DEVELOPING RATING CURVES OF LAKE NASSER, EGYPT, UTILIZING REMOTE SENSING AND GIS TECHNIQUES

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ABSTRACT

In the present study, the authors used the measured available data of Lake Nasser and the extracted data from the processed satellite images (for different years) to create a 3D profile of the Lake Nasser using RS/ GIS techniques. The developed 3D profile is used for the development of the rating curves of Lake Nasser for each of the years 1992, 2000, 2006, 2009, and 2012 (individually and collectively). The accuracy of the developed relationships is assessed by comparing its results with the measured data for the Lake. The root mean square error (RMSE) and the determination coefficient (R^2) are computed for assessment of the performance of the present method and the method used by Aswan High Dam Authority (AHDA). The R^2 is found to be more than 0.97. Also, it is found that the root mean square error values range between 4-5% and 2-3% for (volume / level) relationship and (area / level) relationship respectively. The results indicate that the RS/GIS approach underestimates the water capacity by less than 2% compared to the results obtained by the cross section method for the entire years from 1992 to 2012 at the same water level (175 m amsl). Accordingly, the developed equations can be used to estimate the water volume (capacity) of Lake Nasser instead of the costly measurements. However, field measurements by AHDA and NRI are necessary from time to another to update such equations and for other purposes as well. It is recommended to test the applicability of using the RS/GIS approach to estimate the sediment capacity in Lake Nasser.

Keywords: Lake Nasser, Rating curve, 3D profile, Lake Capacity, Remote sensing, GIS

1 INTRODUCTION

It is very difficult to maintain a continuous record of Lake Capacity. However, a reliable and continuous record of bed levels data (hydrographic survey data) and satellite remote sensing data of a Lake is rather easy and accurate as compared to its water capacity.

For example, to estimate the water capacity of Lake Nasser, extensive measurements and complicated approximation manual methods are required. These manual methods consume time, effort and money. A functional relationship between bed levels, area and capacity (volume) of this lake is called the rating curves, which are considered a useful tool to estimate the water capacity. Generating of these rating curves via the manual computationally labor-intensive methods need an extensive field measurement and consume time, effort and money (Fenton, 2015 and Elsahabi et al., 2016 b).

Developing of the rating curves for Lake Nasser is, therefore, of utmost importance. The Remote Sensing (RS) and the Geographical Information Systems (GIS) approach for the development of the rating curves almost successes to give (volume/ level) and (area /level) relationships accurately. Moreover, this approach (RS/GIS) can overcome most such problems when generating the rating curves and estimating the capacity of Lake Nasser.

For constructing and developing rating curves; various techniques have been proposed including artificial neural network technique (Goel, 2011 and Sudheer & Jain, 2003), genetic algorithm with model tree (Ghimire & Reddy, 2010), spreadsheet approach (Alam et al., 2016), combination of remote sensing (RS) and digital elevation model data approach (Pan et al., 2013), Integration between RS and in-situ measurements technique (Ding & Li, 2011 and Medina et al., 2010), RS/ GIS approach (Elsahabi et al., 2016b), numerical hydrodynamic models (Domeneghetti et al., 2012) and Combination of RS satellite imagery and altimetry data method (Muala et al., 2014).

The present study aims to develop a methodology to establish rating curves of Lake Nasser utilizing RS/GIS approach for each of the years 1992, 2000, 2006, 2009 and 2012 individually and collectively based on its in-situ measurements through these selected years. Then the water capacity of this lake can be easily estimated and compared with the results obtained by the AHDA and the NRI based on the traditional approach (cross sections method).

2 STUDY AREA AND DATA COLLECTION

2.1 The study area

The AHDL is one of the greatest man-made lakes in the world, created after the construction of the Aswan High Dam (AHD).

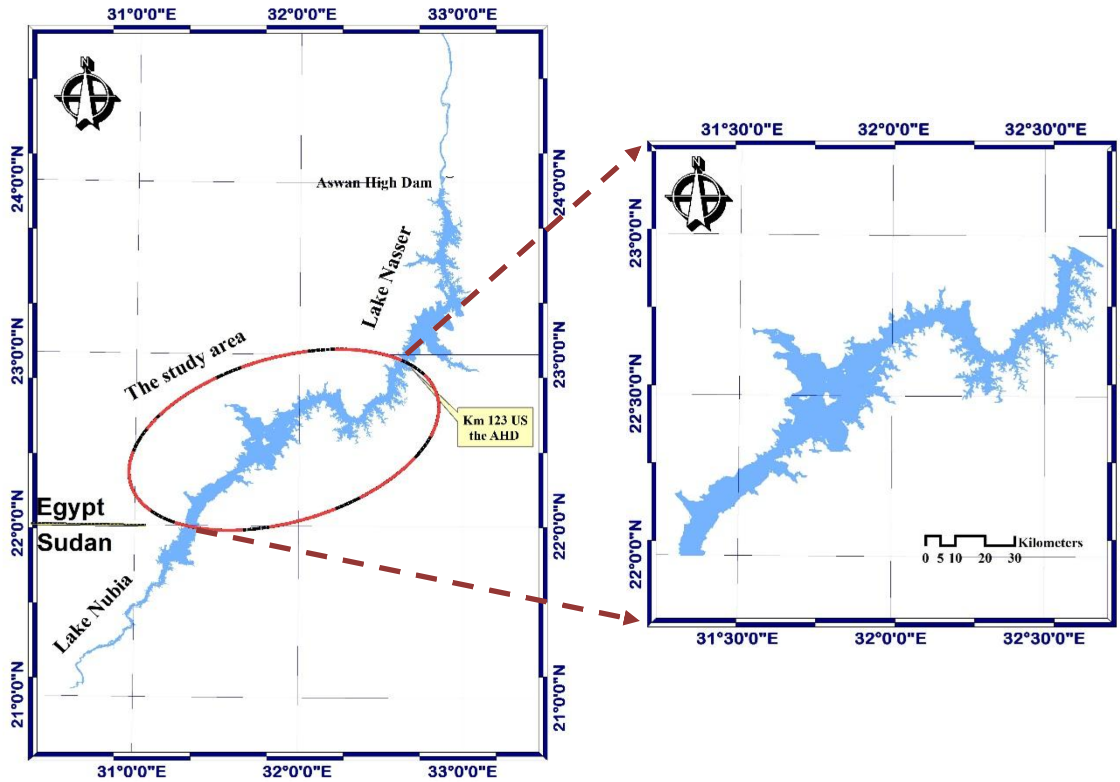

Figure 1. Location map of the study area through the Aswan High Dam Lake.

It consists of two main parts. Egyptian part called Lake Nasser with a length of about 350 km and Sudanese part known as Lake Nubia with a length of 150 km as shown in Figure 1.

Lake Nasser is located between latitudes 22° 00\ 00\\ N (upstream the AHD) and the AHD in the north. The measurements (Hydrographic survey data) cover only the distance that extends from the end of Reservoir Nubia in Sudan to km 123 upstream the AHD in Egypt (behind which no significant sedimentation is observed), Negm et al. (2017). The study area is selected within Lake Nasser, from latitude 22° 00\ 00\\ N to km 123 upstream the AHD where measured data are available, as presented in Figure 1.

2.2 Collected data

The used data in the present study includes:

2.2.1 Hydrographic survey data

The hydrographic survey data presented by Easting, Northing, and Elevation (E, N, and Z) are used to describe the geometry of Lake Nasser study area for years 1992, 2000, 2006, 2009 and 2012. These data were collected using the echo-sounder measurements system provided by (AHDA and NRI), NRI (2012).

2.2.2 Satellite images (Remote Sensing data)

The remote sensing data (Eight Landsat ETM+ images) are used in this study to extract the lake boundaries. Three scenes are needed to completely cover the study area with (Path/Row = 175/045, 174/044 and 175/044). The specifications of the acquired images of the study area are given in Table 1. The data are downloaded freely from the Global Land Cover Facility (GLCF) website, GLCF (2014) in Geotiff (systematic correction) product. Consequently, the collected images are free from geometric, radiometric and noise errors. These images were geo-referenced by USGS using the world reference system (WGS-84 datum) to Universal Transverse Mercator system (UTM), zone 36 North projection.

Table 1. The specifications of the acquired RS data.

Satellite	Sensor	Path/Row	Date	Spatial Resolution (m)	Water Level (m) amsl
Landsat-7	ETM+	175/045	September 2000	30	178
		175/045	March 2006		173
		175/045	March 2009		176
		174/044	March 2005		174
		174/044	November 2001		180
		175/044	September 2000		178
		175/044	April 2006		172
		175/044	March 2009		176

2.2.3 Water levels data

The daily recorded water levels by AHDA gauge stations, MALR (2010), were collected to help in detecting the water surface levels of the study area at the dates of acquiring the satellite images.

3 METHODOLOGY

To achieve the objective of the present paper, the tasks involved in the flowchart shown in Figure 2 were performed.

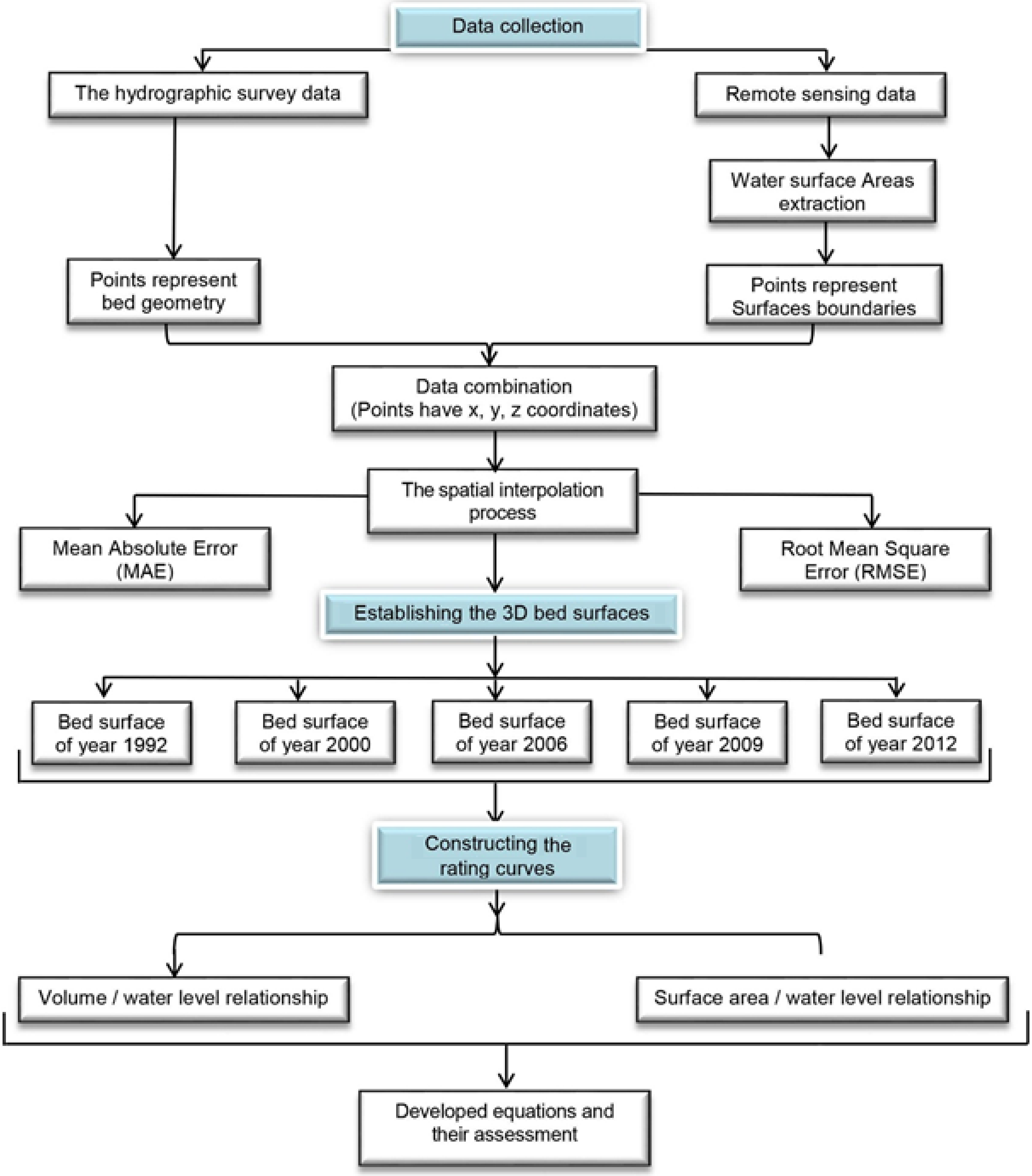

Figure 2. Flowchart of the procedures adopted in this study to develop the rating curves of Lake Nasser

A brief description of the methodology tasks is provided herein:

3.1 Extraction of water surface areas

The unsupervised classification technique was performed to extract the water boundaries of the study area. It is considered the best technique for water areas recognition using Landsat images, (Negm & Elsahabi (2016) and Elsahabi et al. (2016 a,c)). The shape of the lake surface was formed by using the extracted lake boundaries obtained from the satellite images. Then, a group of scattering points (x,y,z) using the WGS84, UTM Z36N as a defined projected coordinate system are formed. These points are used in combination with the hydrographic survey points in the generation of the 3D bed surface of the study area for the selected years from 1992 to 2012.

3.2 Spatial interpolation process

In order to generate continuous knowledge about the bed levels of the study area, it is necessary to approximate the levels values in areas that are not included with measurements (levels points). This is done using the most used three interpolation methods, namely, inverse distance weighting (IDW), radial basis function (RBF) and ordinary kriging (OK)). For more information on the theoretical background of these methods, interested readers can review the help topics of ArcGIS Software, ESRI (2008).

To assess the accuracy of the interpolation methods, a comparison between the performances of these methods was achieved by using the following statistical indicators: the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE).

3.3 Creation of the 3D bed surfaces

In this study, the original lake 3D bed surfaces for the years 1992, 2000, 2006, 2009 and 2012, obtained using the spatial interpolation technique with the best performance are used to compute the storage capacity and surface area variations with the water level changes for Lake Nasser study area for the selected years from 1992 to 2012.

3.4 Constructing the developed rating curves

The values of the two parameters of the lake (water volume / surface area) are estimated from the generated 3D profiles of the lake at different water levels by using 3D analyst tool in ArcGIS software, ESRI (2008). These values are computed in order to establish the rating curves which represent (volume/ level) relationship and (area/level) relationship for all selected years from 1992 to 2012 individually and collectively.

3.5 Rating curves equations and their validation

The equations of the developed rating curves (volume / level), (area / level) and (volume / area) are conducted to estimate the storage capacity and the surface area of Lake Nasser study area at any stage (level) and to monitor the lake morphological changes efficiently.

In our study we assessed the accuracy of the developed rating curves equations using The validation method of these equations by using two standard statistical indicators; root mean square error (RMSE) and coefficient of determination (R^2) (Equations 1 and 2).

$$\text{RMSE} = \sqrt{\sum(Mes - \text{calc.})2 \quad /N} \tag{1}$$

$$R^2 = \sum (\text{calc.} - avg.Mes)^2 \quad / \sum \quad (Mes - avg.Mes)^2 \tag{2}$$

4 RESULTS AND DISCUSSION

4.1 Generation of the 3D Bed Surfaces

The extracted water surfaces by the unsupervised technique from all available Landsat images (remote sensing data) are used in the interpolation process. To obtain the complete predict 3D bed surfaces of the lake by the interpolation process, the RBF method for interpolation was used as it produced the best results (the lowest values for both the MAE and the RMSE) between the other tested methods of interpolation in this study. The MAE for the year 2012 equals 0.31m and the RMSE equals 0.73 m indicating the highest accuracy of the interpolation process. The 3D bed surfaces are created for the years 1992, 2000, 2006, 2009 and 2012. Sample results are presented in Figure 3 for the year 2000 and year 2009.

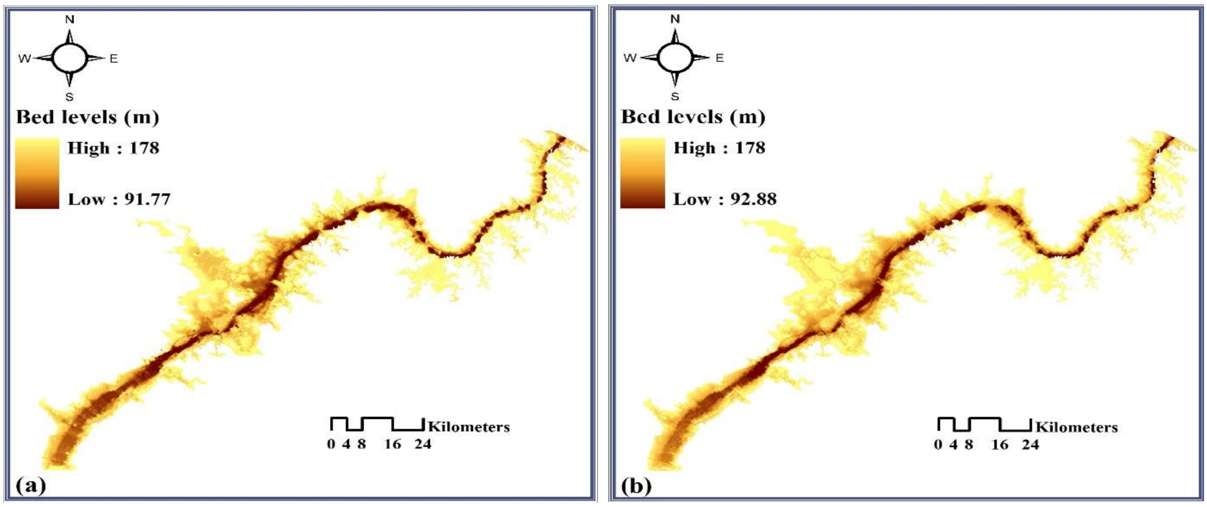

Figure 3. Sample results of the generated bed surfaces: (a) 2000 bed surface and (b) 2009 bed surface.

4.2 Rating Curves And Their Validation

Rating curves which relating Lake Nasser water volume, surface area and level changes were developed to estimate the water volume and surface area variations of this lake. These variations are closely connected with the remotely sensed data and the field measurements (the hydrographic survey data) of this lake.

4.1.2 Volume/ Level relationship

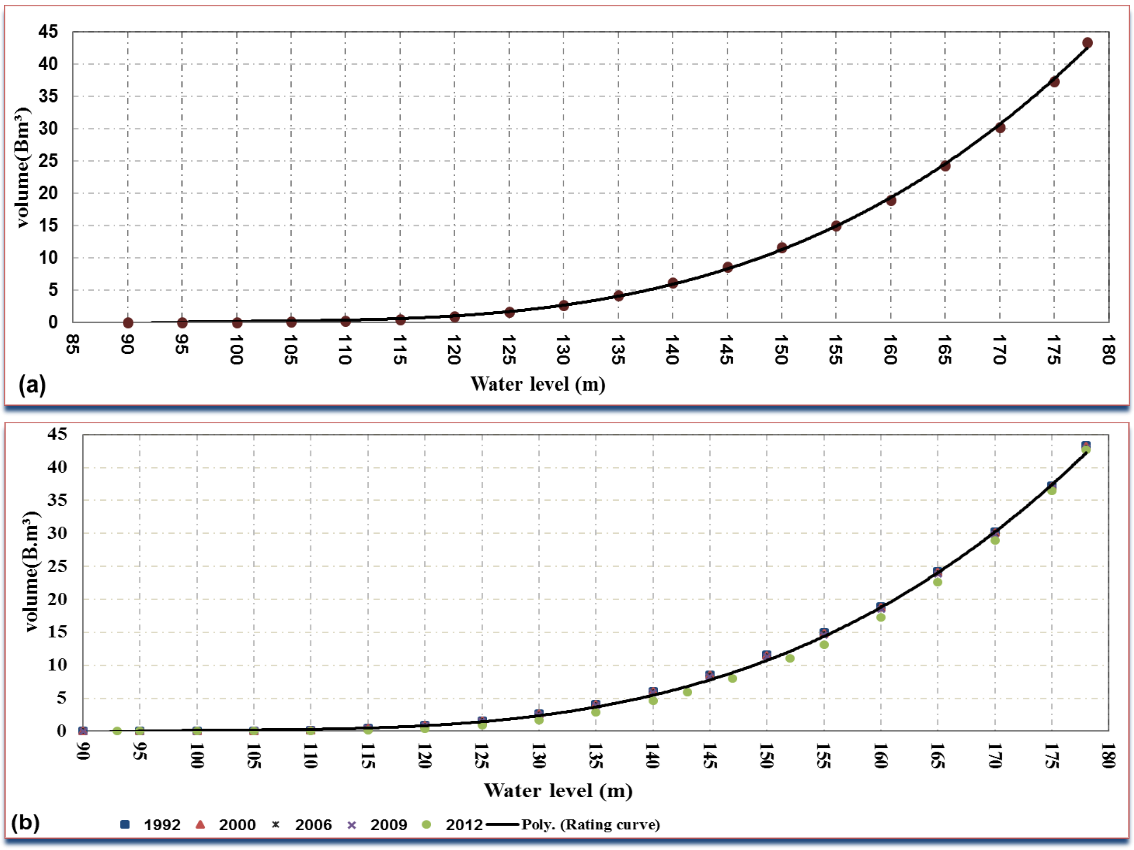

Figure 4. Sample results of the rating curves (volume / level): (a) 1992 rating curve and (b) collective rating curve for the years (1992 to 2012).

Figure 4a and 4b show samples of the constructed (volume / level) rating curves for the year 1992 and collectively for the whole studied period (1992 to 2012). It can be observed from these Figures that, the volume changes as a function of level variations showed a third – grade polynomial relationship.

Table 2 indicates the developed equations for the years (1992, 2000, 2006, 2009 and 2012) and for all years (1992 to 2012) which represent the relationship between (volume / level). According to this table it is clear that the computed volumes are in good agreement with the measured ones where R^2 values are more than 0.99 and RMSE varies from 4 -5%..

Table 2. Evaluation of the developed relationships between water volume and level for the period from 1992 to 2012, individually and collectively

Period of the estimated rating curve	Number of points	R2	RMSE ($B.m^3$)	RMSE (%)	Rating curve equation (y = volume in $B.m^3$ and x = water level in m)
1992	19	0.999	0.49	4.55	y = 0.0000939081x3 - 0.0288x2 + 2.951x - 101.33
2000	19	0.999	0.50	4.60	y = 0.0000943237x3 - 0.0289x2 + 2.972x - 102.18
2006	19	0.999	0.48	4.45	y = 0.0000954247x3 - 0.0294x2 + 3.027x - 104.38
2009	19	0.999	0.47	4.40``	y = 0.0000960099x3 - 0.0296x2 + 3.057x - 105.56
2012	20	0.999	0.38	3.83	y = 0.0001178181x3 - 0.0380x2 + 4.083x - 146.31
1992 – 2012	96	0.998	0.54	5.14	y = 0.0001000332x3 - 0.0311x2 + 3.241x - 112.78

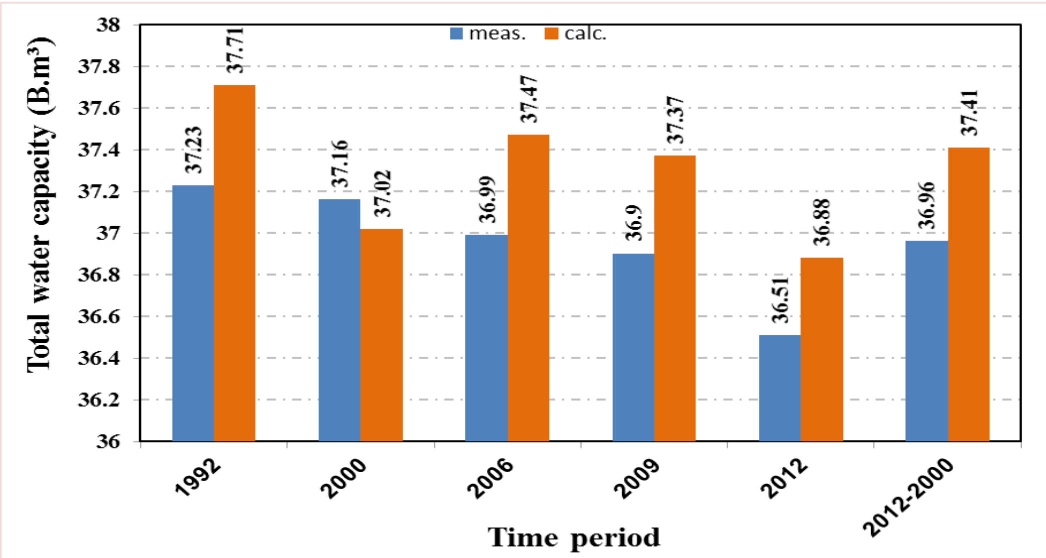

Figure 5. Total water capacity computed from the individual and collective rating curves at water level (175 m amsl).

As a quantitative indicator for above results; Figure 5 shows a comparison between the measured and the calculated water volumes from the developed rating curves equations at water level 175m amsl, as an example. It is clear that the computed and the measured volume values are almost equal which indicate the effectiveness of the developed (volume/ level) relationship using RS/GIS approach.

4.2.2 Area/ Level relationship

The area variations as a function of level changes is represented by a second – order polynomial relation. Samples of the derived relationships are presented in Figures 6a and 6b for the year 1992 and for all years from 1992 to 2012.

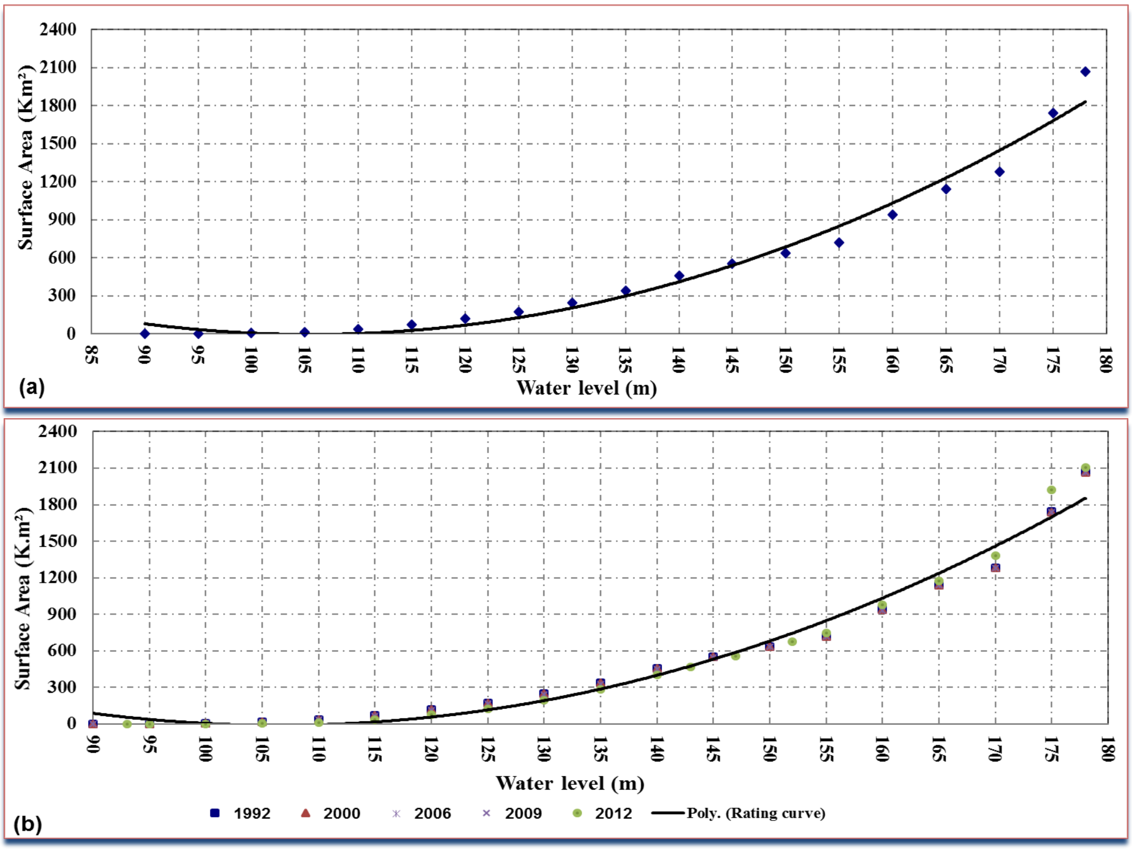

Figure 6. Sample results of the rating curves (area / level): (a) 1992 rating curve and (b) collective rating curve for the years (1992 to 2012).

Similarly, Table 3, presents the developed equations for the relationship between are and level for Lake Nasser for the years (1992, 2000, 2004, 2006, 2008, 2010 and 2012) and collectively for the period from 2000 to 2012. The values of R^2 are more than 0.97 while RMSE ranged between 10.64 to 15.51 km^2. The computed values of both R^2 and RMSE imply that the developed rating curves are reliable enough for detecting the water surface area changes from the level variations. The predicted surface area values using the developed equations are compared with the measured values as shown in Figure 7 for the lake water level of 175m.

Table 3. Evaluation of the developed relationships between water surface area and level for the period from 1992 to 2012.

Period of the estimated rating curve	Number of points	R^2	RMSE ($k.m^2$)	RMSE (%)	Rating curve equation (y = surface area in $k.m^2$ and x = water level in m)
1992	19	0.9791	13.42	2.42	y = 0.3491x2 - 73.685x + 3882.6
2000	19	0.9790	13.56	2.45	y = 0.3496x2 - 73.826x + 3891.7
2006	19	0.9793	13.07	2.37	y = 0.352x2 - 74.482x + 3932
2009	19	0.9794	12.94	2.35	y = 0.3532x2 - 74.798x + 3951.6
2012	20	0.9856	10.64	1.91	y = 0.4164x2 - 90.74x + 4913.5
1992 – 2012	96	0.9787	15.51	2.80	y = 0.3638x2 - 77.435x + 4109

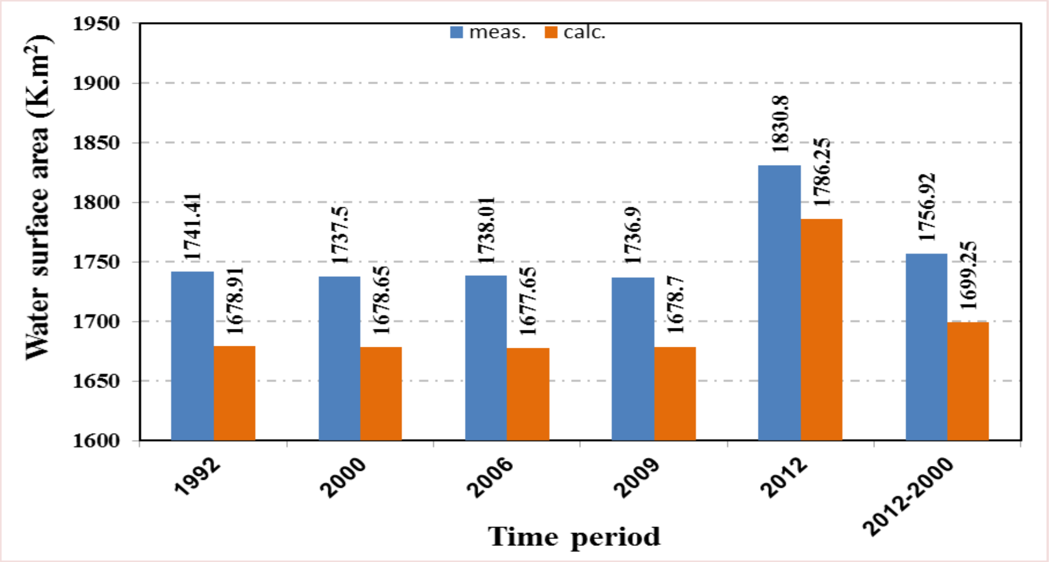

Figure 7. Water surface area computed from the individual and collective rating curves at water level (175 m amsl).

4.3 Application and Comparisons

Finally, both the estimated water capacity (volume) of Lake Nasser study area by both the developed rating curves (present approach) and the traditional method used by AHDA and NRI (reference method) for years 2000 and 2012 and the comparisons is presented in Table 4.

Table 4. Comparison of results between the present approach and the traditional method for estimating the water capacity of Lake Nasser study area for two years that have maximum errors

Year	Estimated water capacity using the developed rating curves ($B.m^3$)	Estimated water capacity by AHDA method ($B.m^3$), NRI (2012)
2000	37.017	37.46
2012	36.88	37.48

According to Table 4, it is clear that the present method underestimates the water capacity by a maximum of about 2.0 % for the entire years from 1992 to 2012. Consequently, the developed equations can be used efficiently to estimate the water volume of Lake Nasser instead of the costly measurements. Whereas, Field trips by AHDA and NRI should be repeated from time to another to update such equations and for other purposes as well.

5 CONCLUSIONS

To the best of the authors' knowledge, it is the first to use RS/GIS to develop the rating curves for (Lake Nasser). The developed rating curves include the relationships between volume and water level and the surface area and the water level. These relationships are developed for the years from 1992 to 2012 individually and collectively. The accuracy of the developed relationships is assessed by comparing the results with the field measurements and the existing rating curves for the lake. The RMSE ranged between 4-5% and 2-3% for (volume / level) relationship and (area / level) relationship respectively. Moreover, the coefficient of determination, R^2, value is more than 0.99 for (volume / level) relationship and is more than 0.97 for (area / level) relationship.

Overall, the obtained results confirming the potential applicability, and great efficiency of the RS/ GIS techniques for developing Lake Nasser rating curves. Also, field trips are necessary from time to another to collect data from the Lake to update these developed equations. The authors recommended to test the application of RS/GIS approach in estimating the water capacity variations of other storage lakes. Also, they highly recommend to test the applicability of using the RS/GIS approach to compute the sediment capacity in Lake Nasser.

ACKNOWLEDGMENTS

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ABBREVIATIONS

The following abbreviations were used in this study:

AHD Aswan high dam
AHDA Aswan high dam authority
AHDL Aswan high dam lake
amsl above mean sea level
$B.m^3$ Billion cubic meters
GIS Geographic information systems
$k.m^2$ Square kilometer
MAE Mean absolute error
Mes Measured
NRI Nile research institute
RBF Radial basis function
RMSE Root mean square error

RS Remote sensing

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