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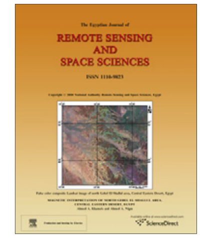

Change detection studies on the world's biggest artificial lake (Lake Nasser, Egypt)

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Abstract Lake Nasser in south Egypt extends over 500 km, 350 km in Egypt and 150 km in Sudan. It has an average width of about 12 km at the 180 m water level. However, as the capacity of Lake Nasser to store water is not without limits, it is of the outmost importance for Egypt to understand properly the changes which occur in this water body, where the water level may fluctuate in places from 160 to 183 m. To have an intimate understanding of these changes it is also important to relate them to the surrounding geomorphic, structural, climatic and geologic factors. This study deals with the presentation and interpretation of available statistical data on water level fluctuations in Lake Nasser. The interpretation is also based on correlation with results of the application of remote sensing change detection techniques. Several Landsat images, acquired at different times (1972, 1982, 1987, 2000, 2003 and 2008), have been processed by using the ERDAS and ARC-GIS softwares to follow changes in the shores of the lake and in its water content (volume).

According to patterns of water volume fluctuations, the lake displays four types of changes distinguishable in seven sectors (areas). The first type is represented in the sectors displaying maximum changes (or fluctuations). The second type is represented in the sectors displaying a moderate degree of change. The third type is represented in the sectors displaying a negligible degree of change. The fourth type is represented in the sectors displaying no change.

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Factors controlling water fluctuations in Lake Nasser are: (i) presence of granite and Nubia Sandstone outcrops, (ii) NW, E–W and NE structures (mainly faults), arranged in decreasing order of influence, (iii) presence of wide surfaces of low and relatively flat topography, this generates extensive water bodies prone to high evaporation, (iv) sand encroachment, often causing the segregation of narrow sectors in the lake, this can also generate broad sectors with shallow water depth, that does not correspond to the average depth of the water body.

1. Introduction

The high water storage capacity of Lake Nasser, generated by the erection of the Aswan High Dam, is a strong testimony of the value of this Dam to the welfare of Egypt. This High Dam stores River Nile flows in Lake Nasser and includes water reserves provided from normal and above normal flood years. The Dam was constructed between January 1964 and June 1968 to the south of Aswan to manage the water of the Nile flood, and also to provide Egypt with low-cost hydroelectric power. For these reasons the detection and understanding of changes in water level in Lake Nasser need careful scientific investigation based on the integration of various data and the application of different techniques. The lake in Egypt lies between Latitudes 22°00′N and 24°00′N and Longitudes 31°00′E and 34°00′E (Fig. 1).

The purpose of this study is to determine the locations and causes of changes in water level (from level 160 to 183 m) in Lake Nasser by taking into consideration the surrounding geomorphic, structural, climatic and geologic features. Water infiltration in the dry valley (wadi) deposits debouching in the lake tributaries and water seepage through the floor of the lake will be investigated by comparing various thematic maps, including physiographic, rock properties and structural maps. Fig. 1 is a map of the River Nile before the initiation of Lake Nasser. It has been taken from the Aswan topographic map produced at a scale 1:500,000 by the Egyptian Survey (1944). In the same figure the lake is drawn from topographic maps of Wadi Al Alaqui, El Sad El Ali, Abu Simmbel and Gabal Hadaib produced at a scale of 1:250,000 by the Egyptian Survey (1986). The figure also includes the nomenclature of the main localities and features around the lake. El-Baz (1989) monitored Lake Nasser by space photography and noticed that the level of this lake is a good indicator for the cycles of wet and dry climates that generated the conspicuous droughts in East Africa.

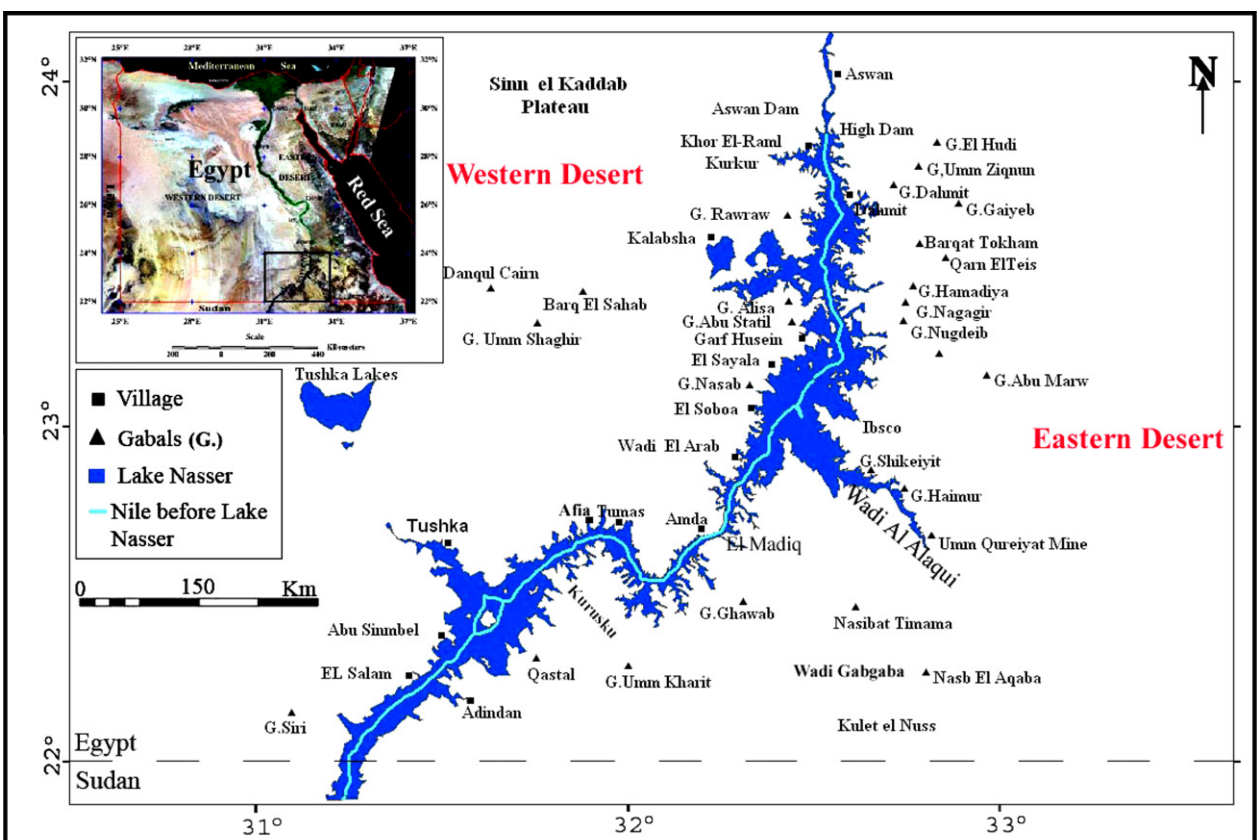

Figure 1 Development of Lake Nasser and location of significant features and localities around the lake.

1.1. Methodology

Two types of data with their respective methods of interpretation are used to investigate change detection in the surface of the lake. The first type includes the consideration of data collected by the Ministry of Irrigation and Agriculture of Egypt and the second type includes the use of remote sensing techniques on images taken at various dates.

In order to detect changes in the surface of the water of Lake Nasser, multi-temporal Landsat images acquired at different times (1972, 1982, 1987, 2000, 2003 and 2008) have been used and processed by mean of the ERDAS and ARC-GIS software. This has been done to estimate changes in the shoreline of the lake. These changes have been related to variations in the size and shape of the water body. The five images used in this analysis were geometrically corrected and positioned according to a fixed coordinate system (Universal Transverse Mercator projection). The positions of the lake area have been traced from TM and merged ETM images and were graphically displayed. The images were also used to produce a digital elevation model (DEM) to estimate, as an additional parameter, the physiographic features which sculptured the shape of the lake.

2. Physical characteristics of Lake Nasser surroundings

Fig. 2 is a simplified geological map of Lake Nasser area (adapted from CONOCO, 1987 and UNESCO Cairo office, 2006). An examination of the geology of the area shows that the most frequently exposed rock units around the lake belong to the Nubia Sandstone. Sand sheets and sand dunes are also conspicuous here. Sinn el Kaddab carbonate plateau lies at the western side of Lake Nasser. Granites and metamorphic hills are found on the lake's eastern side (Fig. 2).

A new generalized physiographic map, showing major morpho-structural units in the area, was prepared by using an ETM Landsat image (Fig. 3). This is done to try to understand where and why the water level fluctuates in the lake. The Kurusku Nubia Sandstone plateau in the eastern side of the lake displays an average elevation of 452 m above sea level, while on the other, eastern, side of this water body, Nubia Sandstone isolated hills are scattered over a wide area with an average elevation of 370 m. The granite and meta-volcanic hills, in the northern part of the eastern side of the lake, involve heights ranging from 390 to 590 m with eroded steep slopes. Here, the surrounding sedimentary terrains have an average height of 250 m. Oligocene basalt extrusions in the area are arranged in a NS direction around Abu Simmbel and in a NW–SE direction around Tushka, in structurally controlled tectonically disturbed zones, within Cretaceous Nubia Sandstone exposures. Sand dunes encroachments into the lake are frequent over major sectors on the northern lake boundaries.

2.1. Climate

South Egypt is an arid area. Weather is very hot in summer and warm during the day in winter. The maximum annual tem-

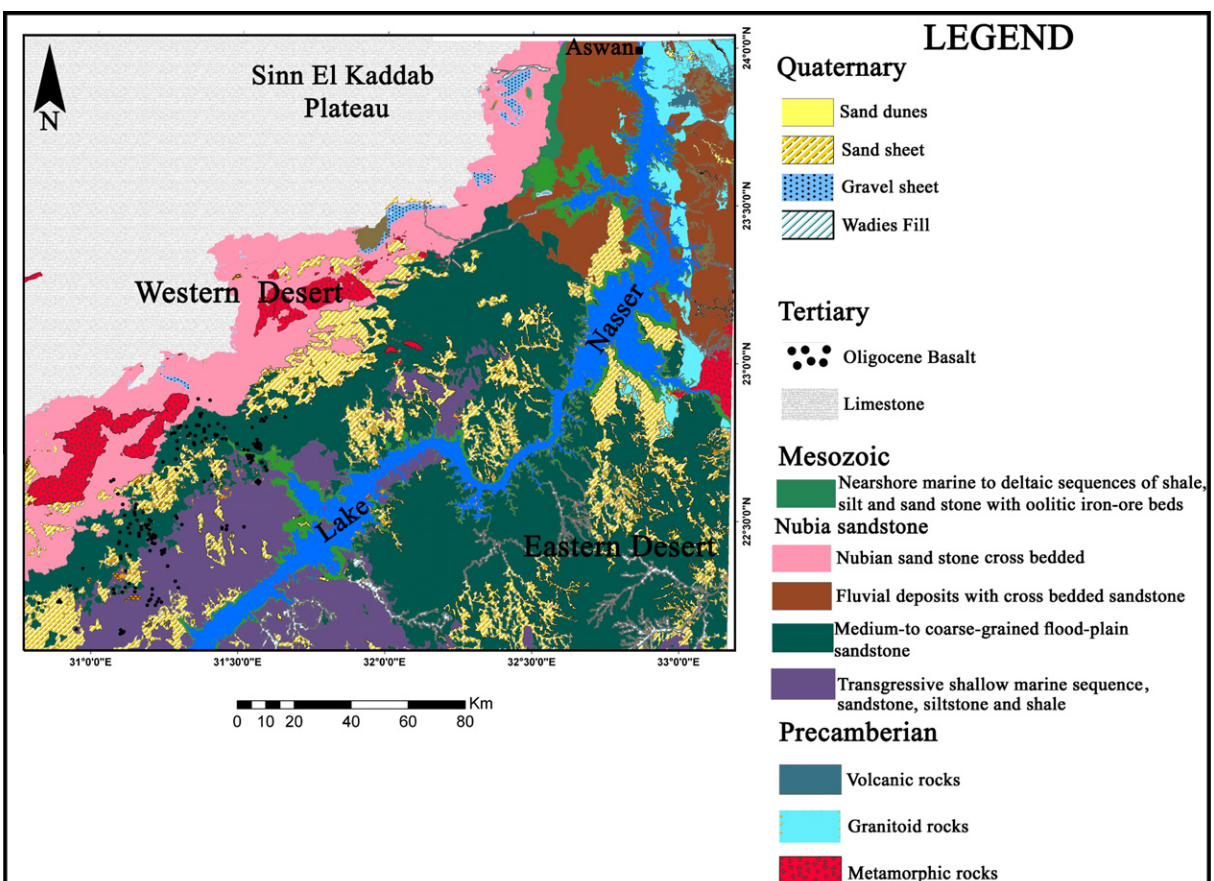

Figure 2 Simplified geological map for Lake Nasser area (adapted from CONOCO, 1987).

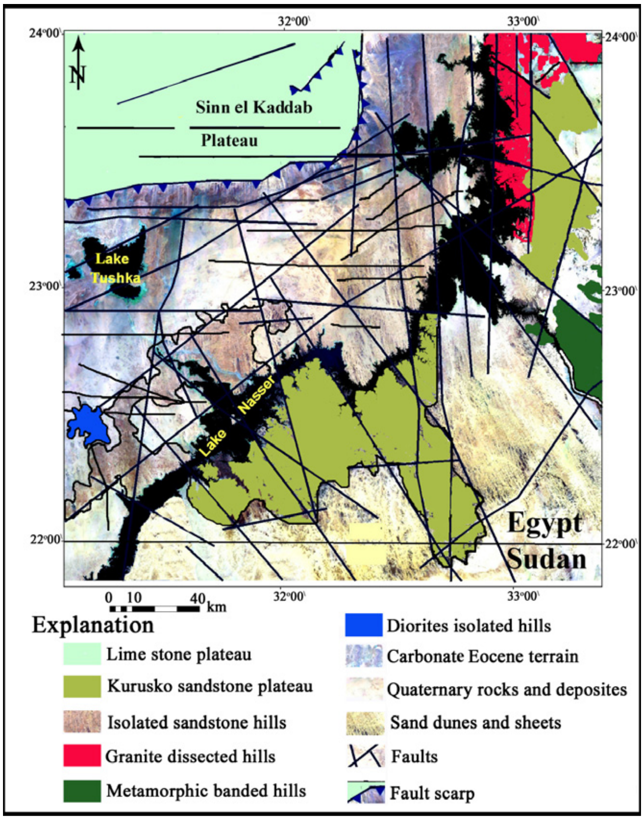

Figure 3 Generalized physiographic map of Lake Nasser (elucidating morpho-structural units), prepared by using an ETM Landsat image.

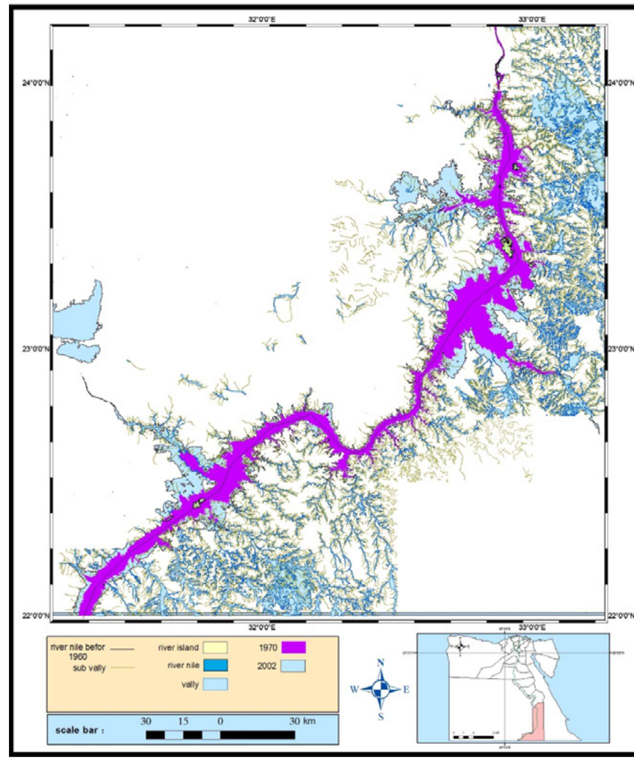

Figure 4 Drainage pattern around Lake Nasser interpreted from a 2002Landsat UTM image mosaic.

perature is approximately 50 °C and the minimum temperature is about 5 °C. In the last 35 years frequent torrential rains afflicted annually the Egyptian Sahara in the months of April and October. Wind direction is from the north and the north-west, with frequent very strong sand/dust storms.

2.2. Hazards caused by dune movements

There is hardly a place on earth where the wind and the sun are as effective and powerful for almost 365 days/year as they are in the Egyptian Western Sahara. Many areas on the borders of Lake Nasser are covered by aeolian dust and sand. These dunes decrease the lake water capacity. They seem to have

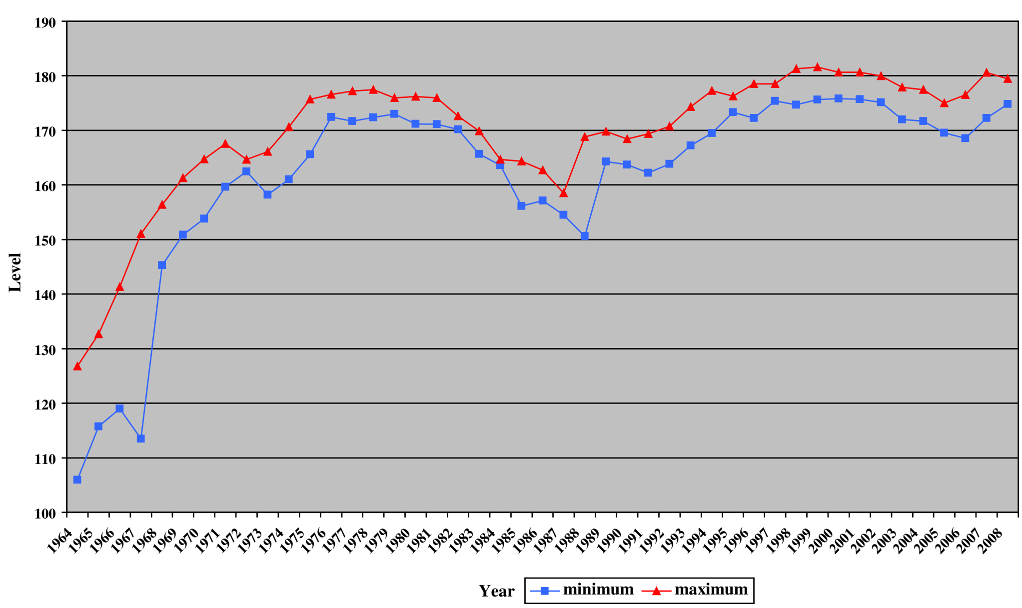

Figure 5 Scatter diagram for water level versus different dates.

their source in a location found to the north. The sediments of the dunes are old intensively reworked aeolian sediments, put into circulation in the Western Desert during various arid phases of the Quaternary. A proper scientific assessment of sand dunes encroachment into the lake is needed. El Gammal and Cherif (2006) studied Ghard Abu Muharik dune field (the longest dune field in the Western Desert) and stated that the dunes increase in size southwards, in direction of their progression. They move at a speed of 25 m/year in the northern part of the dune field and at a speed of 17 m/year in the southern part of the Western Desert. Stabilization of dunes may take place by building a pavement of gravels on the dune. Ultimately, wind will remove the sand grains while the pavement will form a lag layer and probably this will end in converting the sand dunes into sand sheets. Wind breakers, consisting of rows of higher trees for example, are also often important to nullify the power of wind.

2.3. Drainage patterns

Fig. 4 shows the drainage pattern surrounding Lake Nasser as interpreted from a Landsat UTM image mosaic acquired in 2002. The drainage network in the western side of the lake is mostly covered by sand sheets, with the exception of some areas north and south of Kalabsha, which are restricted by two NS faults, and another smaller area at Tushka and near Abu Simmbel. The dendritic pattern dominates in Nubia Sandstone terrains in the eastern side of the lake, with the exception of a large area around Wadi Gabgaba, where the sand sheet covers an area bounded by two NS faults (Fig. 4). Granitic rocks show sub-denderitic pattern in the northern part of the eastern side of the lake. The extensive drainage network over the eastern igneous hills collected water during rainy and wet geologic times into the lake area. Also the Nubian Sandstone aquifer surrounding the lake supplied the area with underground water before the initiation of the lake. This aquifer surrounding the lake is the reason of the restriction of water seepage from the lake exclusively to the surrounding soils and not to the surrounding rocks.

3. Lake Nasser changes

The fluctuation in the amount of water filling the lake should be carefully monitored to enable an optimal management of this resource in the lake and in the surrounding region. This is mainly done to avoid damages caused by high flood, arid periods and sand encroachment from the areas covered by sand dunes. Two approaches were considered to investigate changes in water content of Lake Nasser: the first is the study of data collected by the Egyptian Ministries of Irrigation and Agriculture, and the second approach is the use of remote sensing and GIS techniques.

3.1. Statistical treatment of change detection

The scatter diagram of Fig. 5 shows the variations in water level in the lake in the period of years 1972–2008. This diagram (Fig. 5) shows an almost perfect linear relation. Fig. 5 shows that water fluctuations can be divided into date groups. Before 1972 the lake was in an early initiation stage, from 1984 to 1992 the lake was in a low water support stage and from 2000 to 2008 there was good water support from the Nile River between drought cycles. The differences between maximum (180 m) and minimum (160 m) water levels became constant after 1968 (Nile research institute). This means that the lake water seepage (discharges) became more or less settled since 1968 to the present (see Table 1).

The diagram (histogram) for water level versus lake area in km^2 (Fig. 6) shows an almost perfect linear relation. The histogram for water level versus lake shore line length in km (Fig. 7) shows a moderately linear relation up to water level 170 m and a perfect linear relation from water level 170–180 m. These diagrams also show that the intensities of Nile floods are reflected in the shape of the lake (its shore line) and in its size (area) with the exception of its discharge due to evaporation.

Table 1 Minimum and maximum water level in Lake Nasser, collected from Irrigation Ministry and Agriculture Ministry of Egypt.

Year	Minimum level	Maximum level	Discharge
1964	105.94	126.8	20.86
1965	115.74	132.66	16.92
1966	119.02	141.32	22.3
1967	113.48	151.08	37.6
1968	145.29	156.36	11.07
1969	150.85	161.29	10.44
1970	153.81	164.7	10.89
1971	159.65	167.53	7.88
1972	162.49	164.67	2.18
1973	158.2	166.12	7.92
1974	161.01	170.64	9.63
1975	165.6	175.71	10.11
1976	172.42	176.55	4.13
1977	171.69	177.21	5.52
1978	172.4	177.47	5.07
1979	173.03	175.95	2.92
1980	171.18	176.22	5.04
1981	171.12	175.96	4.84
1982	170.18	172.63	2.45
1983	165.64	169.86	4.22
1984	163.6	164.65	1.05
1985	156.16	164.34	8.18
1986	157.14	162.7	5.56
1987	154.5	158.49	3.99
1988	150.62	168.82	18.2
1989	164.3	169.79	5.49
1990	163.72	168.41	4.69
1991	162.23	169.35	7.12
1992	163.84	170.75	6.91
1993	167.24	174.32	7.08
1994	169.51	177.28	7.77
1995	173.32	176.27	2.95
1996	172.28	178.55	6.27
1997	175.4	178.52	3.12
1998	174.69	181.3	6.61
1999	175.66	181.6	5.94
2000	175.84	180.63	4.79
2001	175.69	180.68	4.99
2002	175.12	179.96	4.84
2003	172.02	177.91	5.89
2004	171.7	177.43	5.73
2005	169.57	175.03	5.46
2006	168.57	176.53	7.96
2007	172.25	180.6	8.35
2008	174.8	179.48	4.68

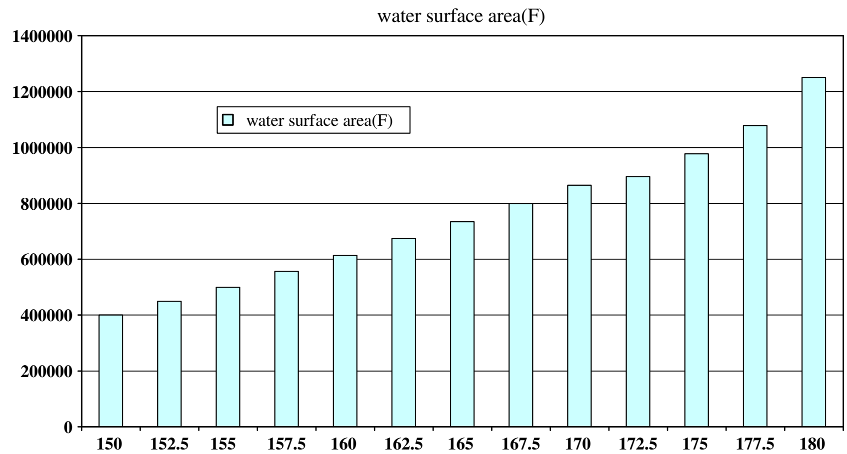

Figure 6 Diagram for water level versus lake area.

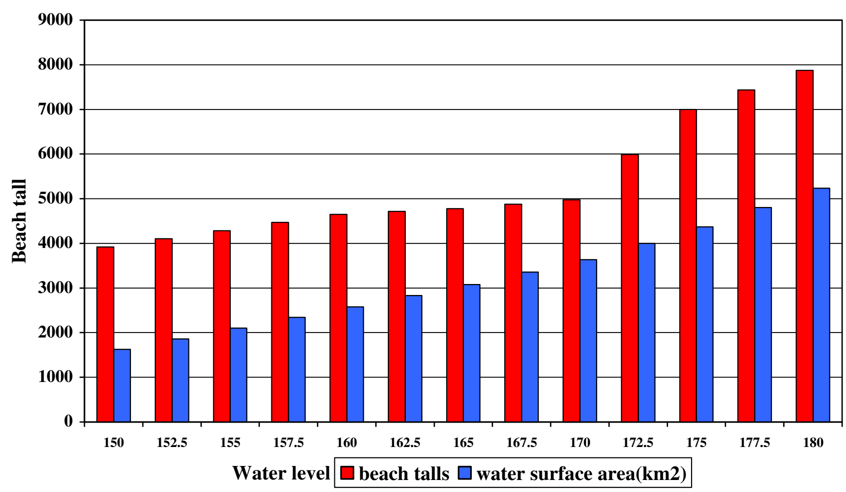

Figure 7 Diagram for water level versus length of lake shore line.

3.2. Use of remote sensing technique in change detection

Fig. 8 shows Lake Nasser "change detection" between 1987, as an example for arid period, and 2000, as an example for rainy period on the River Nile. Fig. 9 shows changes in water fluctuation in the Lake Nasser for the dates of 1972, 1987, 2000, 2003 and 2008. Fig. 10 is a digital elevation model (DEM) for the topographic heights surrounding Lake Nasser. Fig. 11 is a DEM showing changes expressing water fluctuation in the level and amounts of water submerging the area of Wadi Al Alaqui for the dates of 1987 and 2000.

The processed images, which produced the maps of Figs. 8–11 by using the ARC-GIS and ERDAS Imagine softwares, enable the recognition in Lake Nasser of various sectors, with characteristic water fluctuations patterns. These sectors are:

3.2.1. Sector I, from Khor el-Raml to Kalabsha. It displays slight to no change in its eastern part and high rate of change in its western side, at Wadi Kurkur

Changes are not detected in the granitic terrain of the eastern part of this sector, where hard hills of granite constitute walls along the shores of the lake. Here the sector also includes small granitic islands (Figs. 3, 4 and 9). Around Wadi Kurkur, only slight changes are observed, due to the relatively high lands constituted by sedimentary rocks. On the other hand, in small wadis around Wadi Kurkur and in Wadi Kurkur itself, in the western side of the sector, high rates of change are observed. Here, conspicuous vegetation grows upon fine soil deposits covering a wide area with considerable depth. Wadi Kurkur stretches for about 9 km in an E–W direction south of Sinn el Kaddab plateau. It is located near to Aswan and represents a good area for land reclamation and agriculture. This extensive topographically low area frequently affected by shallow water transgressions is subjected to high evaporation rates (Fig. 12).

3.2.2. Sector II, Kalabsha area. It displays a high rate of change

In the eastern side in this sector, high standing granitic rocks do not allow water transgressions and no fluctuations in water level were observed for the five dates investigated, except for 2008, when a narrow water transgression has been detected over short distances in the tributaries surrounding the lake. In the western side of the sector, the water invaded the Kalabsha depression at the five dates investigated. The depression follows an EW structural zone. The transgression over Wadi Kalabsha was at its maximum in the year 2000. In 2008, the

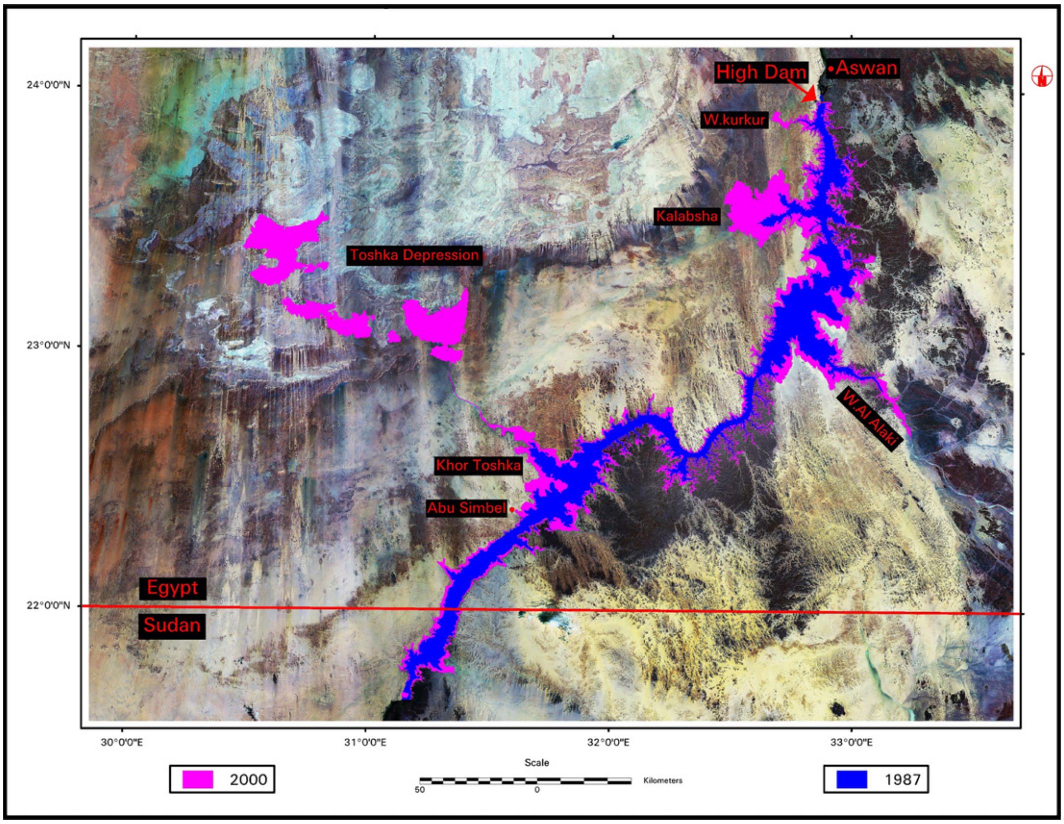

Figure 8 Change detection in Lake Nasser between 1987 and 2000.

water extended over the whole depression and in 2003 the water spread over the Kalabsha area because of the low, flat topography of the sedimentary rocks exposures of the area, enhanced by quarrying activities (Figs. 3, 4 and 9). In cases of more flood, the water will be spread over the western side of the Kalabsha area because of its low and flat topography and the existence of some water seepage. The area around Garf Husein to Wadi El Arab can sustain more agricultural reclamation in both its eastern and western sides.

3.2.3. Sector III, Wadi Al Alaqui area. It displays moderate change

The eastern side of Wadi Al Alaqui is a major NW–SW fault. The floods run in this Wadi, which is a tributary of Lake Nasser. Its head was conspicuously submerged in the years 1987, 2000, 2003 and 2008. The three dimension elevation model of Fig. 11 shows the fluctuations of water levels over the wadi. The transgressions penetrated the wadi for long distances and were of limited width, as they were surrounded by Quaternary fine soil deposits. This soil has a suitable depth and can be used for agricultural land reclamation. In cases of limited Nile floods and low water level in the lake, the water runoff from flash floods collected from the hills surrounding Wadi Al Alaqui drainage basin can be used for irrigation; as the area is frequently affected by flash floods. In the case of higher Nile floods the water of Lake Nasser will penetrate deeply in Wadi Al Alaqui because of the groove shape of this incised wadi, resulting from the fault of its eastern side (Figs. 3 and 11). Flood water submerges the lake according to contour line 180 m in its western side, which is an area of outcrops of sedimentary rocks partially covered by a sand sheet.

3.2.4. Sector IV, from El Madiq to Tumas. It displays no change

This narrow sector in the lake is structurally controlled and restricted by hard Nubia Sandstone exposures. It extended from El Madiq (in the eastern side of the lake) in the north to Tumas (in the western side of the lake) in the south. This sector has been sculptured by NW–SE faults, the Kurusku fault (in the south) and Al Madiq fault (in the north). There is no change (variation in water level) in this sector because of the hard Nubia Sandstone exposures, high topography and rugged terrain of its eastern side. This sector exhibits submergences of narrow shallow water and is subjected to hazards due to sand encroachments coming from Wadi Gabgaba in the eastern side of the lake, where this drainage basin is covered by sand sheets (or dunes). In the future this narrow sector may become closed due to sand encroachment and deposition.

3.2.5. Sector V, from Tumas to Tushka. It displays negligible changes

The sector extends from Tumas to Tushka (Figs. 3, 4 and 9). It is bounded by the Kurusku NW–SE faults in the north and by Tushka in the south. It displays negligible changes in water levels in its western side due to sand encroachment and strictly no changes in its eastern side, which exposes hard Nubia Sandstone outcrops. In the future this narrow part of the lake may well become plugged by mud brought by the floods of the Nile and by sand dunes deposition coming from the north.

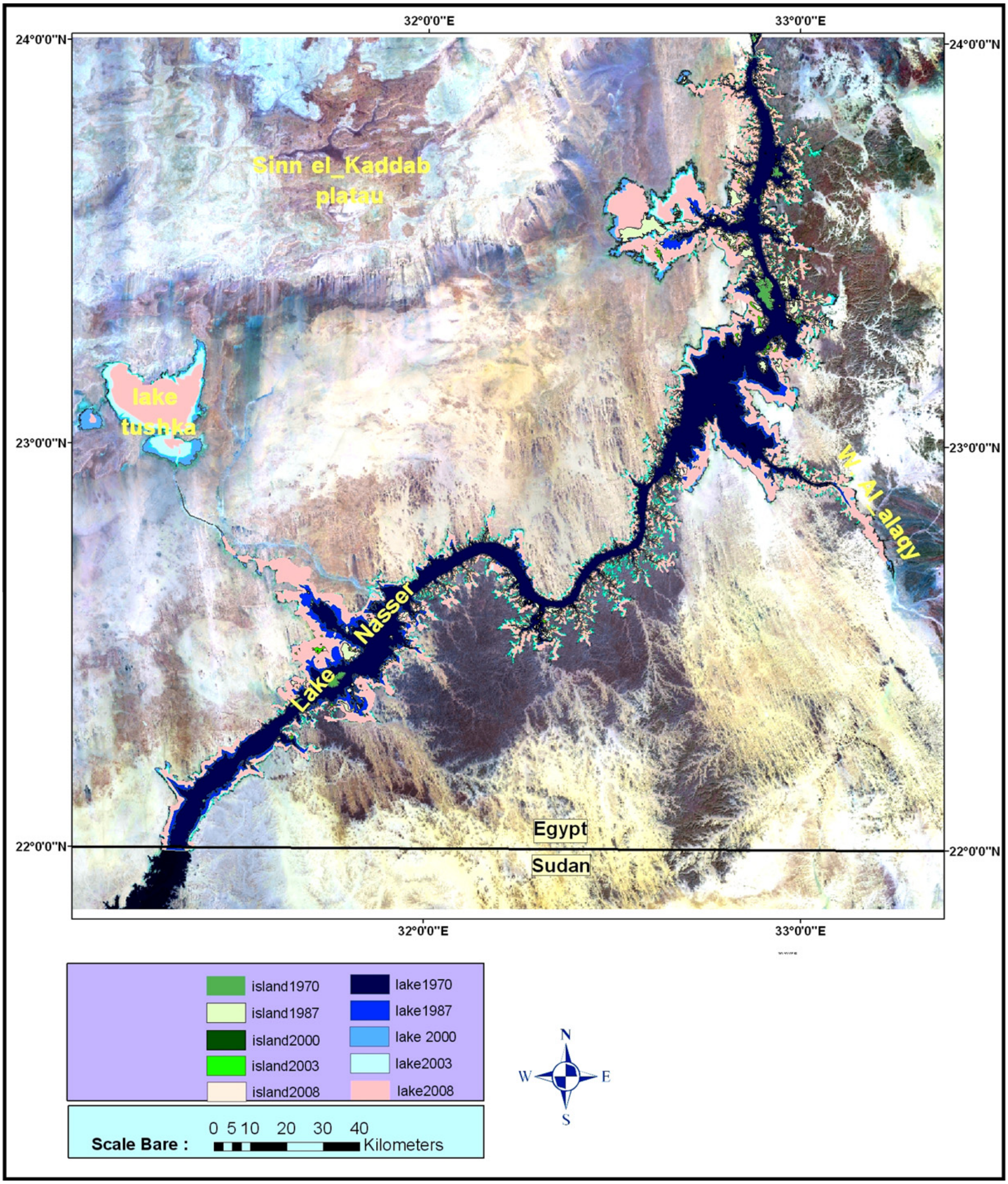

Figure 9 Fluctuations in flood water in Lake Nasser for the years 1970, 1987, 2000, 2003 and 2008.

3.2.6. Sector VI, the Tushka area. It displays high changes
Khor Tushka (Tushka groove) is bound from its western side by a major NW–SW fault. Here, flood waters spread in low lands bound by a north-eastern sedimentary ridge, generated by Aeolian weathering processes. The Tushka area was traced by several E–W faults and restricted in the north by the Sinn el Kaddab southern scarp. In this sector, the water appears on Landsat images as being of shallow depth. This is due to its wide surface, which induces high evaporation.

3.2.7. Sector VII, from Abu Simbil to Adindan. It displays moderate change
This sector spreads from Abu Simmbel (city and Temple), on the western side of the lake, to Adindan, on its eastern side. Isolated Nubia Sandstone restricted outcrops are widespread over the western side of the sector. The low land around these outcrops is covered by Quaternary deposits. This sector displays moderate changes in the levels of flood waters. In the future it seems that the sector will be affected by floods with

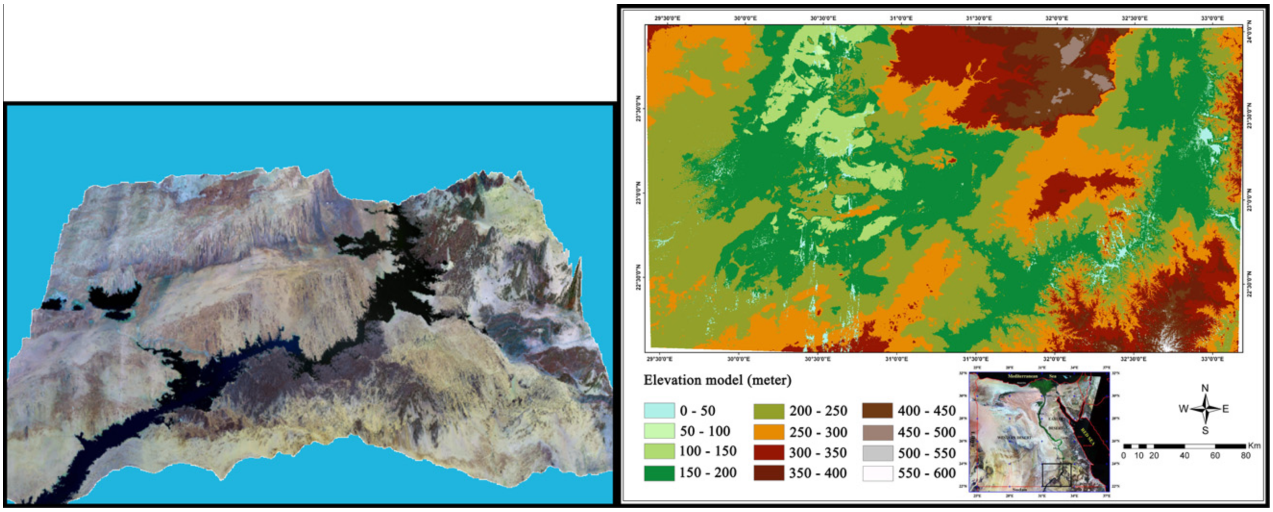

Figure 10 3D digital elevation model and topographic highs for Lake Nasser surroundings.

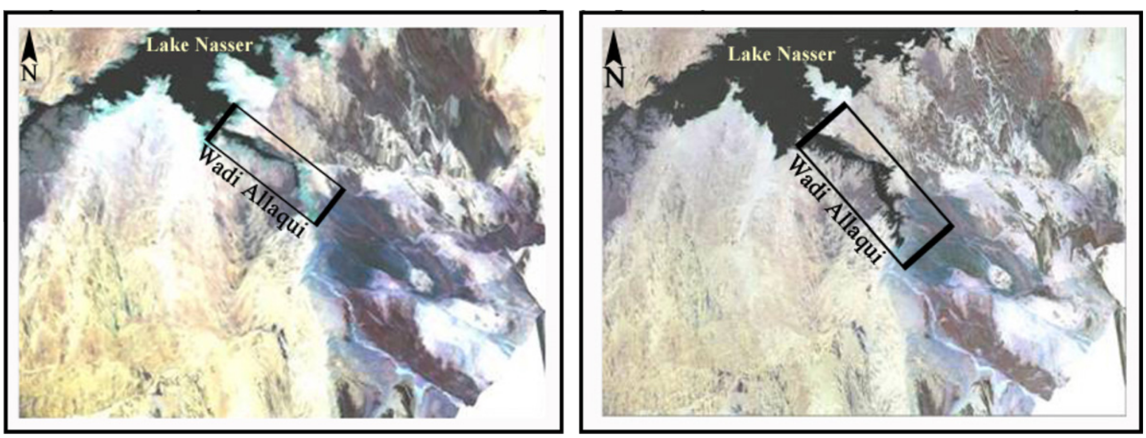

Figure 11 3D DEM changes in the years 1987 and 2000, delineating the water fluctuations in the area of Wadi Allaqui.

Figure 12 Photographs showing natural vegetation and shallow water, covering a wide area in Wadi Kurkur.

shallower water, covering a wider area than the present one (Fig. 9). This sector is impaired by the risk due to sand encroachment from the northern dune fields (Fig. 13) and by Nile mud provided from the south. This will induce marked shallowing of the lake in this sector. This sediment accumulation (of fluvial mud and Aeolian sand) seems to be in the process of generating a new delta near the border between Egypt and Sudan.

Figure 13 Photographs show sand encouragement north Abu Simbil on the western side of the lake.

4. Main characteristics interpreted

The factors controlling flood water distribution and fluctuations in Lake Nasser are:

1. The granite and Nubia Sandstone outcrops limit the water transgressions in most of the eastern lake sectors.
2. Geologic structures (mainly faults) determine the way the different sectors of Lake Nasser evolve through time. The regional NE–SW faults define the limits of the considered lake sectors and affect water fluctuation in the Al Alaqui and Tushka incised wadis (*khors* in Arabic).
3. Low and flat topography in wide areas (such as Abu Simmbel, Tushka and Kalabsha depressions) help in inducing high evaporation. Water transgressions penetrate the low land in the western side of Lake Nasser but do not penetrate and infiltrate the Nubia Sandstone exposures in its eastern side.
4. Sand movements cause the closing of narrow lake sectors. It also induces shallow water depths over large sectors. This is the reason for the failure of the transgressions to fill the majority of the lake with proper water depths, which should exceed the observed values. These sand movements may determine the future evolution of Lake Nasser.
5. The precipitation of mud, provided by the floods of the Nile to the broad divisions (sectors) of the lake, causes a decrease in water velocity and helps high evaporation. This can be observed at Wadi Kalabsha, in the area to the south of Tushka and near the border between Egypt and Sudan.

4.1. Potential for agriculture land use and reclamation

Tushka and Kalabsha areas have been extensively studied, while Wadi Al Alaqui in the east and Wadi Kurkur and Garf Husein in the west, were not sufficiently studied. However, these last mentioned areas seem to be very promising for land reclamation and agriculture, because they have soils with appropriate depth and loamy texture. They enable adequate water seepage, because of their topography, which displays elevations of more than 185 m to reach up to 200 m. Wadi Al Alaqui does not suffer from sand storms and Wadi Kurkur includes a wide area of natural vegetations and is easy to irrigate. For these reasons, Wadi Al Alaqui has been studied in the present work and a 3D elevation model has been produced to trace the variations of the area covered by flood water in the wadi (Figs. 1, 3 and 9).

4.2. Hazards due to sand encroachment

Many parts in Lake Nasser are affected by mud and sand deposition, such as the sector extending from El Madiq to Tushka (Sectors IV and V), in the western side and Wadi Gabgaba, where no true water depth is reached in the eastern part of the sectors. This phenomenon needs detailed investigation, as wind action is high throughout 360 days in the year under such arid hot climate.

4.3. Suitable change detection technique

Change detection by statistical treatment of water data from Egyptian Ministries is suitable and gives good results for the lake as a whole, by considering its water mass. This enabled to elucidate the periodicity of the floods and the amount of water discharge in each flood. The use of remote sensing technique in change detection, however, enables a relatively quick and detailed complete monitoring of each lake division (sector) and enables also correlation with some of the physical properties of the terrain around the lake (as geology, geomorphology, structure, etc.). Such an approach can also be helpful in land use studies and planning.

4.4. Environmental implications

Because of the vital importance of the Nile water for drinking, agricultural and even industrial use in Egypt, the effect of climatic changes in East Africa on the flow of this river should be carefully considered and the behavior of this water body when subjected to seasonal floods should be thoroughly understood. The utilization of the water of this river in Egypt should be optimized as much as possible. New localities for land reclamation and agriculture should also be found. The results of the present study suggest that Wadi Al Alaqui and Wadi Kurkur are the main most promising new localities for agricultural development. This is due to their thick soil, distributed over a wide area, receiving plenty of water during flood periods. Garf Husein, Kalabsha and Tushka areas are also promising for the same purpose (Figs. 1, 3 and 9).

The area from El Madiq to Tumas (Sector IV) will be exposed to considerable natural risk in the near future. Field observations and the above discussions lead to the recommendation to investigate in detail the area covered by this sector. The environmental implications of the data studied and interpreted in the present work show that the shallow water (obvious on Landsat images), noticed over the narrow area of the sector that suffers from sand encroachment during 360 days/year, may end by the complete closure of this part of the lake (Figs. 1, 3 and 9).

5. Conclusions and recommendations

Lake Nasser, the biggest artificial lake on earth, is of utmost importance to Egypt. Therefore, it must be thoroughly studied and the mechanism and causes of the changes that happen in its water level, which varies from 160 to 183 m above sea level, should be carefully studied. To have a reasonable understanding of these processes, the influence of the physical features of the surroundings of the lake on the distribution of the flood water should be accessed. According to the degree of fluctuation of the level of flood water over the lake, the surface of this water body has been subdivided into four types (distributed over seven sectors): Type 1, shows maximum change, Type 2, shows a moderate (medium) degree of change, Type 3, shows a slight to negligible degree of change, and Type 4, shows no change. Geologic structures (mainly faults), extensive granite and sandstone outcrops, climate, topography and sand movements strongly influence the shape of Lake Nasser and its geomorphological evolution through time. These parameters also should have a great influence on the future development of the lake. Sand movements and accumulation on parts of the bottom of the lake cause the development of areas of shallow water in some lake sectors and the lake displays no "true" depth in the majority of its surface. Therefore, it needs careful and detailed monitoring for a scientific management of its water resources. Wadi Al Alaqui in the east and Wadi Kurkur and Garf Husein in the west are very promising areas for land reclamation and agriculture.

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