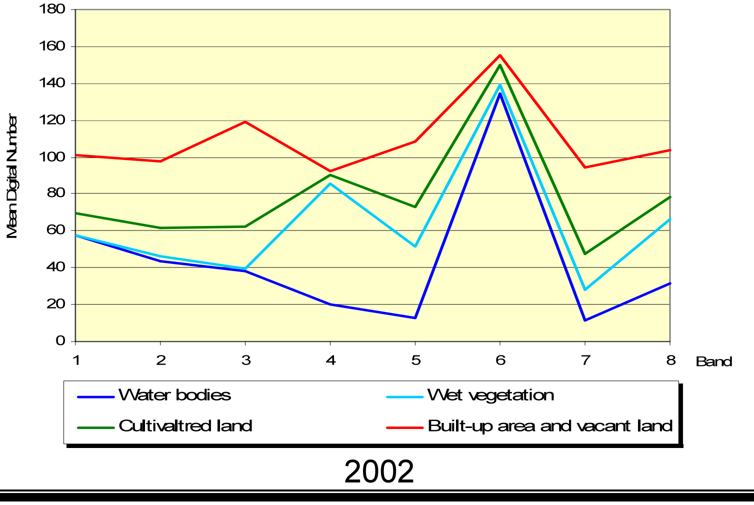
Figure (3) illustrates the multiple plot of the spectral signatures of the generated classes. Such multiple plot is of great importance as it helps in identifying those classes that have similar spectral signatures.

It was noted meanwhile that the resulted classified images had very small classes (as shown in Figure 4); therefore, a filtering approach was used to eliminate the small areas that appeared in the two images as a result of the classification process.

In order to quantify the reliability of the classified images, an accuracy assessment, involving comparing field sample or ground truth points with the produced classified images, was conducted. For that purpose 311 ground truth points were used. The assessment of classification revealed overall classification accuracy of 92.28% and 95.82% for TM image of 1984 and ETM+ image of 2002, respectively. It is clear that the higher accuracy of classification process of the ETM+ image compared to that of the TM image may be attributed to the higher spatial resolution of the former image. The resulted error matrices are shown in tables (1 and 2).

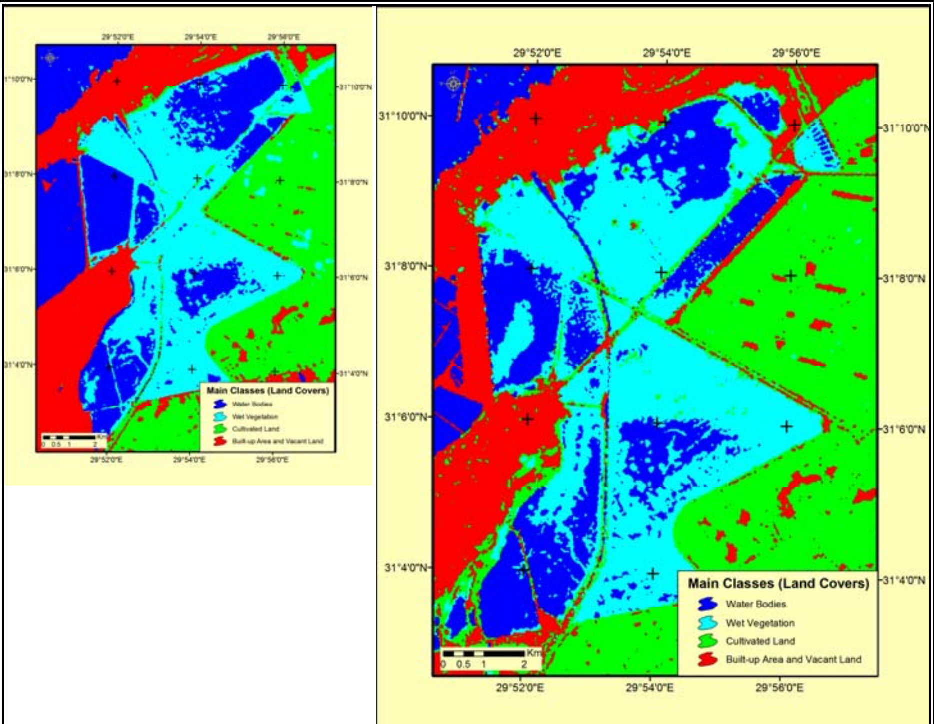
Figure (3):Multiple plots of the spectral signatures of the generated classes in different bands





Source: Done by the researcher using Erdas Imagine 8.5

Figure (4): Landsat TM and ETM+ classified images



TM image of 1984 ETM+ image of 2002

Source: Done by the researcher using Erdas Imagine 8.5 and ArcGIS 9.2

Thereafter, ArcGIS software was used to produce vector layers of the lake area from the two classified images in 1984 and 2002. The produced vector layers of the lake were overlaid to compare and detect the changes in the area of Lake Maryuit between the period from 1984 to 2002 (Figure 5).

Table (1): Error matrix of maximum likelihood classification and the ground truth for TM image of 1984

		Maximum likelihood classification					Accuracy (%)
		Water bodies	Cultivated land	Wet vegetation	Urban and vacant land	Total	
Ground truth	Water bodies	63	0	5	1	69	91.30
	Cultivated land	0	97	3	1	101	96.04
	Wet vegetation	1	3	47	0	51	92.16
	Urban and vacant land	1	8	1	80	90	88.89
	Total	65	108	56	82	311	
Accuracy (%)		96.92	89.81	83.93	97.56		
Overall classification accuracy = 92.28 Kappa statistics = 0.895(*)							

(*) The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with that of a completely random classification. A value of .895 would imply that the classification process avoided 89.5% of the errors that a completely random classification would generate.

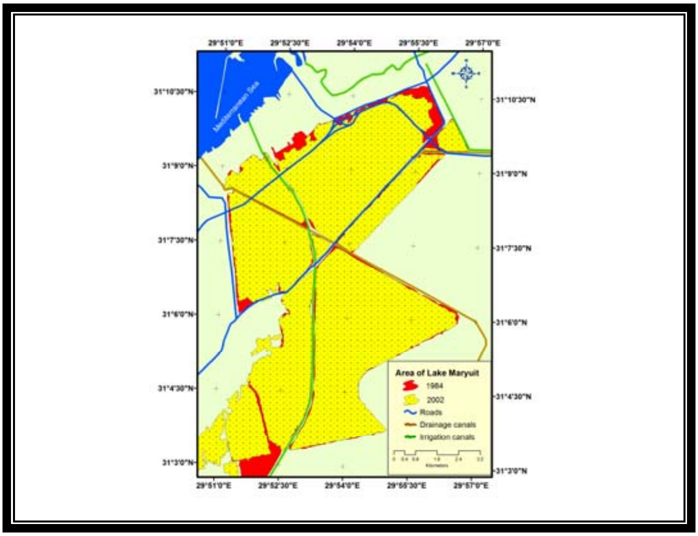
Source: Done by the researcher using Erdas Imagine 8.5

Table (2): Error matrix of maximum likelihood classification and the ground truth for ETM+ image of 2002

		Maximum likelihood classification					Accuracy (%)
		Water bodies	Cultivated land	Wet vegetation	Urban and vacant land	Total	
Ground truth	Water bodies	50	1	4	0	55	90.91
	Cultivated land	0	120	0	2	122	98.36
	Wet vegetation	0	2	52	0	54	96.30
	Urban and vacant land	0	3	1	76	80	95.00
	Total	50	126	57	78	311	
Accuracy (%)		100.00	95.24	91.23	97.44		
Overall classification accuracy = 95.82 Kappa statistics = 0.942							

Source: Done by the researcher using Erdas Imagine 8.5

Figure (5): Changes of Lake Maryuit area between 1984 and 2002



Source: Done by the researcher using ArcGIS 9.2

4. Results and Discussion:

It was found that Lake Maryuit has experienced a noteworthy decline, of about 3.24 km^2 representing about 4.63% of its area during the period between 1984 and 2002 (Table 3). The area decline was found to be uneven between the various basins of the Lake, with that Main Basin and the Aquaculture Basin experiencing the largest decline in absolute terms of all basins of the lake. For instance, about half of the total reduction in the lake area occurred in these two basins, which have lost 1.59 km^2 and 0.32 km^2 during the study period, representing 7.39% and 7.02% of their original area in 1984, respectively (Table 3). Also, the Southwest and Southeast basins have declined by about 0.2 km^2 and 1.13 km^2 accounting for about 2.21% and 3.25% of their original areas in 1984, respectively.

Table (3): Changes of Lake Maryuit area between 1984 and 2002

Basin Name	Area (Km^2)		Change rate %
	1984	2002	
Main Basin	21.52	19.93	- 7.39
Aquaculture Basin	4.59	4.27	- 7.02
Southwest Basin	9.15	8.95	- 2.21
Southeast Basin	34.77	33.64	- 3.25
Total	70.03	66.79	- 4.63

Source: Done by the researcher using ArcGIS 9.2

It is noted that, the main basin has been the one which experienced the highest decline, in absolute terms, compared with other basins, with a decline of 1.59 km^2. It was followed by the Southeast basin with 1.13 km^2. This is mainly due to the location of Main Basin adjacent to built-up area of Alexandria City.

It could be argued that most of this reduction in the Lake area can be attributed to the filling activities for land acquisition purposes. For example the area of the lake adjacent the entrance of Alexandria city, was filled up by the governorate and was sold to private investors for the purpose of developing a commercial center and upper class residential compound in addition to some other activities. Furthermore, there are other forms of encroachment on the lake body, this time by the central government, which authorized the construction of new roads on the lake body. This was clearly the case of a new highway called "Mehwar El Taameer", which was erected on the lake body in 2002-2004 with a length of about 13.2 km of roads[1] (Figure 6). This, it could be suggested, shows that large-scale land filling activities are actually carried out by governmental bodies, suppose to protect the lake area from illegal land filling activities. Thus, large part of the problem lies with these governmental bodies and shed doubts on their ability to protect and manage the lake.

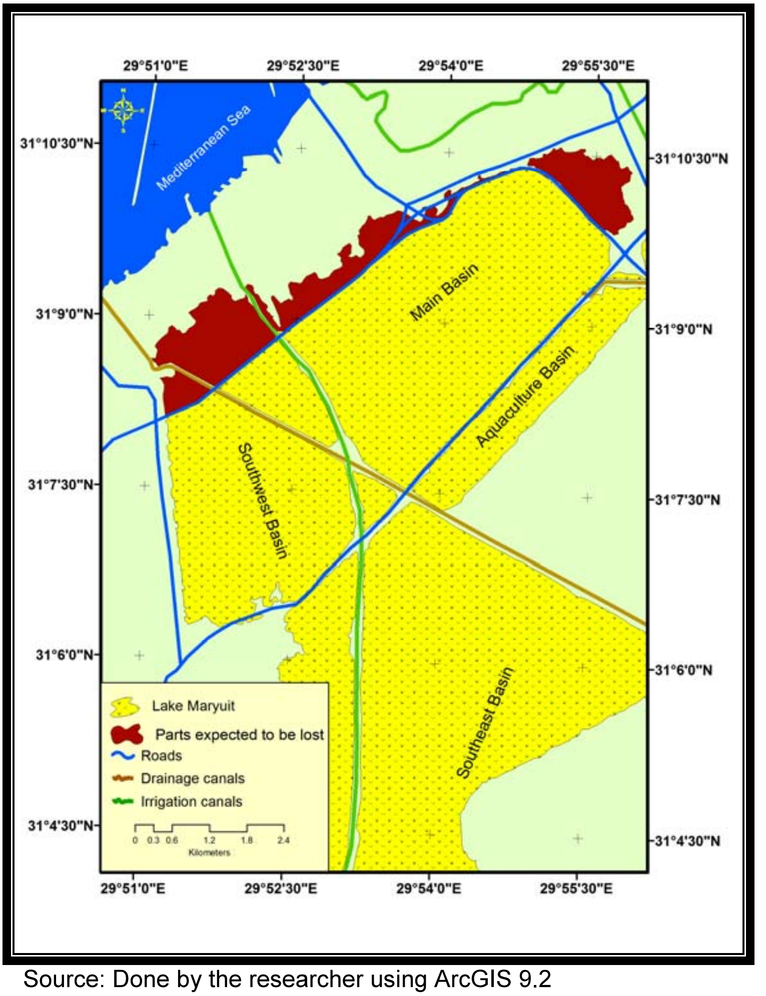
Moreover, such a trend is expected to continue as it was found that Alexandria Governorate adopted a development strategy that relies on more encroachment on the lake body. For example, according to the final report of Integrated Environmental and Social Impact Assessment (IESIA), the area surrounding Lake Maryuit was proposed to be developed through converting some parts of the lake, especially the eastern part of the main basin, into built-up area. This area would have mixed patterns of land use comprising commercial, residential, and recreational uses (Alexandria Governorate, 2007).

[1] This is the length of roads only crossing the lake.

Such land filling activities, in addition to the resulted decline in lake area, could contribute indirectly to further reduction in the lake area. For instance, it was found that the erection of the new highways, which acted in some parts of the lake as dikes, have led to the breaking down of these parts. This is especially true when these areas do not receive any water supply and thus would dry overtime. The total area of those parts that are expected to be lost due to the establishment of "Mehwar El Taameer", was estimated to be about 4.76 km^2, which accounts for as much as 150% of the estimated decline of lake area between 1984 and 2002 (Figure 6). Another indirect impact of the construction of highways and roads on the lake body is manifested in higher accessibility to many parts of the lake and its surrounding areas, which in turn, can promote land filling activities and urban encroachment on those highly accessed parts.

Such a decline in the lake area means loss of all socioeconomic and environmental services provided by the lake to the local community. These services include preventing Intrusion of salt water to the aquifers and agricultural fields surrounding the lake. Also, the lake has a role in adjusting the climate of Alexandria. Moreover, the lake is considered as an ecosystem, which is a habitat for various species. Form economic point of view, the lake represents an important resource of fisheries. In addition, the lake has a great potentials for recreational and tourism activities.

Figure (6): Areas of the lake with higher probability of being land filled in the near future



Source: Done by the researcher using ArcGIS 9.2

Among a wide range of stakeholders groups, which involved in the case of Lake Maryuit, it is clear that the local fishermen are the most affected group as they either lost their jobs and source of income or their jobs and income levels, are highly undermined due to declining area of the lake.

5. Conclusion:

The study showed that the area of Lake Maryuit has been reduced about 4.63% during the period from 1984 to 2002. Such a decline in the area of the lake was mainly due to filling activities and urban encroachment on the lake area. The decline in the area of the lake meant reduction and ultimately loss of the services provided by the lake to the surrounding area in terms of fish production, preventing intrusion of salt water into agricultural land and adjusting the climate of Alexandria city and limit. It also reduces the potentials for developing recreational and tourism activities in the lake. Such reduction of the lake area, meanwhile, took place despite of the existing legal and institutional framework, which puts into question the enforceability of the law.

Accordingly, it could be argued that the lake is facing growing pressures for land filling and urban encroachment, which if persistent and with the absence of control could lead to disappearance of the whole lake. Therefore, any efforts to maintain the lake and improve its environmental quality, should involve all stakeholders at local and national levels, including the civil society. They should, for that purpose, develop a common vision for that lake that takes into account on one hand their individual interests and the public interests, on the other.

Performing the change-detection analysis on Lake Maryuit allowed for the monitoring of the decline of the area of the lake over time. The study provides insight into the extent and nature of decline that has taken place in the area of the Lake Maryuit from 1984 to 2002. It could be suggested that conducting such analysis on regular basis could assist in identifying the magnitude and nature of changes in the lake area over time, and thus provides an effective and efficient monitoring tool of future changes.

Remote sensing and GIS techniques have great abilities to provide reasonable and sufficient information on the nature and rate of changes in land cover and water bodies. However, the case of Lake Maryuit involved large areas with similar spectral behaviour, namely vegetative masses and cultivated land. In such a case, there is an urgent need to differentiate between these adjacent different land covers having similar spectral behavior. Thus the use of techniques that aim at detecting changes directly from radiometry; such as image differencing or multi-date visual composite image, may entail a considerable error factor. Alternatively, post classification techniques can be employed as they detect changes indirectly and independently from images.

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الملخص العربي

بحيرة مريوط هي واحدة من بحيرات مصر الشمالية التي تقع على الساحل الشمالي الغربي لمصر، وتساهم البحيرة بنصيب كبير في الإنتاج السمكي بمصر، كما أنها تقوم بالعديد من الوظائف؛ حيث تُستغل البحيرة كحوض لتصريف مياه الصرف الزراعي من الأراضي الزراعية المجاورة لها، كما تلعب دوراً حيوياً في تلطيف المناخ المحلي لمدينة الإسكندرية، أيضاً تمتلك بحيرة مريوط إمكانيات كبيرة للاستفادة منها في الأنشطة الترفيهية والسياحية. بالإضافة إلى ذلك فإن بحيرة مريوط تُعد نظام بيئي متكامل يوفر بيئة مناسبة لعدد كبير من الأنواع الحيوانية والنباتية.

وعلى الرغم من أهمية البحيرة وتعدد الخدمات التي تقدمها فإنها تتعرض للعديد من الضغوط والتي من أهمها - بالإضافة إلى ارتفاع مستويات التلوث بالبحيرة - عمليات تجفيف مساحات من البحيرة عن طريق ردمها وذلك للحصول على الأراضي اللازمة للنمو الحضري والتي أدت إلى التناقص المستمر في مساحة البحيرة خلال العقود السابقة. ومما لاشك فيه أن مثل هذه الضغوط تؤثر سلباً على البحيرة وتحد من الخدمات التي تقدمها، لذلك فإن هناك حاجة ماسة إلى الرصد الدائم والمستمر للتغيرات في مساحة البحيرة وتحليل الأسباب الرئيسية وراء التناقص في مساحتها.

في هذا الإطار يهدف هذا البحث إلى رصد التغير في مساحة بحيرة مريوط باستخدام تقنيات الاستشعار عن بعد وذلك خلال الفترة فيما بين عامي ١٩٨٤ و ٢٠٠٢م. وقد اعتمدت هذه الدراسة على أسلوب التصنيف (Post-classification technique) لمرئيتين فضائيتين للقمر الصناعي لاندسات إحداهما من نوع (TM) والأخرى من نوع (ETM+).

ولقد اتضح من خلال الدراسة أن مساحة بحيرة مريوط قد تناقصت خلال الفترة ما بين عامي ١٩٨٤ و٢٠٠٢م بنسبة ٤٫٦٣٪، وقد تركزت معظم الأراضي التي تم فقدانها من مساحة البحيرة في الأجزاء الشرقية والشمالية من البحيرة، وذلك نتيجة لعمليات الردم والنمو الحضري للكتلة المبينة للمدينة ومشاريع إنشاء طرق سريعة جديدة فوق جسم البحيرة.