# Estimation of water loss from Toshka Lakes using remote sensing and GIS

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## Abstract

Toshka area is located to the west of Lake Nasser, in the Western Desert of Egypt. By the end of 1998 water in the River Nile has entered Toshka depressions for the first time when the Lake Nasser water level exceeded 178 m a.s.l. Intermittently, water continued to discharge into the depression until the end of year 2001. As a result the lakes continued to aerially expand until the end of year 2001, but thereafter the lakes are shrinking. In this paper we are interested in the assessment of the lakes droughts using an integration of remote sensing and GIS technique. A set of remote sensing images were collected and processed to show the lakes aerial extend shrinkage from 2002 upto recent. Spatially variable bathymetry (i.e. depths) has been interpolated from contour topographic maps surveyed prior to the filling of these depressions with water from Lake Nasser. At a given time, the water volume of the lakes was calculated given the aerial extend derived from the images and the spatially variable depths of these lakes derived from the DEM analysis. Spatial analysis of bathymetry DEM reveals that loss rate is around 2.5 m/year, and the lakes stored around 25.26 billion cubic meters of water in 2002. But in 2006 the stored water was greatly reduced to 12.57 billion cubic meters.

## Introduction:

Toshka area consists of several interconnected depressions located west of Lake Nasser, about 250 km south of Aswan, Egypt (Fig 1). The depressions are currently being used for release of excess water from Lake Nasser maximum storage level (178 m a.s.l) as a natural flood diversion basin to reduce possible downstream degrading to the Nile valley caused by exceptional flooding. The exposed rock units in Toshka area range in age from Pre Cambrian to Quaternary (El Ramly, 1972). However, the depressions are mostly underlied by Paleocene sedimentary formations (Esna Shale) and are partially surrounded by Lower Eocene pediments and scarps of different elevations (El Shazly et al., 1977). The northern borders of the depressions are clearly defined by a prominent escarpment, while its southern borders are gradational and ill defined, and the ground level increases with a very gentle slope. The depression floor is not typically flat; it comprises local isolated hills and benches. Those hills are either basaltic or flat-topped sandstone hills capped by basalts. Additionally, the western depressions are interrupted with sand dunes.
The geomorphology has drastically changed after 1998 as a result of the inflow of excess water from Lake Nasser for the first time since the construction of the High Dam. This inflow was intermitted and stopped by end of the year 2001; the geomorphology of the study area from 1998 up to 2001 was rapidly changing in the direction of gaining more inland freshwater lakes. Inversely, by end of the year 2001 the Loss (i.e. evapotranspiration and infiltration) is dominating the hydrological regime of these lakes. Therefore, there is a continuous reduction of the lakes dimensions.

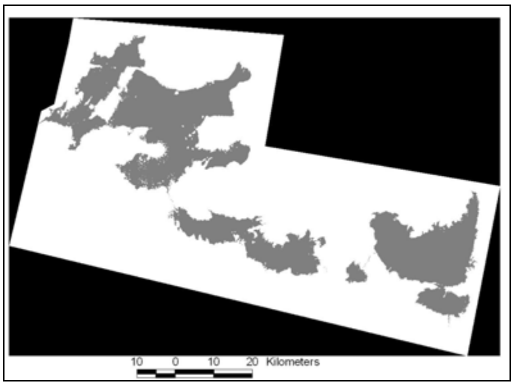
Remote sensing images have been increasingly used to monitor and analyse inundation and fluctuation of playa lakes (Bryant and Rainey, 2002; Castan˜ eda et al., 2005; French et al., 2006). This is driven, firstly, by the abundant availability of multi-temporal resolution of several satellite images during the past three decades. Secondly, Remote sensing plays an important role in the discrimination and delineation of the areal extent of surface water bodies from the surrounding features. This is attributed mainly to the outstanding interaction of electromagnetic spectrum (EM) in the near and middle infrared region of spectrum and water surfaces. Generally, water bodies tend to absorb most of the incident infrared radio magnetic radiation and a slightly higher reflectance of the visible wavelengths (0.4 - 0.8 μm), on the contrary of surrounding features such as land and/or vegetation. Therefore, water bodies stand out in stark contrast to the surrounding soil and vegetation. Consequently, remote sensing can be very efficient in monitoring and assess the ongoing dynamic changes of Toshka Lakes.


***Figure 1:*** Location map of Toshka Lakes.

Most of relevant research aimed to detect and delineate temporal changes of the water bodies' surface area and their relation to environmental parameters (Drake and Bryant 1994; Bryant and Rainey, 2002). However, the increasing demand and management for water resources in such dryland deem it very critical to estimate the lakes water budget along with annual quantity of water loss. In this paper we aim to estimate the water loss of Toshka Lake 1 from the year 2002 up to 2006 using multi-temporal satellite images coupled with digital elevation model (DEM) analysis. DEM can be defined as any digital representation of variation in relief over space (Burrough and McDonnell, 1998). The choice of data sources and generation techniques is very critical to the quality of DEM (Weibel and Heller, 1991). At present, there are various sources of elevation data, including topographic map contours and elevation points, field surveys, aerial photographs, and space-based radar and laser devices (Band, 1993). The source and resolution, and the processing algorithms significantly influence the hydrological analysis of DEM (Zhang and Montgomery, 1994; Wolock and Price, 1994). Topographic maps of scale 1:100,000 produced in the 1960s prior to the formation of these new Saharan lakes were used to generate the DEM of lake bathymetry and surroundings. Herein, GIS is used to estimate Toshka Lakes water budget given the lakes surface extent derived from remote sensing images of a given date and the bathymetry DEM.

## Data and Methods

Toshka lakes water loss modeling required various types of data from different sources. Three Aster images acquired in February 2002 and four Spot4 images of February 2006 were collected, pre-processed and processed to delineate lakes surface areas. The images were rectified into Universal Trans-Mercator (UTM), zone 36. Then they were enhanced in a way to discriminate between lakes and surroundings. The scenes of 2002 and 2006 were mosaiced and classified in order to compute the lakes surface area reduction during the given time span (Fig 2). However, water volume of each lake at a given date requires, in addition, water depths. Usually, bathymetry is estimated using a sonic depth finder instrument. But the Case of Toshka lakes are spectacular, where there are topographic maps of scale 1: 100,000 surveyed prior to the formation of the Lakes (Figs 3 and 4). Therefore, these topographic maps were digitized, and DEM was generated to simulate lakes bed bottom topography and surroundings(Fig 5). The DEM is of 20 m resolution, and was interpolated in Arc Info Topogrid's module using digitized contours, drainage networks and spots heights layers. The DEM was used to estimate the elevation within every square 20 m of the lake bathymetry, or bottom topography and surrounding. The quality and reliability of DEM was examined both visually and analytically. Given the availability of field-measured lakes level, logical query on the DEM was used to derive the lakes surface areas and configurations at given elevations above mean sea level (a.m.s.l). Then the DEM-simulated lakes were overlaid on their counterparts and references of 2002 and 2006 satellite images. This is revealed a high degree of coincidence between the simulated and observed lakes surface areas and configurations (Fig 6). Once the quality of study area-DEM was assured, the volumes of stored water in lakes at given levels were calculated using mathematical functions of Grid Module in Arc Info.



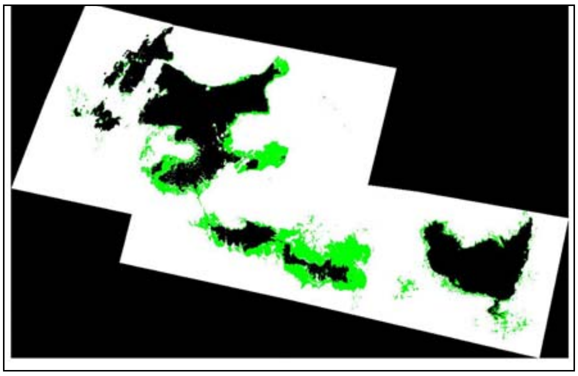


***Figure 2:*** Toshka lakes surface area change from 2002 (left) to 2006 (right).

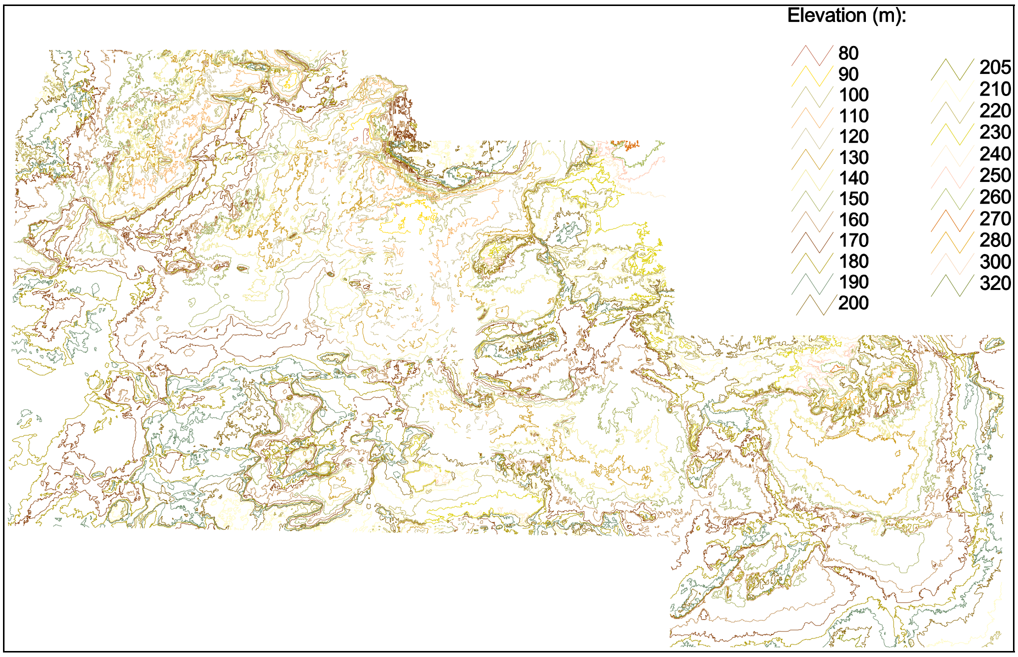



***Figure 3:*** digitized contours of topographic maps for the study area.

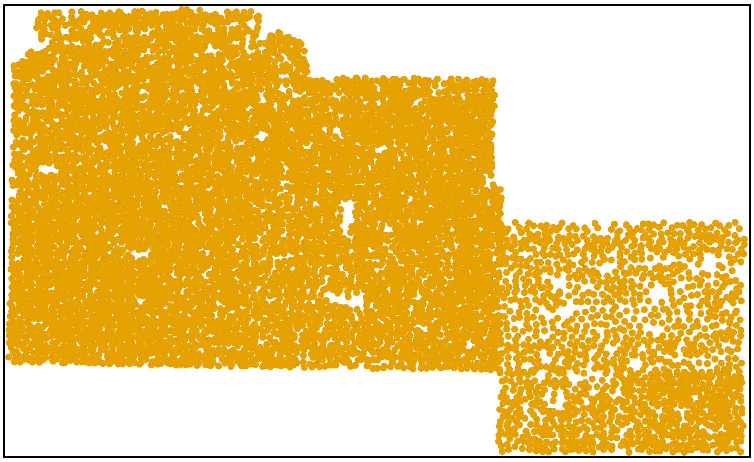


***Figure 4:*** digitized spot heights of Toshka area's 1:100,000 topographic maps.

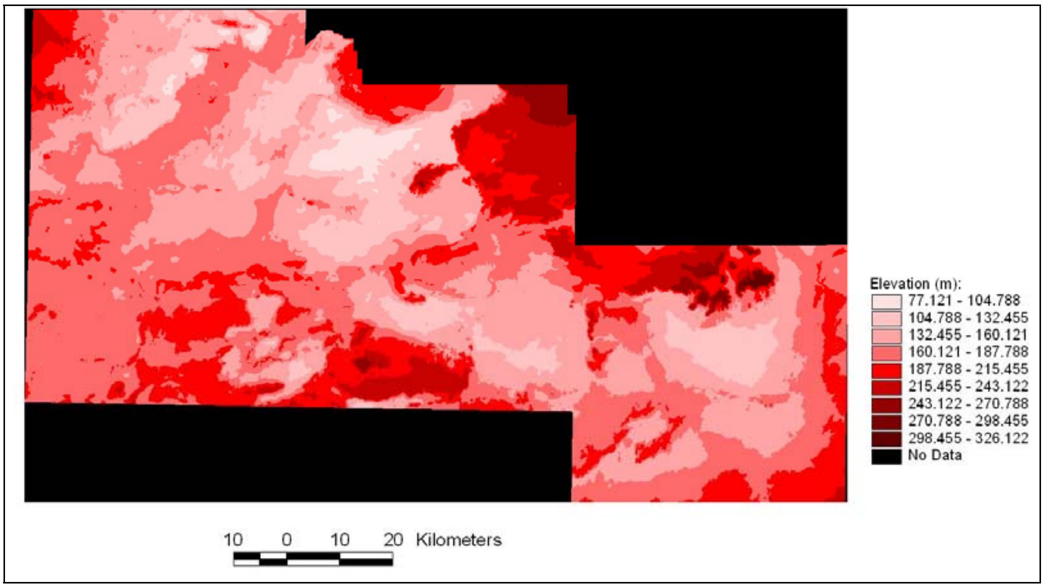



***Figure 5:*** DEM of the Toshka area prior to the formation of lakes.

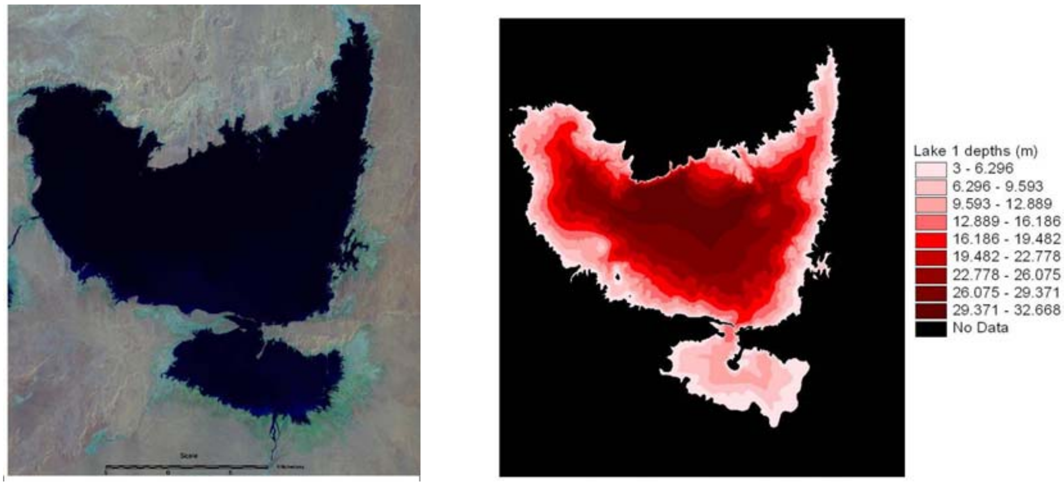



***Figure 6:*** lake 1 image in 2002 (left) and the DEM-simulated configuration and bathymetry for the lake in 2002 (right).

## Results

The estimated total surface area of Toshka lakes in 2002 was 1541 km$^2$ distributed on lakes 1, 2, 3 and 4 respectively as follow: 449, 20, 265 and 807 km$^2$. But in 2006 the lakes surface area were greatly reduced and reached 937 km$^2$. Lake 2 is completely vanished, and surface areas of lakes 1, 3 and 4 were calculated to 286, 101, and 550 km$^2$ respectively (Fig 7). The analysis of DEM revealed that lakes surface stands on different elevation levels. Where lake 1 surface level in 2002 is estimated as 153 m a.s.l and the lakes 2, 3 and 4 levels were 151, 141, and 140 m respectively. However, the rate of drop in the lakes surface level from the year 2002 to 2006 is almost similar, it is approximately 10 m in 4 years. Therefore, lake 1 surface level in 2006 stands at 143 m a.s.l, and lakes 3 and 4 stand at 131 and 130 m a.s.l respectively. The calculated water volumes in Toshka lakes 1, 2, 3, and 4 for the year 2002 are 6.78, 0.044, 2.21, and 16.23 billion m$^3$, and for the year 2006 are 3.45, zero, 0.44, and 8.78 billion m$^3$ respectively (Fig 8). This significant rate and volume of water loss can be attributed to both evaporation and infiltration, since there is no human exploitation of water from Toshka lakes with the exception of very minimal activity around lake 1. The annual evaporation rate is estimated as 2,3 m/year data where it was measured in the field by the General Authority For the High Dam from September 2003 to August 2004. Therefore, most of Toshka lakes water is lost through evaporation with very limited amount being percolated to the ground water.

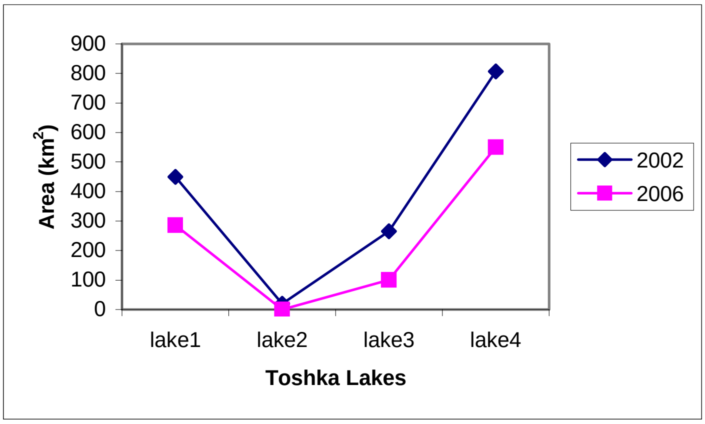



***Figure 7:***Toshka lakes surface area change from 2002 to 2006.

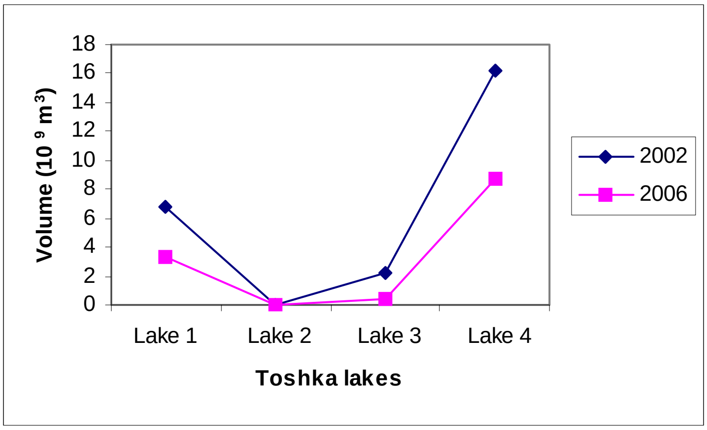



***Figure 8:***Toshka lakes water volumes change from 2002 to 2006.

## Toshka Lakes DEM Limitations

As the DEM was interpolated from topographic maps contain contours at 10 meters interval and scattered elevation points, it is not surprising that extracting the lake boundaries will not exactly match these portrayed from Landsat images. This little discrepancy can be attributed to the density, magnitude and frequency of the sampled elevation values (i.e. contours, and spot heights) recorded on the topographic map. The vertical accuracy of the DEM is measured by integer meters, since the spot heights and contours values are integer. On the other hand, the lake level is regularly measured in the field, with an accuracy of centimeters by the Egyptian Water Resources Research Center expeditions. However, this inevitable and minor discrepancy between lake surface area and level estimation from DEM and satellite images is slightly influencing the analysis. The coincidence of lake surface areas simulation from the DEM and their counterparts on satellite images exceed 98% when the DEM-estimated lake elevation levels errors are less than 1 m from the field measurements.

## Discussion

Toshka spillway was constructed as a first defense line to discharge excess water into Toshka depression in case that Nasser Lake attain its maximum storage capacity at 178 m a.s.l. The massive floods of the Nile River during 1998, 1999, 2000 and 2001 resulted in the gradual formation of new 4 Saharan lakes in Toshka depressions. Thereafter, given the cease of supplies from Nasser Lake, the Toshka Lakes are diminishing. Remote Sensing Images acquired in 2002 and 2006 along with bathymetry DEM generated from topographic maps surveyed prior to the lakes existence, were used to delineate the surface areas change and volumes of stored water. From year 2002 to 2006 the estimated annual loss rate is 2.5 m, and this is resulted in reducing the lakes areas from 0000 to 0000 and stored water volumes from 0000 to 0000. the measured annual evaporation rate is nearly 2.3 m and therefore, this is imply the limited recharge of the groundwater aquifer underlying the lakes.

## Conclusion

Remote sensing images and DEM analysis were integrated to assess the recent surface hydrological changes of Toshka lakes. The location of these lakes in the hyper-arid zone is responsible for high loss rate mainly through evaporation. The percolation of water from lakes to ground water is very limited. It is strongly recommended that measures must be taken to maximize the benefits of these huge, exceptional water resources before totally lost via evaporation. Additionally, geo-environmental problems are likely to arise from the concentration of salts when the lakes dry up.

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