RESEARCHER

ESTIMATION OF EVAPORATION LOSSES FROM LAKE NASSER USING REMOTE SENSING AND GIS RASTER CALCULATOR MODEL

Hala M. Ebaid

Researcher, Survey Research Institute, National Water Research Center,
E-Mail:hala_sri@yahoo.com

ABSTRACT

Remote sensing and GIS technologies with aerodynamic principles have been integrated to estimate evaporation from Lake Nasser. The Moderate Resolution Imaging Spectroradiometer (MODIS), onboard the NASA Terra Earth Observing Satellites images have been used for surface temperature determining, specifically MOD11_L2, Land surface temperature (LST) image. Also a GIS Raster Calculator model technique for storing and processing the raster data, which applied Aerodynamic equations on 4 LST MODIS images, was used for evaporation calculation. Applying and rerunning the model on the four MODIS images showed that the evaporation rate varies from one month to the other throughout the lake, thus ranging from. 5-8 mm/day in February ,9-15 mm/day in May, 17-26 mm/day in August , and 9-12 mm/day in October. As for the evaporation values that represented the 4 seasons of this same year i.e. winter, spring, autumn, summer were 1.50, 2.67, 2.86 and 4.75 billion cubic meter respectively. Hence this summed up value of 11.78 billion cubic meter per year, obtained by applying this technique was slightly higher as compared to that obtained in the year 2005(10.58 billion cubic meter), using pan evaporation method. Evaporation using satellite imagery data, GIS model, and applying Aerodynamic principle could be a promising and reliable technique which is easy to handle and capable for aiding decision making.

KEYWORDS: Remote sensing, MODIS, lake Nasser

1. INTRODUTION

Lake Nasser is the second largest man-made lake in the world, extending from the southern part of Egypt to the northern part of Sudan, about 500 km length, and 6000 km^2 surface area. The level of water oscillates between 147 to 182 meter above the sea level during a year, and from year to year. It is, the water bank of Egypt, contains about 162 billion cubic meters from fresh and renewable water. The lake is surrounded by empty flat desert were the nominal annual insulation is more than 2500 kWh/m^2. The water loss from the lake is one of the national problems. The evaporated water loss ranges between 10 to 16 billion cubic meter every year, which is equivalent to 20 to 30% of the Egyptian income from Nile water (Shaltout,1997).

Many theories and formulas have been developed to obtain accurate estimates of lake evaporation. Common equations describing evaporation are the Penman, Hargreave's, and Hamon's equations. Although these methods are simple ,still yet less accurate results are obtained (Salas,2004). Later , (Shaltout,1997) used Meteosat infra-red window(10.5 – 12.5 um) observations and the empirical models, estimated the evaporated water every day and determined the yearly water loss from the integration of daily values .Nevertheless the Bulk-Aerodynamic Method that utilizes the skin temperature of water, relative humidity, wind speed, and air temperature to estimate evaporation, from Aster images of Elephant Reservoir in New Mexico was carried out by (Herting ,et.al., 2004) and that method shows different temperature of 1.7° Celsius ,and about 1.2426 mm/day evaporation rate difference, between Aster image and measured value at certain point in December through the elephant lake which is considered as a good results. From that, one can say that remote sensing shows promising results.

The objective of this present study is to calculate evaporation loss from lake Nasser using MODIS Satellite image , and GIS spatial analyst model to process surface temperature image values of the lake by applying Bulk aerodynamic principle and automatically calculate evaporation rate per day and the yearly water loss from the integration of daily values using a chain group of raster calculator tools. By this way ,advantages in use of satellite thermal data and GIS spatial model for evaporation calculation are gained.

2. METHEDOLOGY

The research in this paper developed a remote sensing and GIS model to estimate evaporation loss from Lake Nasser. The model uses the energy balance principle (Aerodynamic equation) which utilizes the skin temperature of water data to measure evaporation depth (mm/day) and water loss in billion cubic meters per year. The evaporation depth has a moderate spatial resolution (1000 m by 1000 m). The model is developed in GIS spatial analyst model builder environment, and process 4 MODIS satellite images as representation for all year surface temperature (Mod11_L2 LST raster data), besides utilizing the weather stations data (Air temperature, wind speed, and humidity). The model first calibrates digital image data using raster calculator tool to obtain LST in C˚ and after that utilized Aerodynamic equations on LST Raster data with all necessary meteorological parameters and finally calculate evaporation rate in mm/day and then integrate daily values to get the yearly water loss ,and rerun the model four times for the four months , and then calculate total evaporation in billion m^3/year .

3. STUDY AREA

Lake Nasser is extending from the southern part of Egypt to the northeast part of Sudan and the research area of interest of the lake cover Egypt only. Lake Nasser area (Fig.1) extends along the eastern desert. Its length is about 500 kilometers, its maximum width is 35 kilometers. The total area surveyed is approximately 50,000 feddans. In general the geographic boundary area lies between latitude 21° and 24° 30 north and longitude 31° 30 and 33° east.

4. DATA AND APPROACHES

4. 1 Satellites Data:

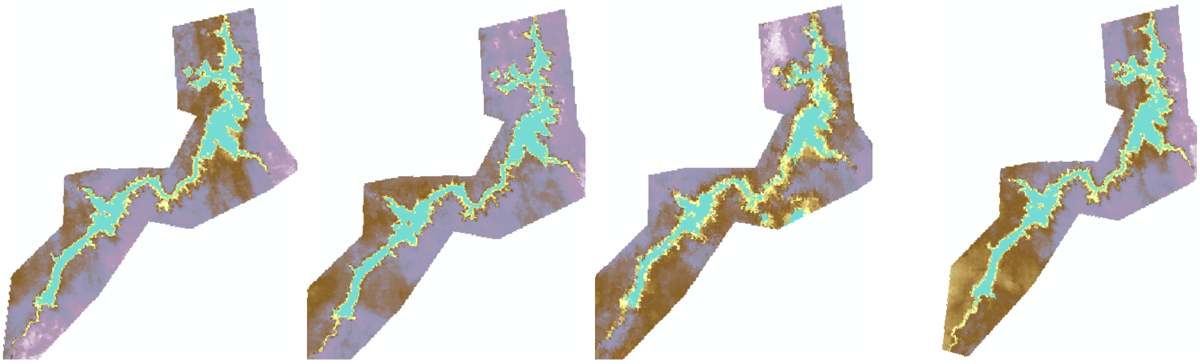
MOD11_L2 are stored in the Hierarchical Data Format "HDF-EOS".In each product file, the parameters are written as science Data Sets "SDS". The parameter LST are scaled to integer to reduce file size , the scale and offset values are provided as SDS attributes to convert back to actual data value ,the following equation are used to convert stored values back to actual data:.
Data values (calibrated) = scale factor* (stored numbers-offset)
MOD11_L2 is retrieved using a generalized split-window algorithm by MODIS land team (Wan and Dozier,1996).Meteorological, hydrological, and agricultural research communities require an accuracy of 0.5-2 ˚C for LST retrieved from satellite observations at 1-10 km spatial resolution (GCOS,2006) ,and MOD11_L2 products have been validated in previous studies and reported to be 1˚C .

In this research four scenes of MODIS images are obtained as shown in Fig.1, from MODIS products through (http:// nasa.gov) via search tool.

Fig. 1. Photo image for part of Lake Nasser & MOD11_L2 (LST raw data, Aug. /2006).

Table 1. Satellite images information

Image type	Acquired date	Cloud percentage	Time/DAY	Scale factor/ Offset	Spatial/Temporal resolution
MOD11_L2.5	22 -2-2006	Less than 5%	9 am /D	0.02/0.0	1km at nadir /5 min.
MOD11_L2.5	6 -5- 2006	Less than 17%	9 am /D	0.02/0.0	1km /5 min.
MOD11_L2.5	4 -8-2006	Less than 10%	9 am /D	0.02/0.0	1km at /5 min.
MOD11_L2.5	6 -10-2006	Less than 4%	9 am /D	0.02/0.0	1km at /5 min.



Feb. 2006 LST | **May 2006 LST** | **Aug. 2006 LST** | **Oct. 2006 LST**

Fig. 2. MOD11_L2 (Raster LST after mask extraction process for different months)

4.2 Meteorological Stations Data

The stations are distributed and centered on the middle part of the lake as seen in Fig. 3. Average calculations per month have been made for the meteorological parameters of the stations that are utilized in the Aerodynamic equations, and have been tabulated as follows.

Table 2. Local station parameters around the lake

Date	Average air temperature (C Deg)	Average Wind speed (m/s)	Average Relative Humidity (%)	Average BP (mbar)
2-2006	21.086	3.164105	31.238	922.6911
5- 2006	31.375	3.534	19.019	928.926
8-2006	36.0638	3.8	17.7517	917.4539
10-2006	28.6381	3.269	28.267	928.453

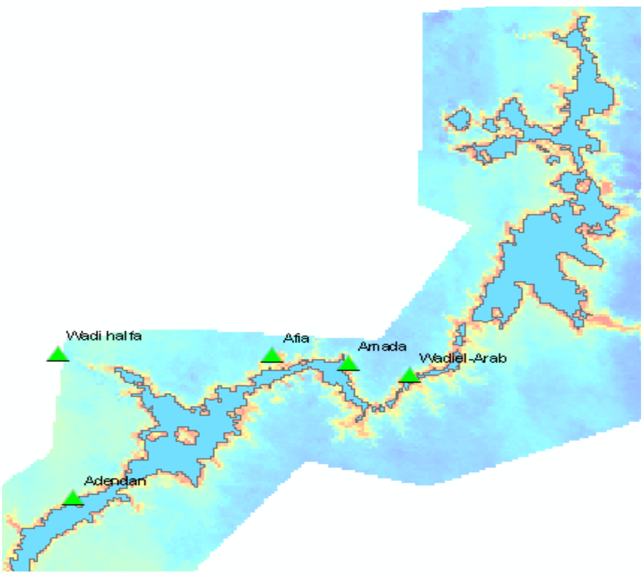


Fig. 3. Meteorological stations distribution around lake Nasser

4.3 Applied Evaporation Method

Aerodynamic Equations:

$$E = K_E U(e_s - e_a)(86.4 * 10^6) \qquad (1)$$

$$e = e_s(R_H)/(100) \qquad (2)$$

Where K_E is determined as follows:

$$K_E = \frac{0.622\rho_a \times (0.4)^2}{P\rho_w \left[\ln \left\langle \frac{z_m - z_d}{z_0} \right\rangle \right]} 2 \qquad (3)$$

Saturation vapor pressure, es, of the air is a property that is dependent on temperature and was estimated by polynomial function (Lowe, 1977). Water surface temperature or “skin” temperature was used to determine the saturation vapor pressure at the water surface. Vapor pressure of the air was determined by multiplying relative humidity with saturated vapor pressure. In this case, saturated vapor pressure of air was determined by using the air temperature (all parameters are defined in the list of symbols paragraph).

$$e = \frac{a_0 + T(a_1 + T(a_2 + T(a_3 + T(a_4 + T(a_5 + a_6 T)))))}{10} \qquad (4)$$

5. PROCESSING WORK FLOW

1- The MODIS satellite raster data are produced in HDF format which cannot be used in GIS environment so it needs a conversion tool to convert the HDF format to GIS format (Geo_TIFF) in order to process the data. The HDF-EOS to GeoTIFF Conversion tool (HEG) can be provided from the internet for free, and it needs special installation instruction to work. It has a graphical user interface, Fig. 4, which uses Java Swing technology. The main purposes of this tool are:
a- Create files that are more useful and informative (GeoTIFF format).
b- Reproject the image to UTM - WGS 84 projection .
The HEG tool works specifically on HDF-EOS Swath and Grid objects.

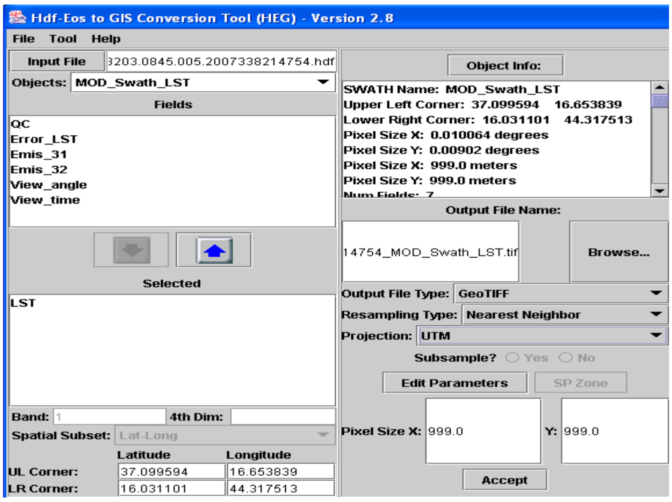


Fig.4. GUI of the HDF-EOS to GeoTIFF conversion tool (HEG).

2- Digitizing vector layers for the four raster LST scenes (August_LST, February_LST ,May_LST, October_LST) which are needed for the evaporation calculation for the lake area as shown in Fig. 5 .

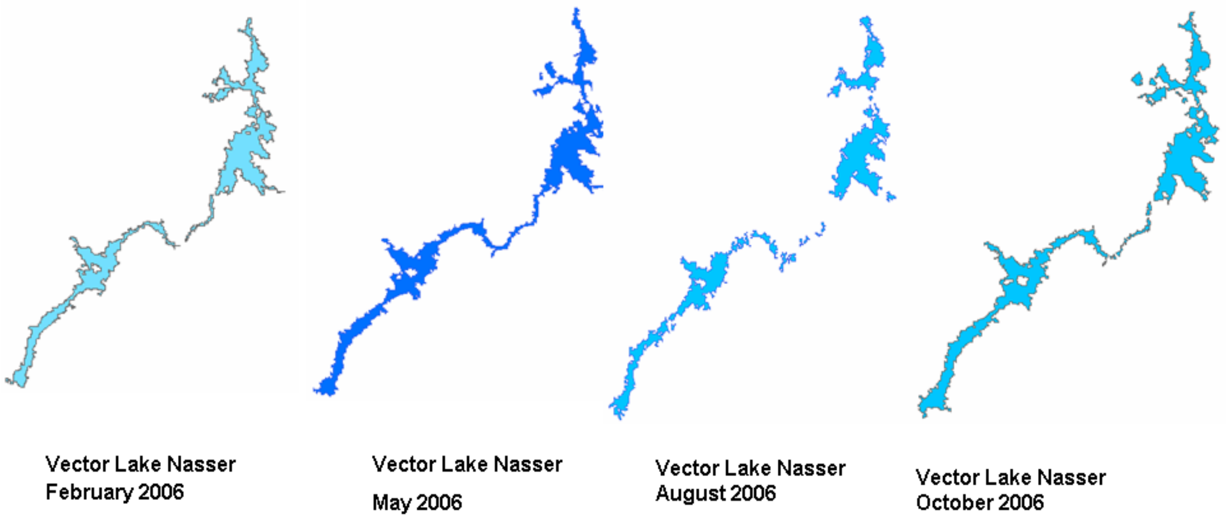


Fig. 5. Four polygons for Lake Nasser digitized from MOD LST images.

3- Preparing logical flow diagram of the GIS model, which utilizes Aerodynamic method on MOD_LST raster data that calibrate and manipulate Lake Nasser raster data from row data stage until yearly evaporated loss calculation stage**.**

4- Running every Raster Calculator tool inside the model builder individually to check the performance and the output raster data see Fig. 6.

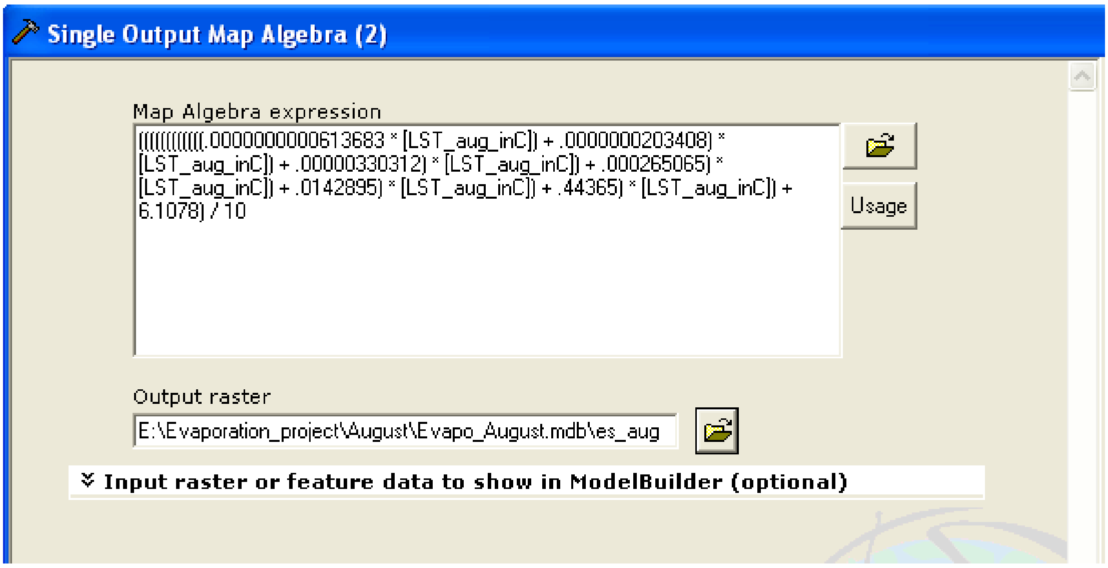


Fig. 6. Applying equation in raster calculator tool.

5- Running the spatial analyst model as one operation as shown in Fig. 7, taking into consideration that the model should be interactive, enabling decision-makers to modify the parameters and data used, and can be re-run to evaluate the new evaporation rate results regarding different months and different meteorological stations data . The entire Evaporation model runs in 3-6 minutes depending on the speed of the processor and tool complexity.

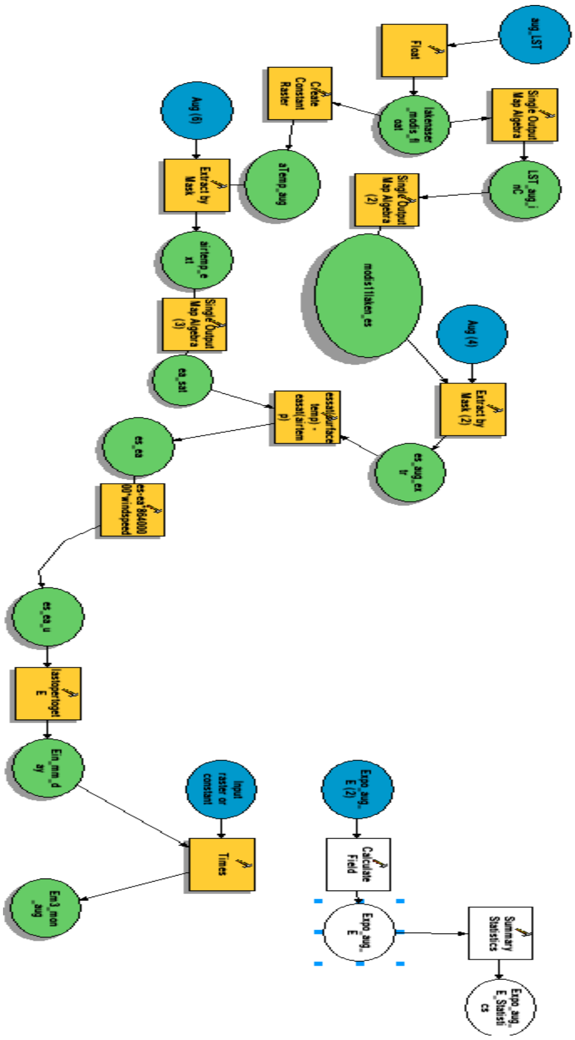


Fig. 7. Aug. evaporation rate calculation model.

6. RESULTS AND DISCUTIONS

From the research work the resulted approximated evaporation losses per year was 11.788 billion m3/year in 2006 which resulted by integrating the 4 season's evaporation values, the yearly evaporated losses was calculated as follows:

1-Multiply the resulted evaporation rate (which resulted by applied evaporation method Aerodynamic equations) by factor to change mm/day to m/3month (for specific season).

2- Multiply the above resulted value by Lake Nasser's specific area for specific month (lake Nasser's area change from month to month) and finally get the season losses m^3/3 months (season) and integrate the 4 seasons losses to get the yearly value and this value is considered as approximated value and may be slightly bigger than the value calculated by pan method in year 2006 for the previous mention approximation. The model results for the 4 months are indicated in Table 3.

Table 3. Evaporation rate results

Month-year	Evaporation rate in mm/day	Evaporation in m^3/month
5-2006	9-15	892307021
8-2006	17-26	1582514569
10-2006	9-12	953955836
2-2006	5-8	500636267.7
Evaporation/year = 11.788 billion m^3/year		

Some aspects have been considered when calculating the evaporation for Lake Nasser:

- There are many assumptions that go into these calculations ,i.e. the wind speed used is assumed to be constant throughout the lake, which it is not, and consider wind speed at 2 m above the lake water surface which may be slight different.
- Also, we apply the monthly average value for air temperature, and relative humidity (%) which is derived from weather stations around the lake , and that is for simplicity but we have to consider the variation of air temperature and relative humidity for all day time for all month , which means that the measured bulk-aerodynamic method had many measured points at different times of the day, while MODIS image used was at only one time. Also the geographic distribution of meteorological stations, which lies on the lake center is fitting for the parameters average calculations
- Another approximation is the calculation of evaporation loss per year depends only on 4 months which represent the four seasons (spring, summer, autumn, winter) and multiply evaporation loss per specific month by 3 to get the evaporation rate per season and integrate the results of four seasons evaporation to get the evaporation loss per year .
- For Evaporation calculation for Lake Nasser area ,we need to determine the exact pixels which cover the lake for digitizing for accurate processing work ,and this is difficult due to: 1)low spatial resolution and 2)shortage information about local surface temperature through the lake for evaluation purpose, and this issue can be solved by careful digitizing for all closed tone colors of the pixels carrying the LST digital values as indicated in Fig. 8. , depending on the fact say that the surface temperature through the lake has slight different in specific time and date as indicated in Fig. 9. , Table 4.

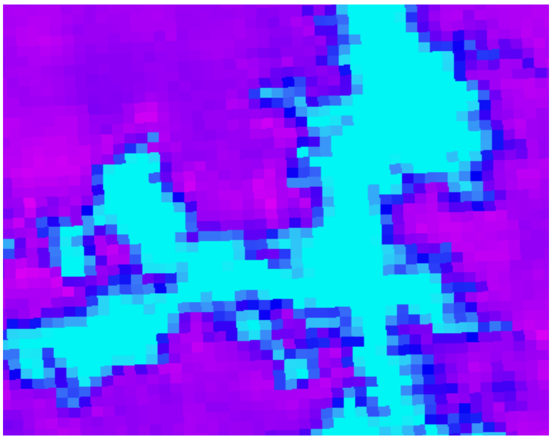


Fig. 8. Closed tone color of pixels carry LST values for August scene

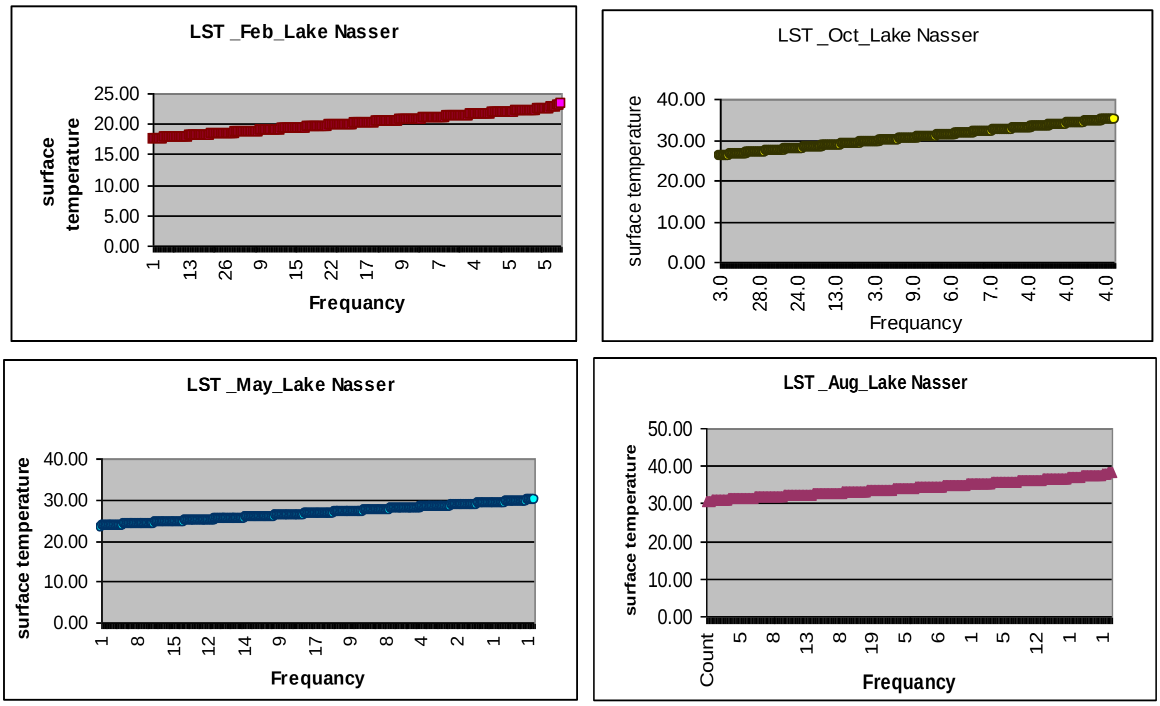


Fig.9. Surface temperature of lake Nasser in (Aug., Feb., Oct., May.)

Table 4. Land Surface Temp. Statistics of Lake Nasser for different months

Month	Minimum Surface temp.	Maximum Surface temp.	Mean Surface temp.	Time
October	25.77	30.51	28.140235	9 O'clock/Day
May	23.35	30.09	26.537279	9 O'clock/Day
August	30.51	38.5499	34.2127	9 O'clock/Day
February	17.38999	23.1299	19.984466	9 O'clock/Day

From the above illustration it can be deducted that evaporation estimates are very useful for practical applications and research. The bulk-aerodynamic method is very promising, and seems to also be the best fit for estimating evaporation using satellite imagery. Further research and data collection are recommended to continue with the progress that has been made and all previous approximation can be manipulated and treated with more investigation and gathering more data.

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LIST OF SYMBOLS

E = evaporation rate [mm day^{-1}]
K_E = coefficient [kPa^{-1}]
u = wind speed measured at 2 m above the surface as standard [m s^{-1}]
e_s = saturation vapor pressure at the water surface [kPa]
e_a = vapor pressure of the air above the water surface [kPa]
K_E = coefficient of efficiency of vertical transport of water vapor by eddies of the wind [kPa^{-1}]
ρ_a= density of air [1.220 kg m^{-3}]
ρ_w = density of water [1000 kg m^{-3}]
P = atmospheric pressure [kPa]
Z_m = height at which wind speed and air vapor pressure are measured [m]
Z_d = zero-place displacement [m]; Zd = 0 over typical water surfaces
Z_o = roughness height of the surface [m]; $Z_0 = 2.30 \times 10^{-4}$ m over typical water surfaces
es = saturation vapor pressure [kPa]
T = temperature [ºC]