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RESEARCH ARTICLE

Evapotranspiration mapping over Egypt using MODIS / Terra satellite data

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Abstract

The evapotranspiration (ETo) is one of the most important regulating factors of climate, at both local and global scales. It is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Remote sensing technique is an important tool supporting the management of natural resources and agricultural practices for wider spatial coverage. The aim of this study is to calculate the potential evapotranspiration over Egypt using remote sensing technique and estimate the water loss from agricultural lands. MODIS/TERRA – LST (Land surface Temperature) and NDVI (Normalize difference Vegetation Index) were used as a variable to calculating the ETo by Hargreaves potential evapotranspiration equation during the period from 2001 to 2013 and estimate the water loss by evapotranspiration. The results indicated that, remotely sensed information, along with ancillary meteorological data, provides the capability to estimate evapotranspiration on pixel basis and well suited for ETo mapping over all Egypt. From the ETo mapping over Egypt one can found that, the highest area of low and high ETo range are found in the years of 2001 and 2008 respectively, while the lowest and highest values were observed in the years of 2004 and 2009 .The maximum value of monthly averages ETo of the 2nd period (from 2008 up to 2013) greater than the 1st period (from 2001 up to 2007), while the minimum value of monthly averages ETo of the 2nd period is lower than the 1st period at most of months. The amount of annual water that are loss from agricultural lands by evapotranspiration have been ranged from about 34.4 to 42.4 billion m^3 of water by the year of 2012. Finally the remote sensing information was able to reproduce the evapotranspiration mapping over all land cover in Egypt.

INTRODUCTION

More than half of the solar energy absorbed by land surfaces is currently used to evaporate water **(Trenberth *et al.*, 2009)**. Evapotranspiration changes may already be under way, but direct observational constraints are lacking at the global scale. Until such evidence is available, changes in the water cycle on land a key diagnostic criterion of the effects of climate change and variability remain uncertain. Land evapotranspiration (ETO) is a central process in the climate system and a nexus of the water, energy and carbon cycles. Global land ET returns about 60% of annual land precipitation to the atmosphere **(Oki *et al.*, 2006)**. Terrestrial ET can affect precipitation **(Koster *et al.*, 2004)**, and the associated latent heat flux helps to control surface temperatures, with important implications for regional climate characteristics such as the intensity and duration of heat waves **(Seneviratne 2006 and Vautard *et al.*, 2007).**

Evapotranspiration varies widely through both space and time, along with the biological and meteorological factors that drive it. Spatial and temporal heterogeneity of vegetation cover and function, as well as differences in available energy and water, all influence the rate at which ET occurs. At present, in most cases, regional values of maximum crop ET (ETc) are estimated by models using standard meteorological network data and land-use characteristics as inputs **(Doorenbos&Pruit, 1977; Allen *et al.*, 1998).** Most of these methods are based on point data, which do not provide good estimation of ET for larger areas. Hydrological models such as SWAP are well suited to map distributed ET **(Droogers, 2000)**, but need considerable expertise in model use and extensive field data to correctly simulate ET at the regional scale. Satellite remote sensing provides information on surface radiative properties, surface temperature and vegetation cover at the regional scale. Hence, remotely sensed information, along with ancillary meteorological data, provides the capability to estimate ETa on a pixel-by pixel basis. The close dependence of surface temperature (Ts) on evaporation rates makes satellites (NOAA AVHRR, MODIS) with thermal bands well suited for ET mapping. Many researchers (e.g. **Vidal & Perrier, 1989; Bastiaanssen, 1995; Granger, 1997)** have developed methodologies by combining the satellite images and meteorological data for large areas. The main objectives of this paper is to study the feasibility of using MODIS/ Terra satellite data to estimate spatial distribution of potential evapotranspiration over Egypt during the period from 2001 to 2013.

Material and Methods

The Land Surface Temperature **LST** - 8 day with resolution 1 Km data which derived from The Moderate Resolution Imaging Spectrometer (**MODIS**) on the **Terra** satellite has been downloaded from http://reverb.echo.nasa.gov for all months of the period from 2001 up to 2013 and used to calculate the Evapotranspiration over Egypt using the Hargreaves potential evapotranspiration equation **(Hargreaves and Samani, 1985**).

$$ET_{o_{HG}} = 0.0023 * \mathrm{R}_a * (\mathrm{T} + 17.8) * (\sqrt{T_x - T_n}\,) \qquad (1)$$

Where,

ET_{o_HG} : Hargreves evapotranspiration;

R_a: Extraterrestrial radiation (calculated from latitude and time of year);

T: Mean monthly temperature;

T_n: Minimum monthly temperature; and

T_x: Maximum monthly temperature.

The Extraterrestrial radiation R_a for each day of the year and for different latitudes is estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24\,(60)}{\pi} G_{sc} d_r \,[\, \omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_{s)}] \qquad (2)$$

Where R_a Extraterrestrial radiation [MJ m^{-2} day^{-1}],

G_{sc} Solar constant = 0.0820 MJ m^{-2} min^{-1},

d_r Inverse relative distance Earth-Sun (Equation 4),

$\boldsymbol{\omega}_s$ Sunset hour angle (Equation 6) [rad],

φ Latitude [rad] (Equation 3),

$\boldsymbol{\delta}$ Solar declination (Equation 5) [rad].

The latitude**φ** expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

$$[\text{Radians}] = \frac{\pi}{180}\ \ [\text{decimal degrees}] \qquad (3)$$

The inverse relative distance Earth-Sun d_r and the solar declination $\boldsymbol{\delta}$ are given by:

$$d_r = 1 + 0.033\ \cos\ (\frac{2\,\pi}{365} J) \qquad (4)$$

$$\delta = 0.409\ (\frac{2\,\pi}{365}\ J - 1.39) \qquad (5)$$

Where J is the number of the day in the year. It must be between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle $\boldsymbol{\omega}_s$ is given by:

$$\omega_s = \arccos\ [-\ \tan(\varphi) \tan(\delta)] \qquad (6)$$

Daylight hours (N) are given by:

$$N = \frac{24}{\pi} \omega_s \qquad (7)$$

Where $\boldsymbol{\omega}_s$ is the sunset hour angle in radians, as given by Equation 6.

Arc GIS, ERDAS Imagine, and Microsoft excel are the tools which are used in calculating and analysis the ET_o.

Result and Discussion

Evapotranspiration mapping

The present study estimates the potential evapotranspiration over Egypt using MODIS temperature satellite data. The mapping of ETo for all months during the period from 2001 up to 2013 is shown in figure (1) for illustration. The horizontal look for this figure enables the viewer to monitoring the ETo values in the specific month within different years while the vertical look can compare between the ETo of different years for all months and detected the months of the extreme ETo values.

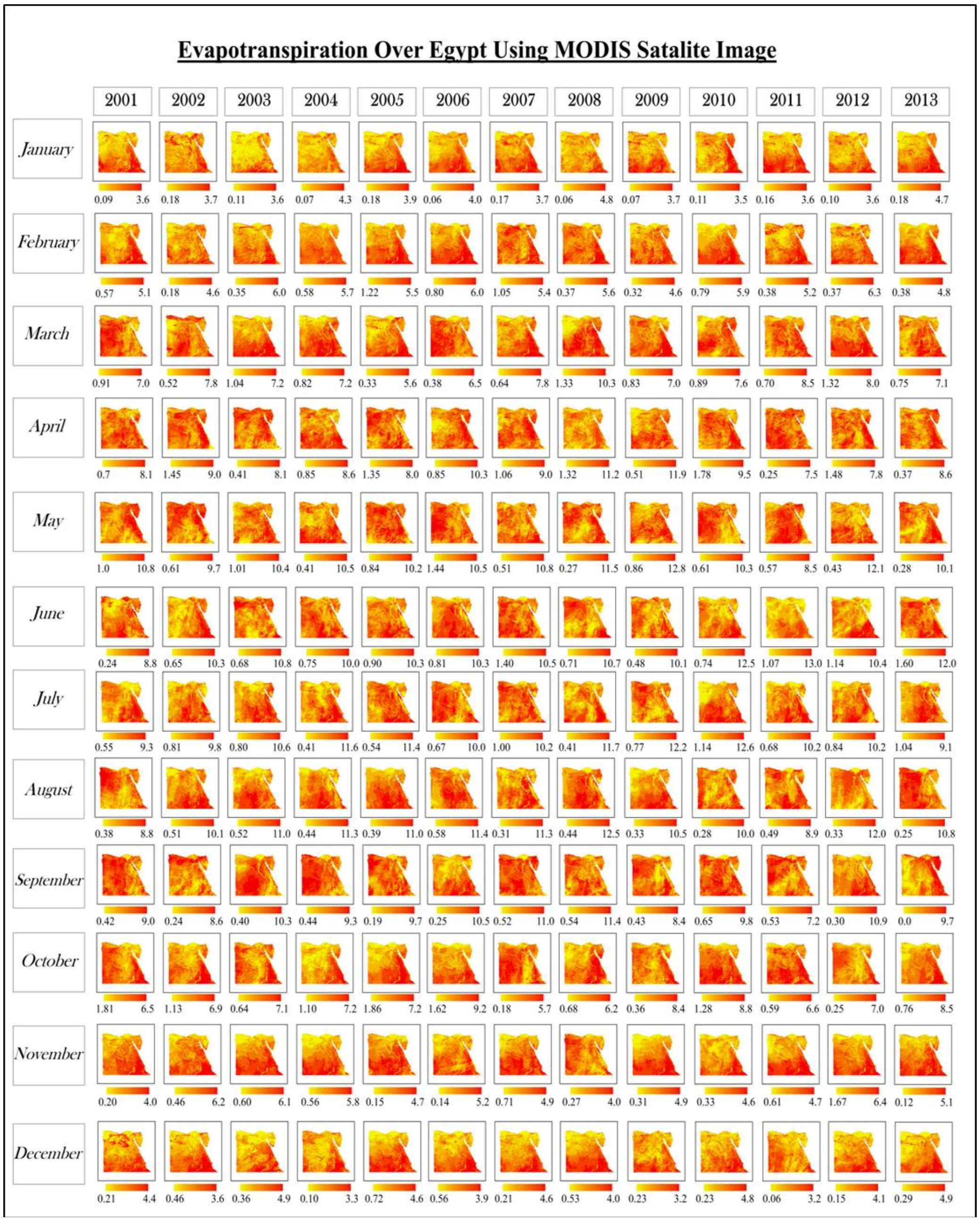

Figure (1): ETo mapping over Egypt for all months during the period 2001 up to 2013

Lowest and Highest Evapotranspiration

Table (1) shows the year of Lowest and highest ETo in Egypt for each month, and it's observed that, the highest ETo for all months were found in the years from 2006 up to 2013, and 2008 was the most of them where it has the highest maximum ETo (for the months Jan, Mar, Aug, and Sep.), while the lowest ETo for all months were observed in all years except in the years of 2003, 2004, 2006, 2009, and 2010. Also it’s observed that, the 2008 year was the most one has the lowest minimum ETo (in Jan., May, and Jul.).

Table (1): the years of lowest minimum and highest maximum of ET_ovalues over Egypt during the period from 2001 up to 2013.

ETo	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Lowest Min.	2008	2002	2005	2011	2008	2001	2008	2013	2005	2007	2013	2011
Highest Max.	2008	2012	2008	2009	2009	2011	2010	2008	2008	2006	2012	2013

Changes of ETo during two periods

Studying the monthly mean ETo as an average of two periods separately (from 2001 up to 2007, and from 2008 up to 2013) found that, the averages of the maximum ETo in second period was higher than the averages of the first period at all months except in the months of Feb., Sep., Nov., and Dec. where its averages of the first period were higher than the averages of second period [see Figure (2)].

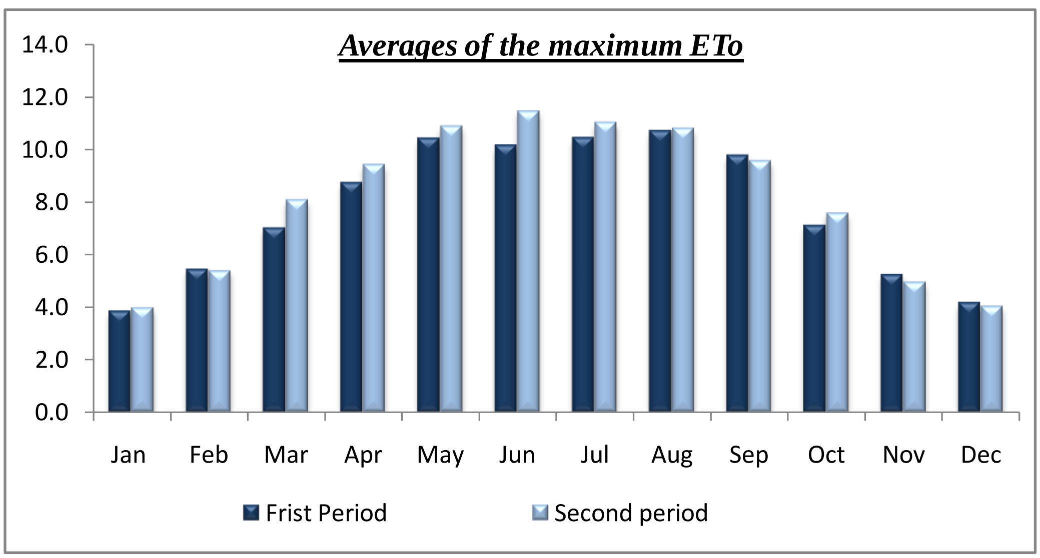

Figure (2): Comparison between the averages of maximum ETo in the period from 2001 up to 2007 (first period) and from 2008 up to 2013 (second period).

Figure (3) shows the comparison between the averages of the minimum ETo in the first and second period and we found that, the averages of the first period is higher than the second period in all months except in the months of Mar., Jun., Jul., Sep., and Nov.

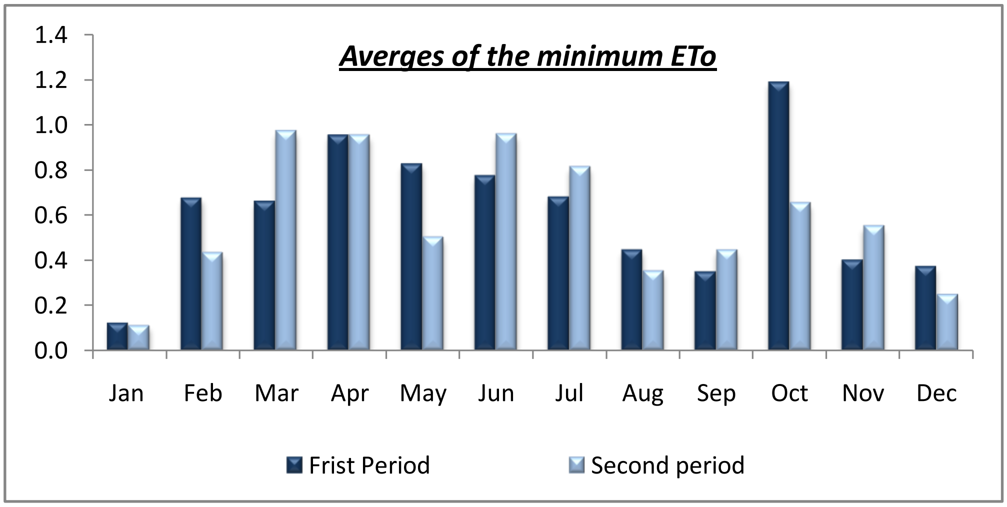

Figure (3): Comparison between the averages of minimum ET_o in the period from 2001 up to 2007 (first period) and from 2008 up to 2013 (second period).

Seasonal Evapotranspiration

The minimum and maximum seasonal ETo over Egypt during the period from 2001 up to 2013 are shown in table (2) and it has been found that, the highest maximum ETo is observed in the years of 2004, 2008, 2010, and 2006 at winter, spring, summer, and autumn seasons respectively, while the lowest minimum ETo is observed in 2012 and 2001 at winter and summer, and in 2013 at spring and autumn seasons. Also it has been observed that, the summer of 2010 has the highest value of ETo in the studied years while the winter of 2012 has the lowest value.

Table (2): the minimum and maximum seasonal ET_o over Egypt during the period 2001 up to 2013.

	Min ETo (mm/day)												
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Winter	0.3	0.2	0.3	0.3	0.5	0.5	0.6	0.3	0.3	0.4	0.3	0.2	0.2
Spring	0.9	0.9	0.8	0.7	0.8	0.9	0.7	1.0	0.7	1.1	0.5	1.1	0.5
Summer	0.4	0.7	0.7	0.5	0.6	0.7	0.9	0.5	0.5	0.7	0.7	0.8	1.0
Autumn	0.8	0.6	0.5	0.7	0.7	0.7	0.5	0.5	0.4	0.8	0.6	0.7	0.4
	Max ETo (mm/day)												
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Winter	4.4	4.2	4.4	5.0	4.2	4.9	4.6	4.9	4.1	4.2	4.5	4.4	4.5
Spring	8.6	8.9	8.6	8.8	7.9	9.1	9.2	11.0	10.6	9.1	8.2	9.3	8.6
Summer	9.0	10.1	10.8	11.0	10.9	10.6	10.6	11.6	11.0	11.7	10.7	10.9	10.7
Autumn	6.5	7.2	7.8	7.4	7.2	8.3	7.2	7.2	7.2	7.7	6.1	8.1	7.7

The Average Annual of Evapotranspiration

The average annual ETo over Egypt for the years from 2001 up to 2013 is shown in figure (4) and it has been observed that, the highest area of low and high ETo range are found in the years of 2001 and 2008 respectively, while the lowest and highest values observed in the years of 2004 and 2009 but in a few points (for example see figure 5).

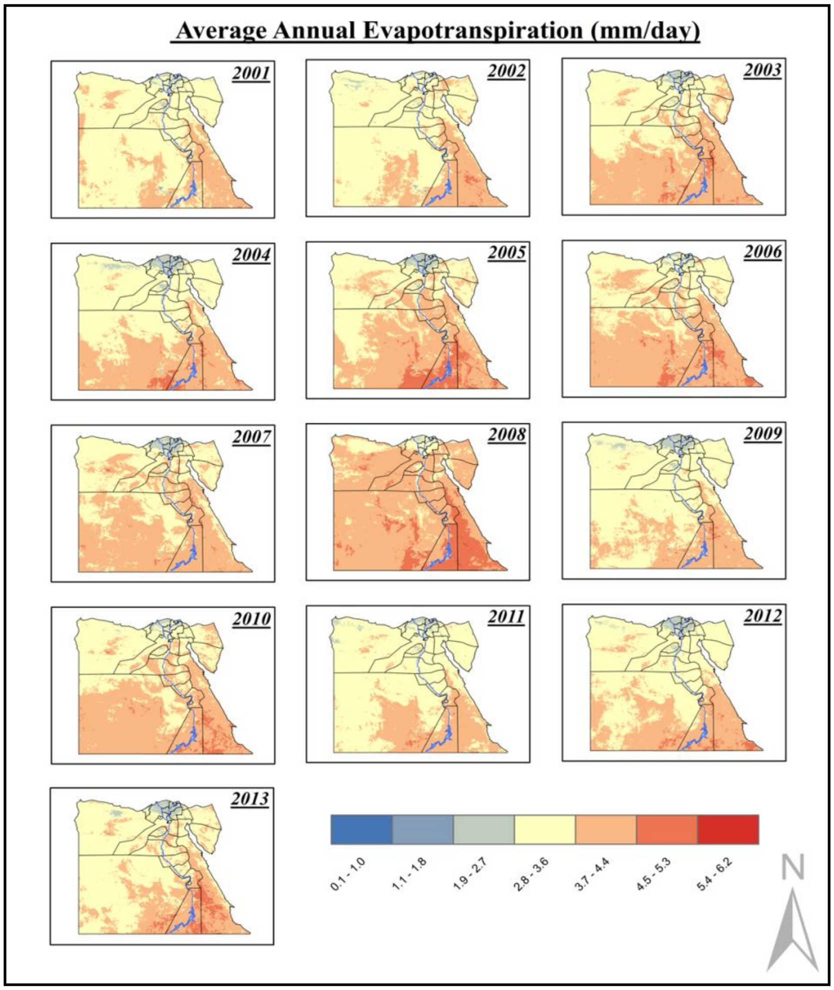

Figure (4): The average annual of ET_o for years from 2001 up to 2013.

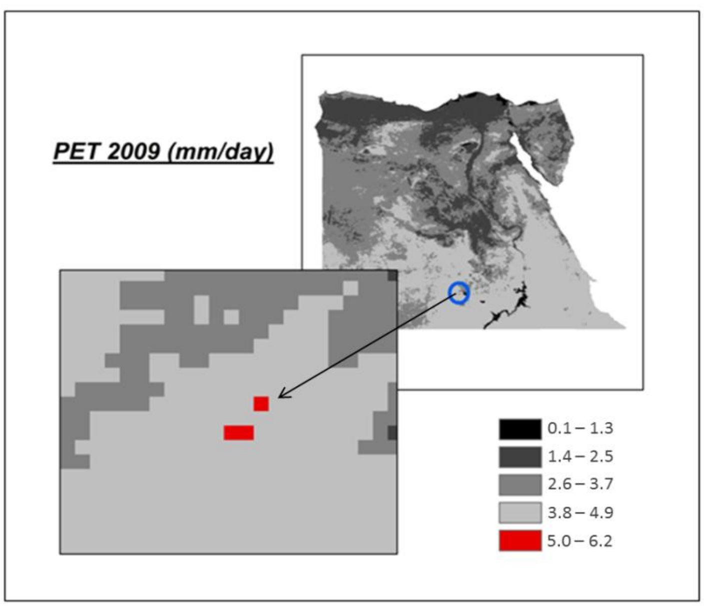

Figure (5): The area of highest ETo in 2009.

Evapotranspiration over agricultural lands and water loss

The agricultural lands in Egypt have been determined using NDVI data of MODIS TERRA with spatial resolution 500 meter for the months from Jan. to Dec. during the period (2001-2013) as shown in figure (6). Extracting the ETo values over them indicted that the months of May, Jun., Sep., and Feb. have the maximum average of the spring (MAM), summer (JJA), autumn (SON), and winter (DJF) seasons respectively, and among of all months the month of Jun. has the maximum values and Jan. has the minimum values at most of studied years as shown in figure (7) which present the average ETo values over the agricultural lands for the months from Jan to Dec. during the period (2001-2013).

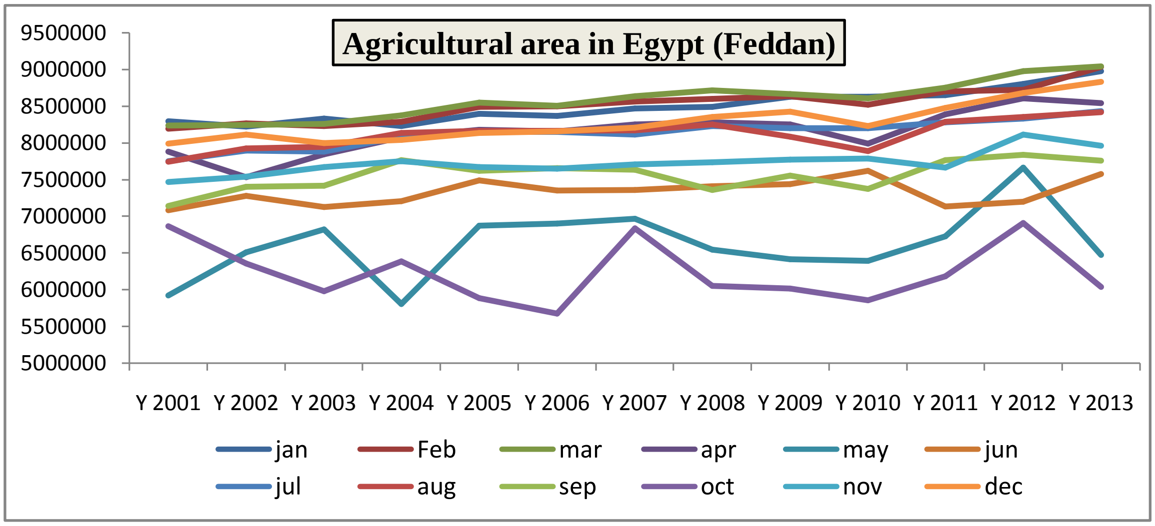

Figure (6): Area of the agricultural lands in Egypt during the period (2001-2013).

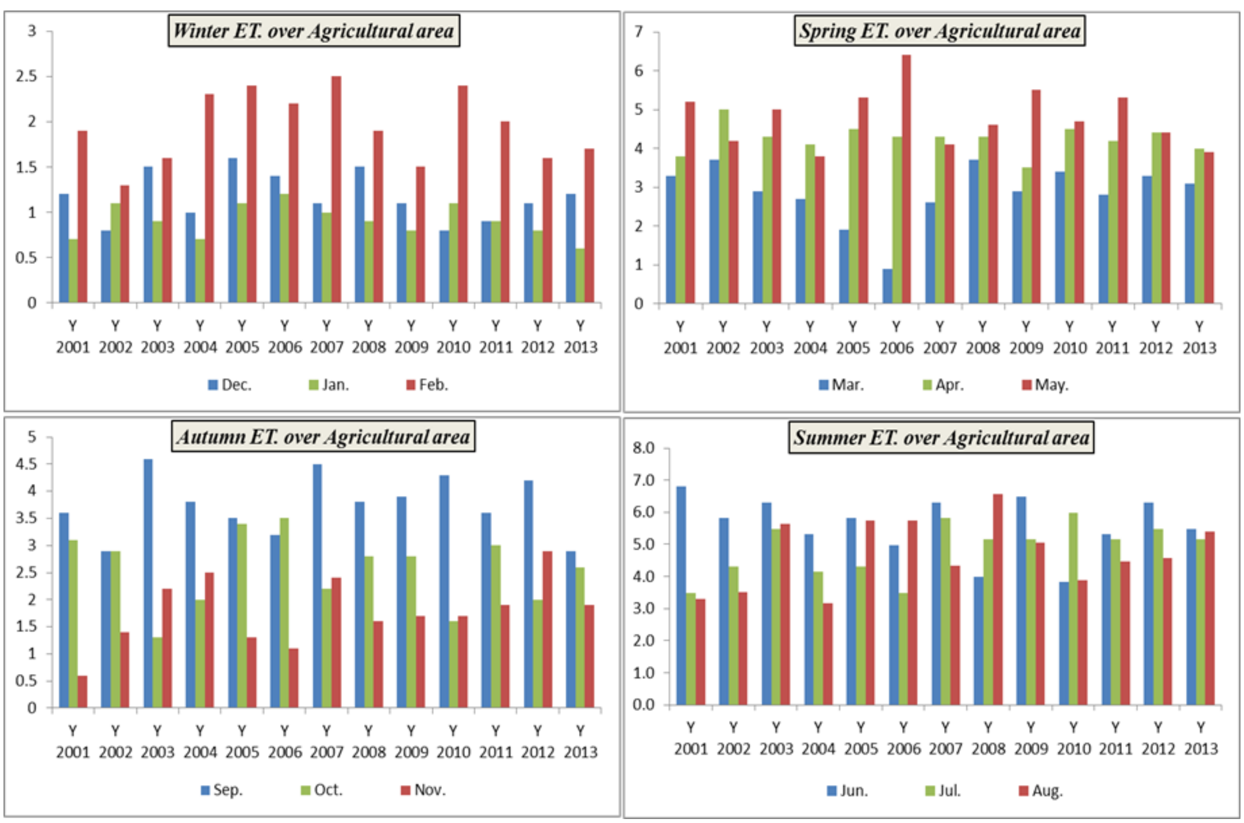

Figure (7): The average ETo values over the agricultural lands for the months from Jan. to Dec. during the period (2001-2013).

The average evapotranspiration from the agricultural lands for the whole Egypt is shown in table (3), with noticeable heterogeneities. The amount of annual water that are loss from agricultural lands by evapotranspiration has been estimated and as shown in figure (8) which found the results ranged from about 34.4 billion in the year of 2004 to 42.4 billion m^3 of water by the year of 2012.

Table (3): The average ETo from the agricultural lands in Egypt during the period (2001-2013).

Average ETo from the agricultural lands (mm/day)												
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Y 2001	0.7	1.9	3.3	3.8	5.2	6.8	3.5	2.8	3.6	3.1	0.6	1.2
Y 2002	1.1	1.3	3.7	5.0	4.2	5.8	4.3	3.0	2.9	2.9	1.4	0.8
Y 2003	0.9	1.6	2.9	4.3	5.0	6.3	5.5	4.8	4.6	1.3	2.2	1.5
Y 2004	0.7	2.3	2.7	4.1	3.8	5.3	4.2	2.7	3.8	2.0	2.5	1.0
Y 2005	1.1	2.4	1.9	4.5	5.3	5.8	4.3	4.9	3.5	3.4	1.3	1.6
Y 2006	1.2	2.2	0.9	4.3	6.4	5.0	3.5	4.9	3.2	3.5	1.1	1.4
Y 2007	1.0	2.5	2.6	4.3	4.1	6.3	5.8	3.7	4.5	2.2	2.4	1.1
Y 2008	0.9	1.9	3.7	4.3	4.6	4.0	5.1	5.6	3.8	2.8	1.6	1.5
Y 2009	0.8	1.5	2.9	3.5	5.5	6.5	5.1	4.3	3.9	2.8	1.7	1.1
Y 2010	1.1	2.4	3.4	4.5	4.7	3.8	6.0	3.3	4.3	1.6	1.7	0.8
Y 2011	0.9	2.0	2.8	4.2	5.3	5.3	5.1	3.8	3.6	3.0	1.9	0.9
Y 2012	0.8	1.6	3.3	4.4	4.4	6.3	5.5	3.9	4.2	2.0	2.9	1.1
Y 2013	0.6	1.7	3.1	4.0	3.9	5.5	5.1	4.6	2.9	2.6	1.9	1.2

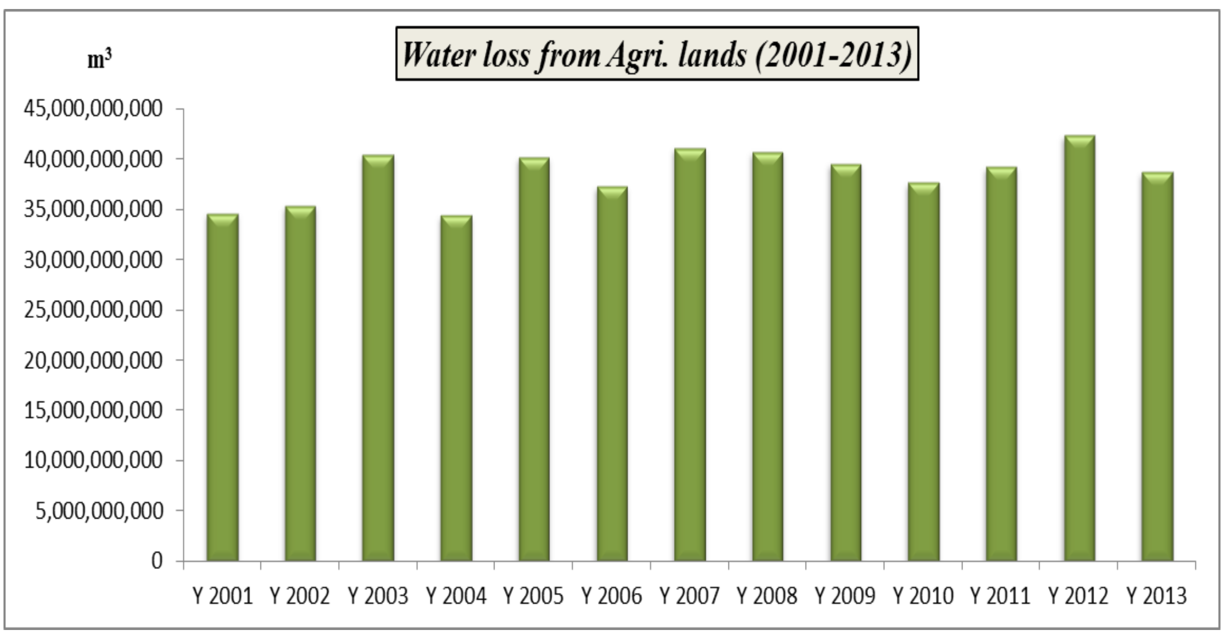

Figure (8): The annual water loss from agricultural lands by evapotranspiration during the period (2001-2013)

In general, these results are in accordance with **(Irmak *et al.*, 2011)**, which recorded that the utilize Mapping Evapotranspiration at High Resolution using Internalized Calibration model in Great Plains environmental settings to understand water use in managed ecosystems on a regional scale. Also similar results obtained by **(PATEL *et al.*, 2006)** who reported that the satellite observations supplemented with routine meteorological data provide a unique capability to estimate actual evapotranspiration over large areas needed for irrigation management and water balance. **Mu, Q. *et al.*, 2007a** who developed an algorithm to estimate ET using the Penman-Monteith approach driven by Moderate Resolution Imaging Spectro radiometer (MODIS)-derived vegetation data and daily surface meteorological inputs including incoming solar radiation, air temperature, and Vapor pressure deficit (VPD). In the same line **(Mu, Q. *et al.*, 2009)** found that the MOD1S ET algorithm has a good performance in generating global ET data products, providing critical information on global terrestrial water and energy cycles and environmental changes. Also **(Wan, Z. *et al.*, 2002 and 2004)** who found that the great advantage in using MODIS data for estimating ET is the high accuracy of surface temperature images associated with the spatial variability of this process at the regional scale. Similar results obtained by **(Guerschman *et al.*, 2009)** who developed a new algorithm for estimating monthly actual evapotranspiration (AET) based on surface reflectance from MODIS-Terra and interpolated climate data. Finally Remote sensing methods are attractive to estimate ET as they cover large areas and can provide estimates at a very high spatial resolution. Intensive field monitoring is also not required, although some ground-truth measurements can be helpful in interpreting the satellite images.

Conclusion

This study presents a new technique in calculating the potential evapotranspiration where by this method we can calculate and study the ETo at any location and apply different application on it. The study estimates ETo for the period from 2001 up to 2013 over all Egypt using LST- MODIS satellite data and concluded that, the averages of the minimum monthly ETo for the years (2001 - 2007) was greater than the averages of the minimum monthly ETo for the years (2008 - 2013) at most of months. The averages of the maximum monthly ETo for the years (2008 - 2013) was greater than the averages of the maximum monthly ETo for the years (2001 - 2007) at most of months.

Seasonal highest ETo was in the years of 2004, 2008, 2010, and 2006 at winter, spring, summer, and autumn seasons respectively. Also the seasonal lowest ETo was in the years of 2012 and 2001 at winter and summer, and in 2013 at spring and autumn seasons. The average annual ETo was the lowest in 2001 over all Egypt, while the highest valuesummer, and in 2013 at spring and autumn seasons. The average annual ETo was the lowest in 2001 over all Egypt, while the highest value was observed in the year of 2009.

The highest area of low ETo range is found in the year of 2001 and while the highest area of high range is found in the year of 2008. Average ETo over the agricultural lands were the highest in the months of May, June, Sep., and Feb. of the spring (MAM), summer (JJA), autumn (SON), and winter (DJF) seasons respectively. Among of all months the month of June has the maximum ETo values and Jan. has the ETo minimum values at most of study period. The amount of annual water loss from agricultural is ranged from about 34.4 to 42.4 billion m^3 of water by the year of 2012.

References

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirement. FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization, Rome, Italy.

Bastiaanssen, W. G. M. (1995). Regionalization of surface flux densities and moisture indicators in composite terrain.A remote sensing approach under clear skies in Mediterranean climate. Report 109, Agricultural Research Department, Wageningen, The Netherlands.

Doorenbos, J., and Pruit, W. O. (1977). Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper no. 24, Food and Agriculture Organization, Rome, Italy.

Droogers, P. (2000). Estimating actual evapotranspiration using a detailed agro-hydrological model. J. Hydrol. 229, 50–58.

Granger, R. J. (1997). Comparison of surface and satellite derived estimates of evapotranspiration using a feedback algorithm. Applications of remote sensing in hydrology.Proc. Third International Workshop NHRI Symp.17 (16–18 October 1996, NASA, GSFC, Greenbelt, Maryland, USA).

Guerschman, J. P., Van Dijk, A. I. J. M., Guillaume M., Jason B., Lindsay B. H., Ray L., Robert C. P., and Brad S. S. (2009). Scaling of potential evapotranspiration with MODIS data reproduces flux observations and catchment water balance observations across Australia. Journal of Hydrology 369 (2009) 107–119.

Hargreaves, G. H., and Samani, Z. A. (1985)."Reference crop evapotranspiration from temperature." Appl. Eng. Agric., 1(2), 96–99.

Irmak, A., Ratcliffe, I., Ranade, P., Hubbard, K., and Singh, R. K. (2011). Estimation of land surface evapotranspiration with a satellite remote sensing procedure. Great Plains Research 21 (Spring 2011):73-88.

Koster, R. D.; Dirmeyer, P. A.; Guo, Z.; Bonan, G.; Chan, E.; Cox, P.r; Gordon, C. T.; Kanae, S.; Kowalczyk, E.; Lawrence, D.; Liu, P.; Lu, C.; Malyshev, S.; McAvaney, B.; Mitchell, K.; Mocko, D.; Oki, T.; Oleson, K.; Pitman, A.; Sud, Y. C.; Taylor, C. M.; Verseghy, D.; Vasic, R.; Xue, Y.; and Yamada, T.(2004). Regions of strong coupling between soil moisture and precipitation. Science 305, 1138–1140 (2004).

Mu, Q., Heinsch, F.A., Zhao ,M., and Running, S. W. (2007a). Development of a global evapotranspiration algorithm based on MODIS and global meteorology data, Remote Sensing of Environment, 111, 519-536, doi: 10.1016/j.rse.2007.04.015.

Mu, Q., Jones, L. A., Kimball, J. S., McDonald, K. C., and Running, S. W. (2009). Satellite assessment of land surface evapotranspiration for the pan-Arctic domain. Water Resources Research 45, Number W09420 - 2009 (doi: 10.1029/2008WR007189).

Oki, T., and Kanae, S. (2006). Global hydrological cycles and world water resources. Science 313, 1068–1072.

PATEL, N. R., RAKHESH. D., and MOHAMMED. A. J. (2006). Mapping of regional evapotranspiration in wheat using Terra/MODIS satellite data. Hydrological Sciences–Journal–des Sciences Hydrologiques, 51(2) April 2006.

Seneviratne, S. I., Lu¨ thi, D., Litschi, M. , and Scha¨r, C. (2006). Land–atmosphere coupling and climate change in Europe. Nature 443, 205–209 (2006).

Trenberth, K. E., Fasullo, J. T., and Kiehl, J. (2009). Earth's global energy budget. Bull. Am. Meteorol. Soc. 90, 311–323 (2009).

Vautard, R. P. Yiou, F. D'Andrea, N. de Noblet, Viovy, N., Cassou, C., Polcher, J., Ciais, P., Kageyama, M., and Fan, Y.(2007). Summertime European heat and drought waves induced by wintertime Mediterranean rainfall deficit.Geophys. Res. Lett. L07711 (2007).

Vidal, A. and Perrier, A. (1989). Analysis of a simplified relation used to estimate daily evapotranspiration from satellite thermal IR data. Intl. J. Rem. Sens. 10(8), 1327–1337.

Wan, Z., Zhang, Y., Zhang, Q., Li, Z.L.(2004). Quality assessment and validation of the MODIS global land surface temperature. Int. J. Remote Sens. 2004, 25, 261-274.

Wan, Z., Zhang, Y., Zhang, Q., Li, Z. L. (2002). Validation of the land-surface temperature products retrieved from Terra Moderate Resolution Imaging Spectro radiometer data. Remote Sens. Environ. 2002, 83, 163-180.