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ESTIMATION OF EVAPORATION LOSSES USING REMOTE SENSING TECHNOLOGY

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الملخص:
تعتير مصر من أحدى الدول التي تواجه التحديات نتيجة مواردها المائية المحدودة. فبحيرة ناصر تعتبر المصدر الرئيسى للمياه العذبة وفواقد البخر منها له تأثير مباشر فى الميزان المائى. لذلك فإن الحسابات الدقيقة للبخر ضرورية للإدارة المتكاملة للموارد المائية. الهدف من هذا البحث هو حساب معدلات التبخر الشهرية بإستخدام تقنيات الإستشعار عن بعد ونظم المعلومات الجغرافية. ولتحقيق هذا الهدف تم تطبيق طريقة (SEBS) وإستخدام صور الأقمار الصناعية المأخوذة من Terra MODIS لسنوات 2006 و 2012. بالإضافة إلى ذلك، تم استخدام بيانات صور نموذج (MOD16) الخاصة بحوض النيل لتقدير التوزيع المكانى لمعدلات التبخر الشهرية بالبحيرة لأعوام 2006, 2010 و 2012.
تمت معالجة صور الأقمار الصناعية بإستخدام نظم المعلومات الجغرافية ومقارنة نتائجها مع معدلات التبخر المحسوبة من بيانات محطات الأرصاد الجوية الموجودة بالبحيرة والتابعة لهيئة السد العالى. وقد أظهرت نتائج التحليل الإحصائى بإستخدام برنامج (SPSS 22.0) وجود علاقة قوية بين نتائج البخر(SEBS) و(MOD16) مما يشير الى إمكانية إستخدام إحدى الطريقتين لتقدير معدلات التبخر.

ABSTRACT
Egypt is one of the countries facing challenges due to its limited water resources. Lake Nasser is a man-made fresh water reservoir and its evaporation losses are an important contributing factor to the lake water budget. Although, no universally recognized method is known for evaporation estimation, reliable evaporation data are necessary for efficient management of the reservoir and the scare water resources. The aim of this research is calculating monthly evaporation rates using Remote Sensing (RS) and GIS techniques. The study applied Surface Energy Balance System (SEBS) method using Terra Moderate Resolution Imaging Spectroradiometer (MODIS) satellite earth observation data for the years 2006 and 2012. Additionally, remote sensing ET product from the MODerate Resolution Imaging Spectrometer (MOD16) at years 2006, 2010 and 2012 were used to determine the monthly spatial distribution evaporation rates at Lake Nasser. The results were processed using ARC-GIS software. The evaporation rates calculated from HADA data were compared with SEBS and MOD16 estimation. High correlation between SEBS and MOD16 was found by using IBM SPSS 22.0 software package, which gives a good indication of the use of only one method to estimate the evaporation rates.

Key words: Evaporation rate, Remote Sensing, SEBS, MODIS, MOD16.

INTRODUCTION

The accurate estimation of evaporation losses from surfaces (especially with huge surface area as Lake Nasser) plays an important role in monitoring and management of water resources.

Remote sensing considered one of the most feasible means to monitor inaccessible areas to provide spatial distribution of evaporation over large areas in a cost-effective manner at different scales. The data from polar-orbiting satellites provide spatially and temporally continuous information over vegetated and water surfaces useful for regional measurement and monitoring of surface biophysical variables affecting ET estimation in near real-time. Varies and wide range of satellite platforms (such as: Landsat, AVHRR, ASTER and MODIS) can be used in environmental dynamics studies (Chinyepe, 2010)**.**

Remote sensing techniques produce spatial and temporal variation of ET from catchment to various scales. (Courault, et al., 2005) , (Nouri, et al., 2013) classified Remote sensing techniques used to estimate ET into four categories. (1) The empirical direct methods utilize the data from remote sensing entered directly in semi-empirical models. (2)The vegetation index methods (inference methods) depend on calculating reduction factor for actual evapotranspiration estimation using remote sensing. (3)The deterministic methods use remote sensing data either as the input parameters for complex models, or in assimilation procedures retrieve adequate parameters for ET estimation. (4) The residual methods of the energy budget (SEB models) combining some empirical relationships and physical modules. The SEB algorithms comprise one-source models, such as: the Surface Energy Balance Index (SEBI), the Simplified-Surface Energy Balance Index (S-SEBI), Surface Energy Balance Algorithm for Land (SEBAL), Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC), Surface Energy Balance System (SEBS), and multi-source models, such as: TSEB and SEB-4S.

Remote sensing data combined with varies techniques have been studied by many researchers such as: (Ramoelo, et al., 2014) evaluated the quality of global evapotranspiration product (MOD16) using two eddy covariance flux towers data in the African Savanna, South Africa. Also, (Zhang, et al., 2015)used (MOD16) and (MOD17) data to evaluate eight-day and annual water use efficiency values in China against eddy covariance-measured.

More accurate sensible and latent heat estimation proved when (Zhuang, et al., 2014) applied improved TSEB combined with ASTER images and meteorological data by to estimate the surface energy fluxes in the Heihe River Basin in the arid northwest region of China. (Xiong, et al., 2008) calculated ET for Jing River basin using three-temperature model (based on surface energy balance) with remote sensing data to used it at large catchment scale. (Jin, et al., 2005) , (Wang, et al., 2008) , (Chinyepe, 2010) and (Sharma, et al., 2016) applied SEBS algorithm combined with remote sensing data to estimate surface energy balance component and daily evaporation.

Meanwhile, evaporation estimation losses from Lake Nasser have been studied by many scientists, (Abou El-Magd, et al., 2012)Applied SEBAL algorithm using satellite images of (NOAA-AVHRR) for year 2008 and the resulted maximum and minimum evaporative losses from the lake were 16.3 and 12.5 BCM/year. Beside (Hassan, 2013) who applied the same algorithm using Landsat TM spectral and metrological recorded data for selected days from October 1998 to October 2000, the estimated evaporation rate was 7.15 and 5.80 mm/d at 15-Oct-1998 and 17-Mar-2000 respectively.

The main objective of this research is to calculate the monthly evaporation rate of Lake Nasser; in an accurate, reliable and cost effective manner. To achieve this goal the following algorithm was applied: (i) Terra MODIS images were downloaded and ILWIS software used with SEBS algorithm and GLDAS atmospheric data. (ii) Monthly MOD16 product images for Nile Basin region were downloaded and processed using ARC GIS. (iii) Finally, the resulted evaporation rate (mm/d) compared with HADA calculated value.

STUDY AREA DESCRIPTION

High Aswan Dam Reservoir lies between 23°58'N at the High Aswan Dam and 20°27'N at the Dal Cataract in the Sudan and between longitudes 30°07'E and 33°15'E. It's designed to have a maximum water level 182 m above (MSL). At this level, the reservoir has a length close to 500 km (about 335 km within the Egyptian borders and 165 km inside the Sudanese borders), average width about 13 km , surface area of about 6500 km^2.

Seven meteorological stations operated by High Aswan Dam Authority (HADA) covering Lake Nasser in Egypt, as shown in figure1, to monitor the lake meteorologically. These stations are: Raft, Khor Kalabsha, Khor Allaqui, Amada, Toshka, Khor Toshka and Abu Simble. The hourly measured data from these stations are used by HADA to calculate the evaporation rate using *Harbeck equation*:

$$Eh = N * U * (e_{sw} - e_s)$$

Where: (Eh) is the evaporation rate using Harbeck (mm/ hr) , (N) is Lake Nasser Coefficient (0.0525), (U) is the wind speed at 2m above the water (m/s), (e_{sw}) is the saturated vapor pressure of air at water surface temp (kpa) , (e_s) is the Actual vapor pressure of air at 2m above the water.

Figure 1 The study area and the distribution of HADA metrological stations

METHODS AND DATA SOURCE

SEBS Model:

(SEBS) is a single-source surface energy balance model, and uses the satellite earth observation data in combination with meteorological data (either in-situ measurements or meteorological forecasts for larger scales) to compute atmospheric turbulent fluxes (sensible and latent heat fluxes) (Z. Su 2002). SEBS requires three types of input data: (1) Remote sensing data to calculate surface roughness parameter [albedo, emissivity, temperature and Normalized Difference Vegetation Index (NDVI)] (2) Meteorological data as : air temperature, air pressure, relative humidity and wind speed (3) Radiation data as downward solar radiation.

The SEBS equation which is provided by (Z. Su 2002) to estimate the evaporation is written as:

$$R_n = G_0 + H_{wet} + \lambda E_{wet}$$

Where: (R_n) is the net radiation (G_0) is the soil heat flux (H_{wet}) is the turbulent sensible heat flux (λE_{wet}) is the turbulent latent heat flux (λ is the latent heat of vaporization and E is the actual evapotranspiration). Based on the energy partitioning under dry and wet limit conditions, (Jin, et al., 2005) evaporative fraction (EF) and daily evaporation (E_{daily}) is calculated using SEBS methods as follow:

$$EF = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}}$$

$$E_{daily} = 8.64 \times 10^7 \times \Lambda_0^{24} \times \frac{R_n - G_0}{\lambda \rho_w}$$

Where: (H_{dry})is the sensible heat flux at the dry limit (H_{wet}) is the sensible heat flux at the wet limit (Λ_0^{24}) is the daily evaporative fraction (ρ_w) is the density of water.

SATALITE IMAGE DATA:

MODIS (**Mod**erate **R**esolution **I**maging **S**pectroradiometer) is a sensor onboard of the two NASA satellite platforms “TERRA” and “AQUA”. MODIS Terra is at an altitude of 705 km and has a cross track and along track swath of 2.330 km and 10 km respectively, with a global coverage every 1 to 2 days. It has 36 spectral bands between 0.405 and 14.385 µm, it obtains data at three spatial resolutions (250m, 500m and 1000m).

Twenty four images (one image per month to represent it) for years 2006 and 2012 are Downloaded in "HDF" format from NAS`s Level 1 and Atmospheric Archive and Distribution System (LAADS).

HDFView 2.11, ModisSwath Tool and ILWIS are open sources software used to deal with the download image (Projection, conversion and preprocessing) to get the daily evaporation rate. Figure 2 shows the flowchart illustrate simply the processing of MODIS for SEBS algorithm. Twenty four GLDAS (Global Land Data Assimilation System) open-access database are used to provide the metrological input data{downward solar radiation (Watts/m^2), specific humidity (kg/kg), air temperature (Celsius), Wind speed (m/s), Pressure at reference height (Pa)} needed by SEBS to calculate evaporation rate.

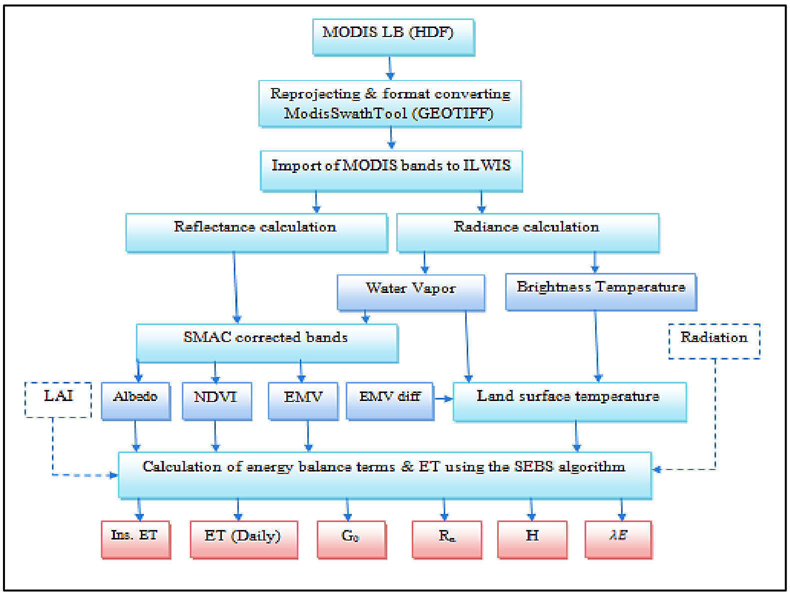

Figure 2 Flowchart for the processing of MODIS for SEBS algorithm

MOD 16 Global ET:

MOD16 ET is part of NASA/EOS project to estimate global terrestrial evapotranspiration from earth land surface using satellite remote sensing data. It provides key information for water resource management. It is available since 2000 up to 2013. The ET algorithm is based on the Penman-Monteith equation:

Thirty six MOD16 ET image for years 2006, 2010 and 2012, with monthly temporal resolution and 1 km spatial resolution, were acquired from the University of Montana's Numerical Terra dynamic Simulation. The evaporation rate was extracted from each pixel of the MOD16 ET images using ArcGIS 10.1 after multiply by 0.1.

RESULTS AND DISCUSSION

MOD 16 ET:

Thirty-six MOD16 ET images with monthly temporal resolution were downloaded for years 2006, 2010 and 2012 then processed using Arc GIS. Figure 3 present the evaporation rates (mm/d) for the selected years and table1 summarizes the resulted monthly evaporation rate (mm/d) and volume (Mm^3).

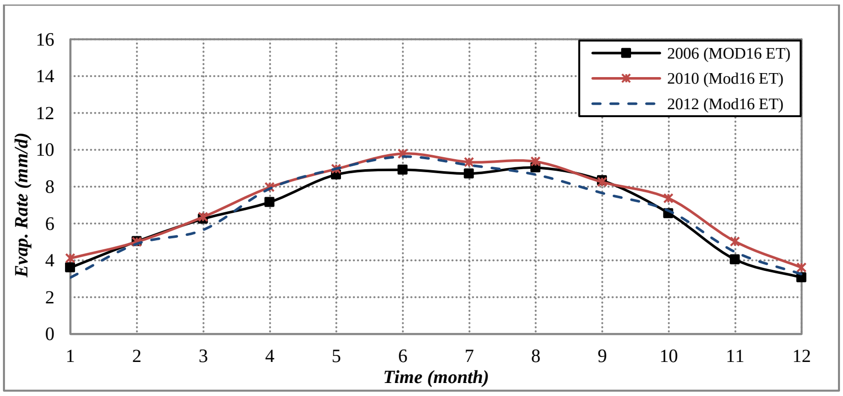

Figure 3 Evaporation rate for 2006, 2010, 2012 using MOD16 ET

Table 1 the estimated monthly evaporation rate and volume using MOD16 ET product

Months	2006 (MOD16 ET)		2010 (MOD16 ET)		2012 (MOD16 ET)	
	Evap. Rate (mm/d)	Evap. Volume (Mm^3/month)	Evap. Rate (mm/d)	Evap. Volume (Mm^3/month)	Evap. Rate (mm/d)	Evap. Volume (Mm^3/month)
1	3.601	730.013	4.109	715.921	3.063	533.360
2	5.025	790.260	4.999	785.550	4.895	769.816
3	6.247	1087.634	6.357	1106.594	5.655	984.584
4	7.159	1206.239	7.964	1341.605	7.893	1329.843
5	8.651	1506.162	8.958	1559.544	8.973	1562.299
6	8.911	1501.375	9.788	1649.086	9.627	1622.066
7	8.708	1516.124	9.331	1624.514	9.164	1595.302
8	9.028	1571.762	9.354	1628.601	8.649	1505.866
9	8.328	1403.197	8.244	1388.998	7.647	1288.411
10	6.552	1140.687	7.356	1280.710	6.680	1125.544
11	4.038	680.393	5.016	845.014	4.446	749.033
12	3.059	532.448	3.600	626.669	3.239	563.853
Average	**6.528**		**7.033**		**6.616**	

From table 2 and figure 3 it is noticed that: the maximum evaporation rate was 9.788 mm/d at June 2010 with evaporation volume 1649.086 Mm^3/month and the minimum rate occurred at December 2006 with evaporation volume 532.448 Mm^3/month. The evaporation rate at year 2010 is higher than the others. The difference between average evaporation rate for the three years are not more than 0.5mm/d and there is not considered statistically significant differences between evaporation rates for each month. Figure from 4 to 7 illustrate seasonal spatial distribution of evaporation rate along the reservoir for year 2010. It is observed that the evaporation rates are higher in the middle (deeper) than the border.

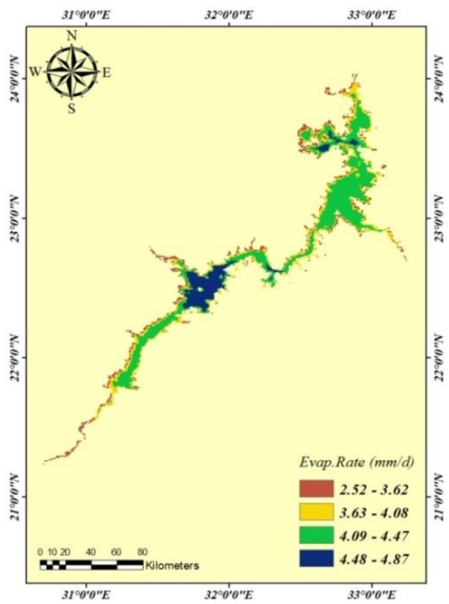

Figure 4 Evap. Rate at Jan.2006

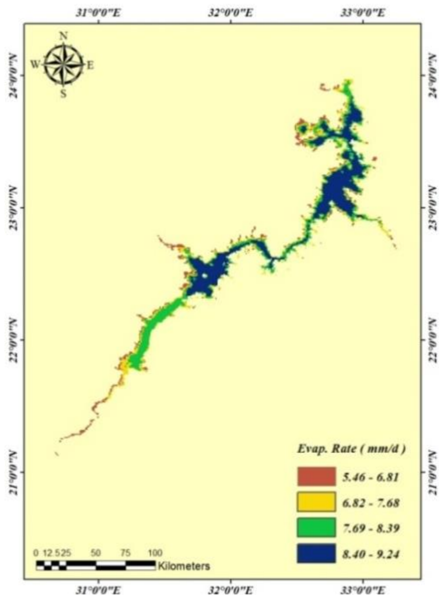

Figure 5 Evap. Rate at April. 2006

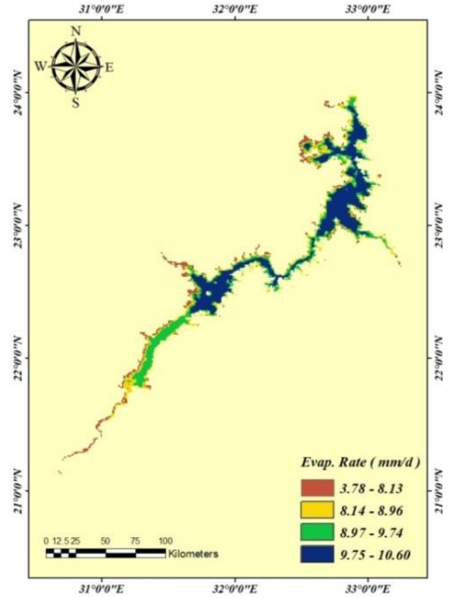

Figure 6 Evap. Rate at August.2006

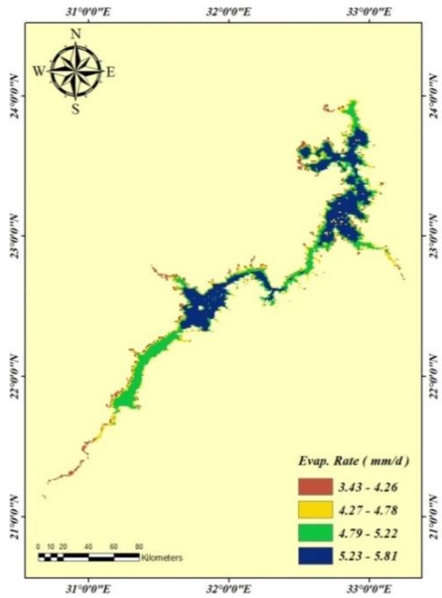

Figure 7 Evap. Rate at November.2006

SEBS results:

SEBS is integrated in ILWIS to derive daily evaporation rate using images from MODIS for years 2006 and 2012. It can be observed from figure 8 that June 2006 recorded the maximum evaporation rate of 8.40 mm/d while the minimum was 3.11 in January 2006. The evaporation rates ranged from 3.11 to 8.40 mm/d and averaged 6.29 mm/d during the study period. Figures from 9 to 12 show the monthly distributed evaporation rate along the lake.

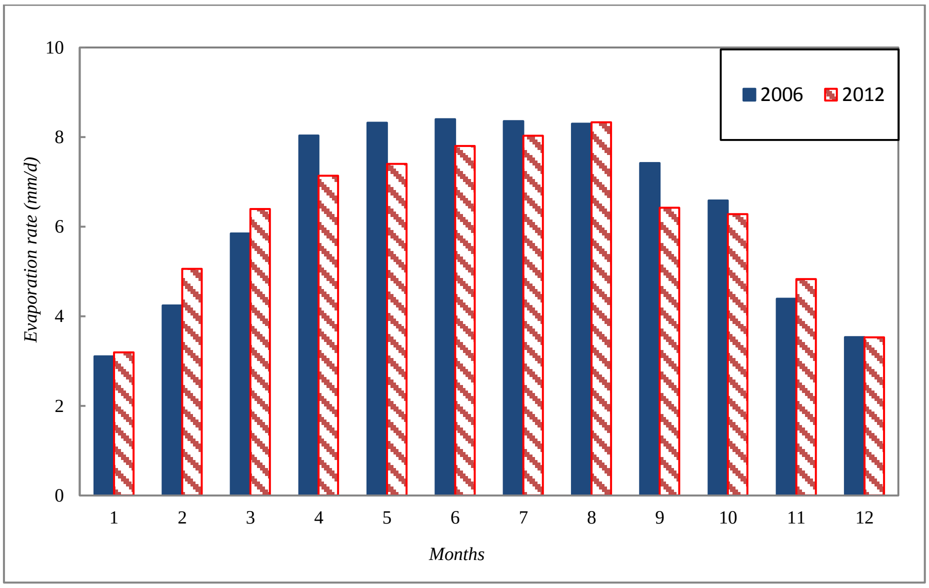

Figure 8 Calculated monthly evaporation rate using SEBS for years 2006, 2012

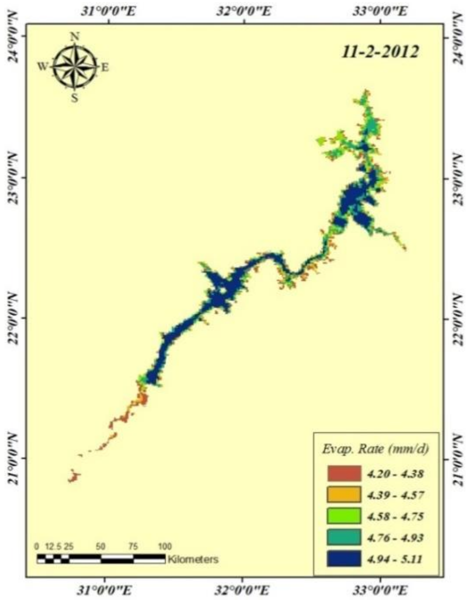

Figure 9 Evap. Rate at Feb. 2012

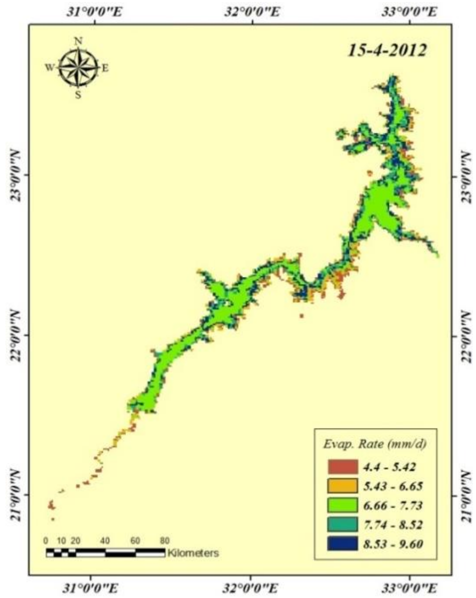

Figure 10 Evap. Rate at April 2012

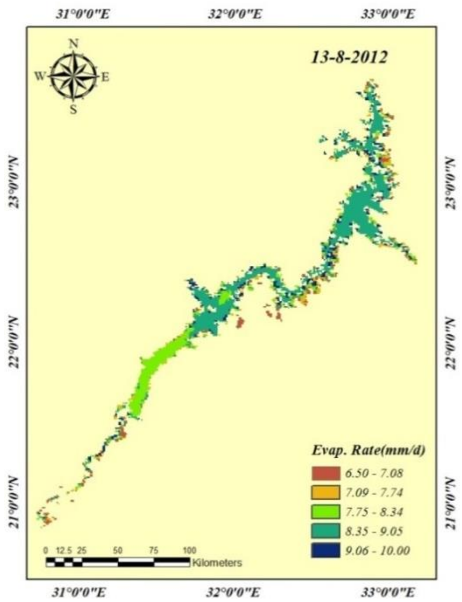

Figure 11 Evap. Rate at August 2012

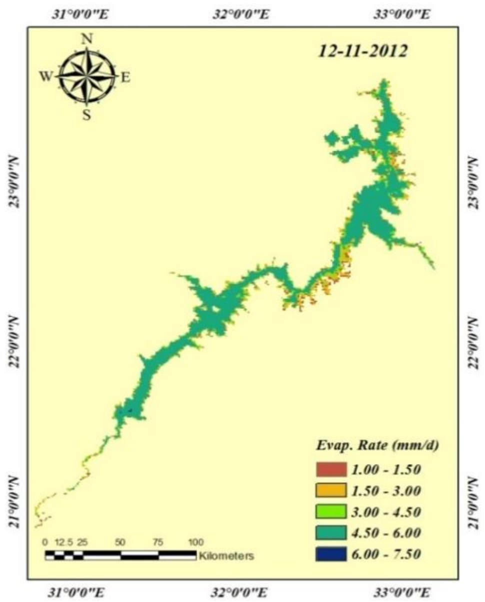

Figure 12 Evap. Rate at November 2012

Comparisons between Different Methods:

We compared resulted evaporation rate from the above methods with the calculated one by HADA and figure 13 presented the result for year 2006. It can be noticed that there is closed correlation between SEBS and MOD16 ET (both use satellite images data to provide evaporation rate). Also, by using SPSS 22.0 software package, a high correlation was found between SEBS and MOD16 ET (R^2=0.969 and $P<0.01$), that give good indication of the use of only one method to estimate the evaporation rates. There is a good correlation also between HADA calculation and MOD16 ET estimation at years 2010 and 2012 (R^2=0.641, R^2=0.746 and $P<0.01$).

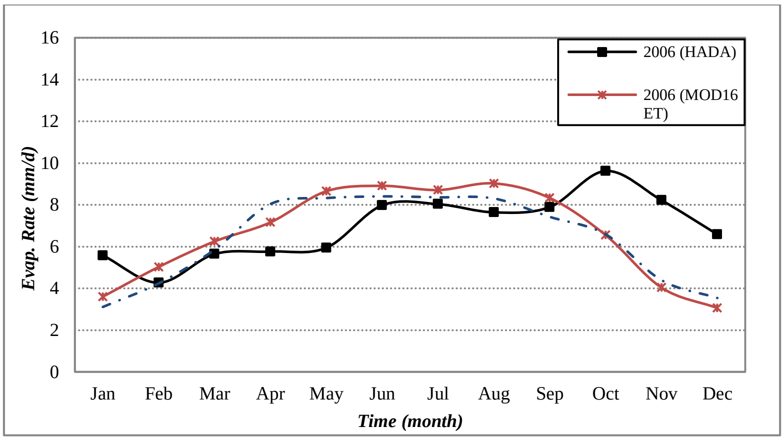

Figure 13 Comparison between the resulted evaporation rates for year 2006

CONCLUSION

Monthly evaporation rates are estimated using different methods and compared with HADA results and other studies. MOD16 ET product provided spatial distribution of evapotranspiration along the lake at 8days; monthly and annual interval form 2000 to 2013 with resolution 1km which is not enough for daily monitoring and long term studies. SEBS algorithm gives a high correlation with MOD16 ET and good correlation with HADA estimations. In spite of the metrological stations along the lake reflect the actual atmosphere and the measured parameters are more reliable to be used to calculate evaporation losses but it didn't cover the whole surface area of such huge lake. Accordingly, applying energy balance algorithms (SEBS) based on remote sensing data is an effective alternative approach to estimate the near real-time evaporation from Lake Nasser directly as the residual of the energy balance; it provides spatial and temporal quick reliable distribution of evaporation losses which help decision makers in integrated management of limited water resources.

RECOMMENDATION:

The research recommended to apply SEBS algorithm combined with high resolution images in representing the spatial and temporal variation of evaporation rates along the lake particularly where metrological stations measurements are not available because of the lack distributed stations along the lake. Besides, adding more metrological stations are needed to cover the lake climatically and to reduce the large distance served by some stations. Finally, further studies are essential to accurate estimation of evaporation losses using improved remote sensing techniques combined with high resolution images.

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