International Journal of Plant & Soil Science
6(6): 350-358, 2015; Article no.IJPSS.2015.125
ISSN: 2320-7035

SCIENCEDOMAIN ***international***
www.sciencedomain.org

Evaluation of SEBAL and SEBS Algorithms in the Estimation of Maize Evapotranspiration

Bahman Farhadi Bansouleh[1*], Ali Reza Karimi[1] and Homayoun Hesadi[2]

[1]Department of Water Engineering, Razi University, Kermanshah, Iran.
[2]Department of Soil Conservation and Watershed Management, Kermanshah Agricultural and Natural Resources Research Center, Kermanshah, Iran.

Authors' contributions

This work was part of an MSc thesis which was carried out in collaboration between all authors. The authors were the supervisor, researcher and advisor of this research respectively. The first draft of the manuscript written by author BFB. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2015/15711
Editor(s):
(1) Kefeng Zhang, Ningbo Institute of Technology, Zhejiang University, Zhejiang, China.
(2) Ying Ouyang, Department of Agricultural Forest Service, USA.
(3) Sławomir Borek, Faculty of Biology, Department of Plant Physiology, Adam Mickiewicz University, Poland.
Reviewers:
(1) Shaohua Zhao, Satellite Environment Center, Ministry of Environmental Protection, Beijing, China.
(2) Anonymous, China.
(3) Faheem Iqbal, Discipline of Geography and Spatial Sciences, School of Land and Food, University of Tasmania, Australia.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=958&id=24&aid=8785

Original Research Article

Received 14th December 2014
Accepted 24th March 2015
Published 14th April 2015

ABSTRACT

Crop evapotranspiration (ET) is an important parameter for agricultural water management. This parameter can be estimated by multiplying of reference crop evapotranspiration (ETO) and crop coefficient. Usually ETO is calculated based on (daily) weather data at the weather stations. Considering the spatial variations of the weather parameters and subsequently of ET, application of the methods which can consider these variations are interested. Developed algorithms to estimate ET based on satellite images is one of those methods. The aim of the current study was to assess the accuracy of estimated ET based on SEBAL and SEBS algorithms using LANDSAT TM images in Mahidasht, Kermanshah province, Iran. For this purpose, the ET of maize was calculated using four images of LANDSAT during the maize growing season in year 2010. At the same time, the actual ET of maize was measured in a Lysimeter in the same region. Results indicating reasonable match between measured and calculated crop evapotranspiration by both algorithms. The maximum difference between the calculated evapotranspiration by SEBAL and SEBS algorithms with measured values by Lysimeter were about 9.79% and 4.56% of measured ET, respectively.

**Corresponding author: E-mail: bfarhadi2001@yahoo.com, bfarhadi@razi.ac.ir;*

Keywords: Evapotranspiration; SEBAL; SEBS; LANDSAT TM; satellite image.

1. INTRODUCTION

Evapotranspiration (ET) is a key parameter for water resource management especially in the arid and semi-arid regions where water is one of the main constraints for agricultural development. Weather parameters, crop characteristics, management and environmental aspects are factors affecting evaporation and transpiration [1]. The spatial variation of ET over a region is expected as affecting factors on ET have spatial variation. Application of conventional methods of ET measurement (Bowen ratio, Eddy covariance, Lysimeter) which are dependent of the field or landscape scales in large scales are costly and time consuming [2]. Therefore, considering the spatial variations of the weather parameters and subsequently of ET, application of the methods which can consider these variations are interested. Developed algorithms to estimate ET based on satellite images are among those methods.

Currently, remote sensing techniques are used to acquire required parameters to estimate evapotranspiration on various spatial and temporal scales [3]. During the past three decades, significant progress has been made in estimating actual evapotranspiration using satellite images. According to Verstaeten et al. [4] remote sensing based assessment of evapotranspiration methods could be classified into four categories based on (i) the parameterization of the surface energy balance; (ii) the Penman-Monteith equation; (iii) the water balance approach, and (iv) relationships between vegetation indices and land surface temperature. Li et al. [5] had a review on the advantages and disadvantages of various remote sensing based ET models. They have concluded there is no model developed nowadays can be used everywhere in the world without modification or improvement to estimate the ET from satellite data because of great differences in the land surface characteristics, the climate and terrain.

Surface Energy Balance Algorithm for Land (SEBAL) [6] and Surface Energy Balance System (SEBS) [7] are among surface energy balance methods which have been applied using different satellite images in the various parts of the world [8-10]. So far, various studies have been done to evaluate the performance of these algorithms and to estimate the actual evapotranspiration using these techniques in different parts of the world, which have led to different and sometimes conflicting results. Gibson et al. [11] reviewed the application of energy balance methods in South Africa and showed that SEBAL model is the most widely used method in that region, but highlighting the potentials of the SEBS model. Bastiaanssen et al. [12] using the field measurements of evapotranspiration in the large farms of China, India, Spain and Pakistan evaluated the accuracy of estimated ET by SEBAL algorithm. Their results showed that 85% of obtained data from SEBAL algorithm with no calibration matched the field data. Ramos et al. [13] applied the SEBAL algorithm to fifteen LANDAST images during the years 1997 – 2000 in the North East Spain. They have compared estimated ET by SEBAL and measured ET in two weighing Lysimetes. They have concluded that the SEBAL algorithm can provide accurate daily ET estimations for grass as reference crop, maize and wheat. Lin et al. [14] applied SEBS algorithm using MODIS / TERRA images for estimating surface fluxes in northeastern China. Their results showed that estimated evapotranspiration by SEBS algorithm has a good agreement with the Lysimetric data. Su et al. [15] conducted a study to assess evapotranspiration estimated by the SEBS algorithm with the values measured in the Soil Moisture–Atmosphere Coupling EXperiment (SMACEX) project. The results of that study showed that the difference between the estimated and measured values of evapotranspiration for soybean and maize was between 10 and 15 percent. Furthermore, the results of this analysis showed that the accuracy of estimating evapotranspiration for maize was better than that soybean. Shan [16] applied SEBS algorithm on MODIS images to estimate the spatial and temporal changes of actual evapotranspiration in a river basin. The results showed that evapotranspiration and NDVI (Normalized Difference Vegetation Index) are highly correlated and are directly connected . Temsgen [17] by the use of MODIS images, meteorological data and SEBS algorithm, estimated the annual evapotranspiration in 2008 for a basin in northwestern Ethiopia and compared the results with the conventional ground methods. Annual actual evapotranspiration calculated by SEBS was 1519 mm while the calculated potential reference crop evapotranspiration (ETO) through Penman-

Monteith model [1] for the same year was 1498 mm. In that study the temporal and spatial changes of ET in the basin were also assessed. The actual ET estimated by SEBS method during wet seasons was more than the ETO of the Penman-Monteith method and during drier periods was lower. Gebreyesus [18] estimated values of ET and soil moisture for Guarena watershed in Spain based on 13 MODIS images and using SEBS algorithm and compared the results with ground data of 23 soil moisture meters and 5 meteorological stations. Their results showed that SEBS can give a good estimation of soil moisture in farm scale and reliable estimation of actual evapotranspiration.

Literature review showed that the most of the conducted studies on the SEBAL and SEBS algorithm were applied on satellite images with low spatial resolution. Considering the small size of the farms in Iran, estimation of ET using medium spatial resolution images such as LANDSAT could be an appropriate option. The aim of the present study was to evaluate the accuracy of the SEBAL and SEBS algorithms by the use of LANDSAT images in one of the semi-arid regions of Iran.The study area is located in Mahidasht plain, Kermanshah province, Iran which has both mountainous and flat areas.

2. MATERIALS AND METHODS

The study was carried out in Mahidasht plain, Kermanshah province, Iran which has a semi-arid climate with mean annual temperature and precipitation of 14.2ºC and 396 mm respectively. This area is located in the zone 38 N in UTM coordinate system. Ground water is the main source of water in this plain and all crops are irrigated during the summer.

A Lysimetric study was carried out to obtain reliable amounts of evapotranspiration to assess the accuracy of calculated actual evapotranspiration by SEBAL and SEBS algorithms.However, in these type of studies it is recommended to use weighing Lysimeteres equipped with data logger but it was not available in the study area. In the absence of the weighing Lysimeters in this study drainable Lysimeter was used. Since the major crop in the study area was maize, 10 ha maize was planted on 15 May 2010 at the research farm of Mahidasht agricultural research station (Fig. 1). At the same time maize was cultivated in a drainable Lysimeter (1 m* 1.5 m* 1.5 m) which was located almost in the middle of the research farm. Fertilizers were applied based on the results of soil fertility analysis and the recommendations of local soil research institute. Fungicide, herbicide and pesticide were applied based on the recommendations of provincial agricultural organization experts. Maize actual ET was calculated in each irrigation interval (10 days) based on the water balance equation in the Lysimeter. There was no rainfall during the growing season, hence all the water requirement was applied thorough irrigation.

In addition, actual evapotranspiration was calculated according to LANDSAT TM images using SEBAL and SEBS algorithms. These algorithms are based on energy balance equation (Eq. 1):

$$LE = \lambda\ ET = R_n - G - H \qquad (1)$$

Where, LE,λ, ET, R_n, G and H are respectively latent heat flux (wm^{-2}), latent heat of vaporization ($J\ kg^{-1}$), evapotranspiration (mm), net solar radiation (wm^{-2}), soil heat flux (wm^{-2}) and sensible heat flux ($w.m^{-2}$). Although, both algorithms are trying to calculate components of energy balance equation (Rn, G, H andλ) in order to calculate ET but they are using different approaches. As these algorithms are documented in a few publications [19,20], they are not explained in this paper anymore. Available LANDSAT TM satellite images during the growing season of maize in 2010 (25June, 11July, 27 July and 12 August) were downloaded free of charge from the http://glovis.usgs.gov website (last access date: 13 March 2015). There are several open source and commercial software packages which can be used to apply SEBAL and SEBS algorithms. In the current study ILWIS package was used which is an open-source software and can be download free of charge from "http://52north.org/" website (last access date: 13 March 2015). All equations of SEBAL and SEBS algorithms are coded in this software by authors. The average of ET over the internal pixels in the maize farm was considered as the actual maize ET.

In this study results of SEBAL and SEBS algorithms were evaluated by i) comparison of calculated actual ET at the maize farm based on SEBAL (ETS_{EBAL}) and SEBS (ET_{SEBS}) algorithms with measured ET in the Lysimeter ($ET_{Lysimeter}$) and ii) comparison of the maximum evapotranspiration estimated by SEBAL

($ET_{SEBAL,m}$) and SEBS ($ET_{SEBS,m}$) algorithms in the plain with the calculated potential crop reference evapotranspiration using FAO-56 Penman Monteith equation (ETO). ETO was calculated using Penman - Monteith formula [1] based on daily weather data obtained from Mahidasht weather station (Eq. 2).

$$ETO = \frac{0.408\,\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where, in this equation ETO, R_n, G, T, e_s, e_a,Δ and γ are potential crop reference evapotranspiration (mm day^{-1}), net radiation at the crop surface ($MJm^{-2}day^{-1}$), soil heat flux (MJ m^{-2} day^{-1}), air temperature at 2 m height (°C), wind speed at 2 m height (ms^{-1}), saturation vapor pressure (kPa), actual vapor pressure (kPa), slope of vapor pressure ($kPa°C^{-1}$) and psychometric constant ($kPa°C^{-1}$) respectively.

The absolute and relative differences between the calculated values of ET (ET_{SEBAL} and ET_{SEBS}) with measured ET ($ET_{Lysimeter}$) was used to describe the accuracy of the calculated ET values. Relative percentage of differences was calculated using Eq. 3.

$$\text{Relative difference (\%)} = \frac{(\text{Calculated ET} - \text{Measured ET})}{\text{Measured ET}} * 100 \quad (3)$$

3. RESULTS AND DISCUSSION

Calculated actual evapotranspiration over the study area using SEBAL and SEBS algorithms are presented in Figs. 2 and 3 respectively. Results are indicating that evapotranspiration increases from June to August which is in agreement with increasing of air temperature and vegetation density in the irrigated fields of the study area. Maximum and average of calculated actual ET over the study area is presented in Table 1. Maximum actual ET over the study area has been occurred in the irrigated farms. It should be mentioned that maize is the major crop in the study area during the summer. The lowest values of ET are occurred on the mountainous area.

Since there was no possibility for daily measurement of ET in the Lysimeter, therefore ET was calculated in each irrigation interval (10 days) and then converted to daily ET by dividing on irrigation interval. Results of Lysimetric study indicated that daily actual ET of maize on 25June, 11July, 27 July and 12 August was 4.13, 7.74, 7.45 and 8.05 $mmday^{-1}$ respectively. Daily

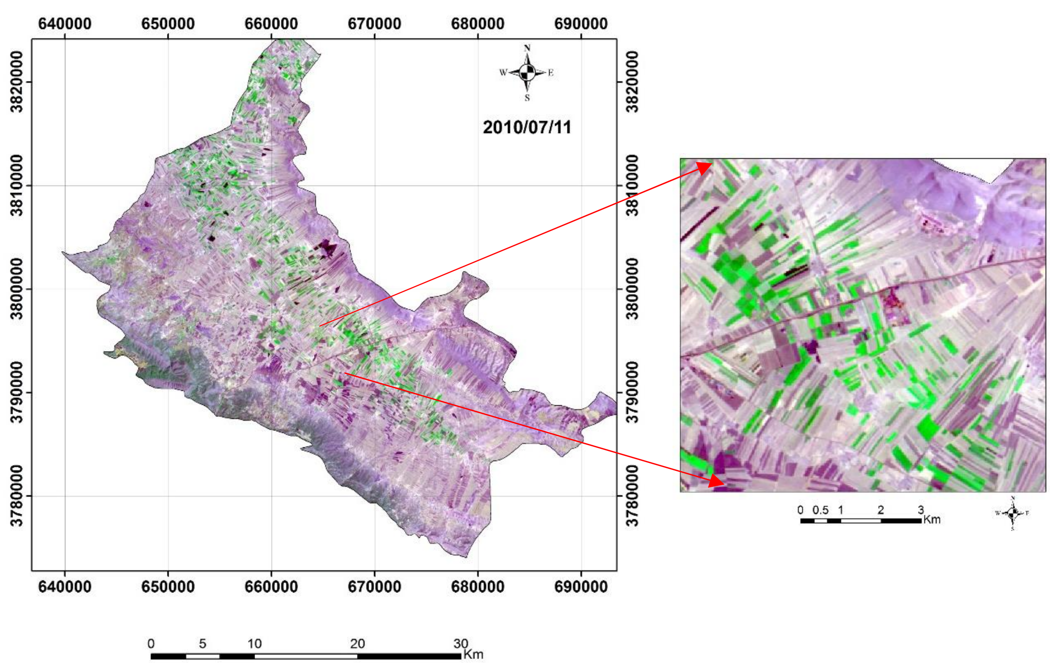

Fig. 1. Location of the research farm in Mahidasht plain (11 July 2010)

Table 1. Maximum and average of calculated actual ET over the study area based on SEBAL and SEBS algorithms (mmday^{-1})

Algorithm	25June		11July		27 July		12 August	
	Max	Average	Max	Average	Max	Average	Max	Average
SEBAL	6.26	2.85	9.01	4.20	8.24	3.92	8.32	3.97
SEBS	6.32	2.99	9.02	5.17	8.30	4.78	8.53	4.86

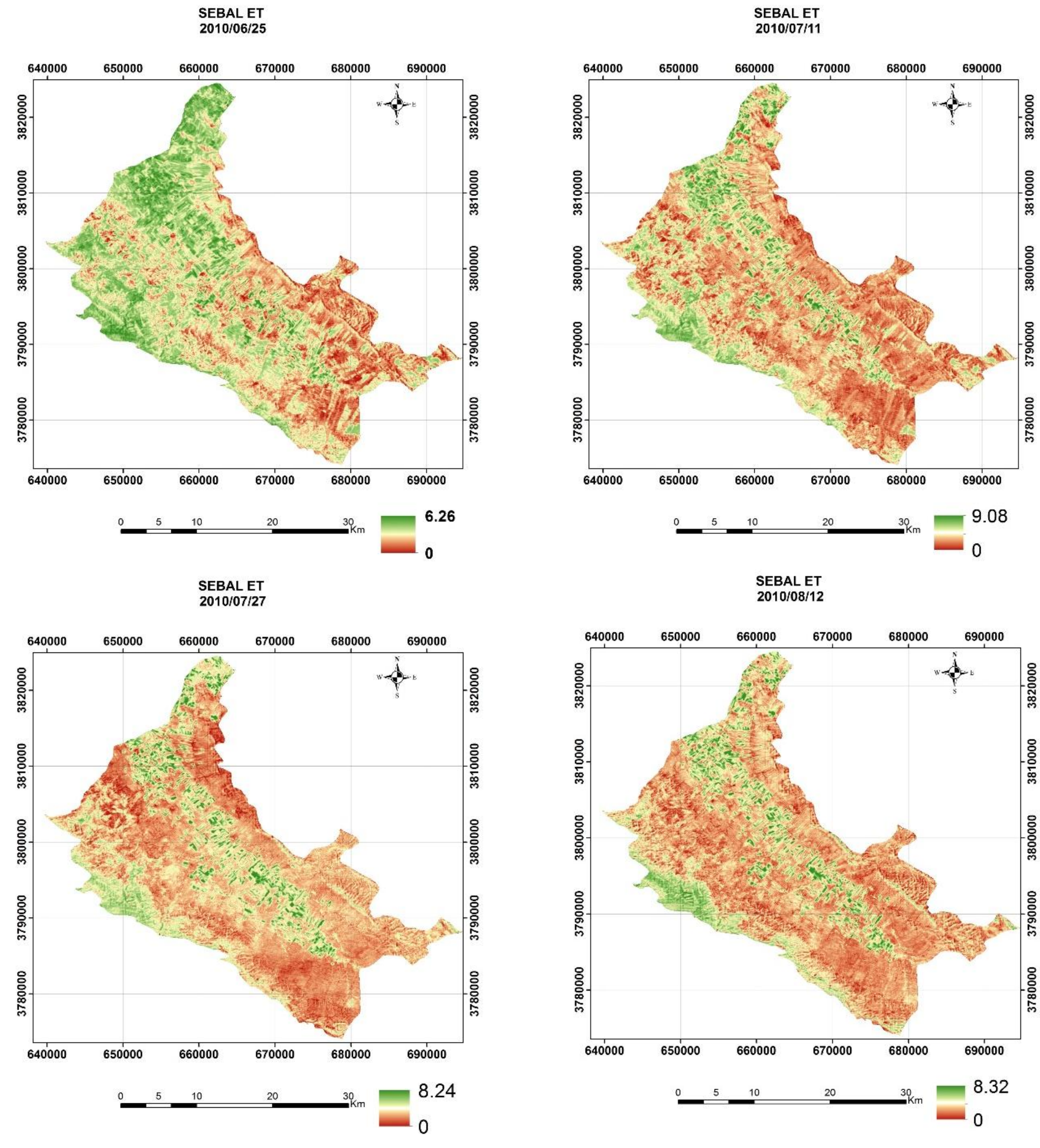

Fig. 2. Calculated actual evapotranspiration over the study area using SEBAL algorithm (mm day^{-1})

estimated ET in the maize field by SEBAL and SEBS algorithms and measured ET in the Lysimeter are presented in Table 2. In all four dates calculated ET based on both algorithms (ET_{SEBS} and ET_{SEBAL}) was less than actual measured ET by Lysimeter ($ET_{Lysimeter}$) (Fig. 4). The maximum absolute difference between the ET_{SEBAL} and ET_{SEBS} with $ET_{Lysimeter}$ has been occurred on 27 July with the amounts of 0.73 and 0.34 mm day^{-1} respectively. These results are comparable with the results of Ramos et al. [13] whom they obtained mean absolute difference of 0.6 mm day^{-1} between estimated corn evapotranspiration by SEBAL and Lysimetric data. Considering the maximum relative difference of 9.79% between calculated and measured ET it could be concluded that estimated ET by both algorithms are acceptable (Table 2). Results are also indicated that differences between calculated ET by SEBS algorithm in all imagery dates were less than SEBAL algorithm. The differences between $ET_{Lysimeter}$ with ET_{SEBAL} and ET_{SEBS} could have various reasons. For example $ET_{Lysimeter}$ is the average of ET over a decade while ET_{SEBAL} and ET_{SEBS} are for a specific date.

In the absence of ground-based measurements of evapotranspiration at the regional level, maximum amount of evapotranspiration estimated by SEBAL and SEBS algorithm was compared with ETO (Table 3).

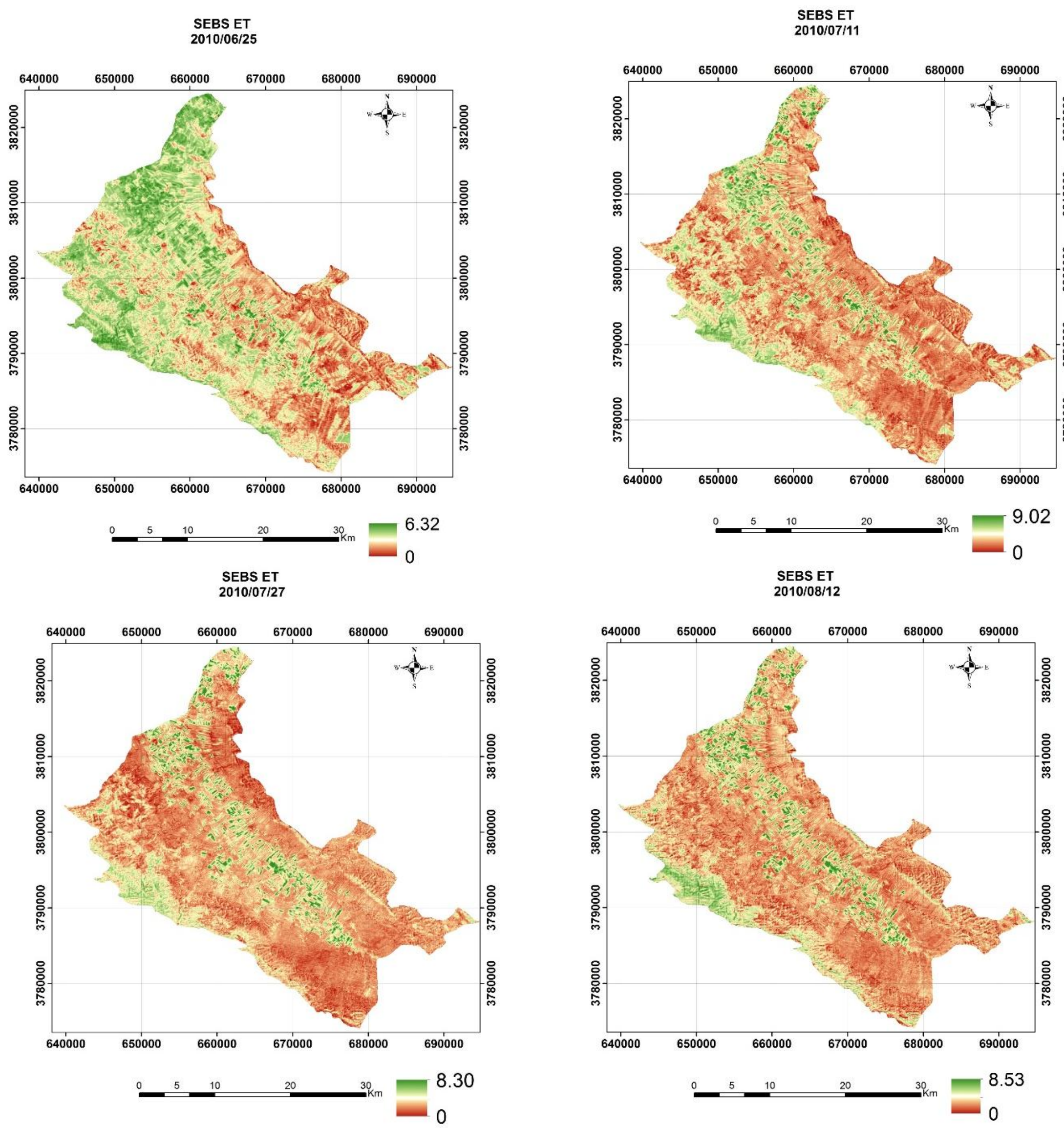

Fig. 3. Calculated actual evapotranspiration over the study area using SEBS algorithm (mm day^{-1})

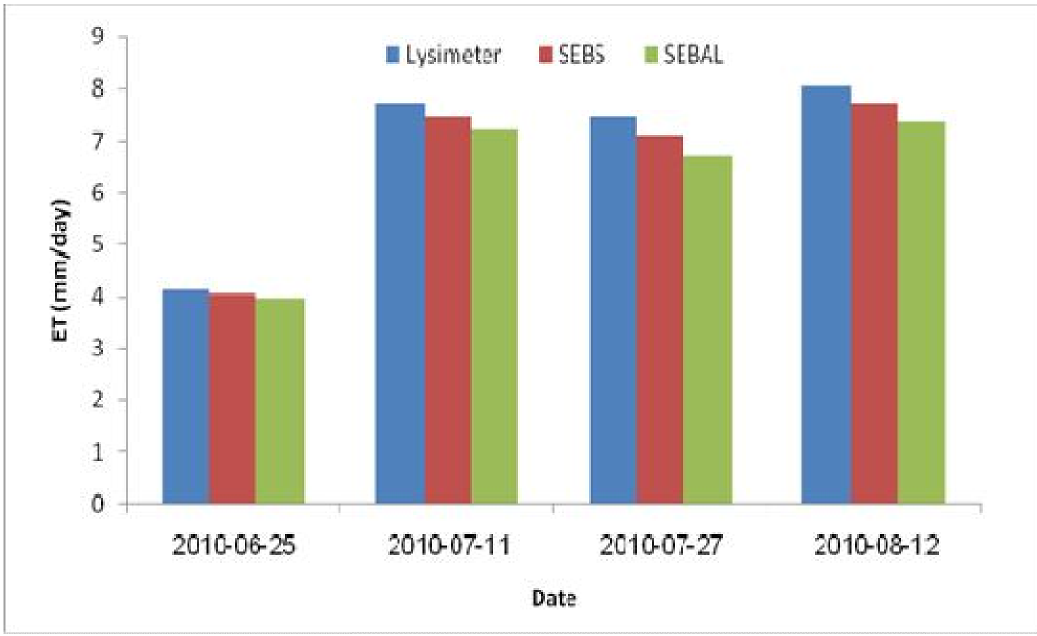

Fig. 4. ET_{SEBAL}, ET_{SEBS} and $ET_{Lysimeter}$ in the maize field (mm day^{-1})

Table 2. Comparison of measured and calculated ET on the satellite image dates

Date	$ET_{Lysimeter}$ (mm day^{-1})	ET_{SEBAL} (mm day^{-1})	ET_{SEBS} (mm day^{-1})	Absolute difference (mm day^{-1})		Relative difference (%)	
				SEBAL	SEBS	SEBAL	SEBS
25-06-2010	4.13	3.97	4.05	0.16	0.08	3.87	1.94
11-07-2010	7.74	7.20	7.47	0.54	0.27	6.97	3.49
27-07-2010	7.45	6.72	7.11	0.73	0.34	9.79	4.56
12-08-2010	8.05	7.35	7.72	0.70	0.33	8.69	4.10

Table 3. Comparison of the maximum regional ET_{SEBAL} and ET_{SEBS} with ETO

Date	ETO (mm day^{-1})	ET_{EBAL} (mm day^{-1})	ET_{SEBS} (mm day^{-1})	Absolute difference (mm day^{-1})		Relative difference (%)	
				SEBAL	SEBS	SEBAL	SEBS
25-06-2010	5.90	6.26	6.32	0.36	0.42	6.10	7.12
11-07-2010	9.00	9.01	9.02	0.01	0.02	0.11	0.22
27-07-2010	7.45	8.24	8.30	0.79	0.85	10.60	11.41
12-08-2010	7.00	8.32	8.53	1.32	1.53	18.86	21.86

The maximum difference between estimated ET by SEBAL and SEBS algorithms with ETO belongs to the date of 12.08.2010 with 18.86 and 21.86 percent respectively. The results of this study are also in consistent with the results of Ramos et al [13] and Temsgen [17].

4. CONCLUSION

Results of the current study showed that the SEBAL and SEBS algorithms can estimate the actual ET of maize with acceptable accuracy in the Mahidasht. In this study the accuracy of SEBS in the estimation of maize ET was better than SEBAL algorithm. It is recommended to do study on other remote sensing based approaches of ET and compare the results with SEBAL and SEBS models. In the absence of measured ET data at the regional level it was difficult to have a reasonable judgment on the accuracy of estimated values of ET by SEBAL and SEBS algorithms in this scale.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Allen RG, Pereira LS, Raes D, Smith M. Crop evapotranspiration - Guidelines for computing crop water requirements. Rome, Italy: FAO Irrigation and Drainage paper No. 56, FAO; 1998.
2. Gao Y, Long D, Li ZL, Estimation of daily actual evapotranspiration from remotely sensed data under complex terrain over the upper Chao river basin in North China. International Journal of Remote Sensing. 2008; 29(11):3295-3315.
3. Santos CACd, Bezerra BG, Silva BBd, Rao TVR. Assessment of daily actual evapotranspiration with SEBAL and S-SEBI algorithms in cotton crop. Revista Brasileira de Meteorologia. 2010;25(3): 383-392.
4. Verstraeten WW, Veroustraete F, and Feyen J, Assessment of evapotranspiration and soil moisture content across different scales of observation. Sensors. 2008; 8(1):70-117.
5. Li Z-L, Tang R, Wan Z, Bi Y, Zhou C, Tang B, et al. A review of current methodologies for regional evapotranspiration estimation from remotely sensed data. Sensors. 2009; 9(5):3801-3853.
6. Bastiaanssen WGM, Menenti M, Feddes RA, Holtslag AAM. A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. Journal of Hydrology. 1998;212-213(0):198-212.
7. Su Z. The surface energy balance system (SEBS) for estimation of turbulent heat fluxes SEBS-The Surface Energy Balance. Hydrology and Earth System Sciences. 2002;6(1):85-100.
8. Muthuwatta L, Ahmad MD, Bos M, Rientjes THM. Assessment of water availability and consumption in the Karkheh River basin, Iran—using remote sensing and geo-statistics. Water Resources Management. 2010;24(3):459-484.
9. Tang R, Li ZL, Jia Y, Li C, Sun X, Kustas WP, et al. An intercomparison of three remote sensing-based energy balance models using Large Aperture Scintillometer measurements over a wheat–corn production region. Remote Sensing of Environment. 2011;115(12):3187-3202.
10. Rwasoka DT, Gumindoga W, Gwenzi J, Estimation of actual evapotranspiration using the surface energy balance system (SEBS) algorithm in the Upper Manyame catchment in Zimbabwe. Physics and Chemistry of the Earth, Parts A/B/C. 2011; 36(14-15):736-746.
11. Gibson L, Jarmain C, Su Z, Eckardt F. Review: Estimating evapotranspiration using remote sensing and the Surface Energy Balance System–A South African perspective. Water SA. 2013;39(4):477-484.
12. Bastiaanssen W, Pelgrum H, Wang J, Ma Y, Moreno J, Roerink G, et al. A remote sensing surface energy balance algorithm for land (SEBAL).: Part 2: Validation. Journal of hydrology. 1998;212:213-229.
13. Ramos JG, Cratchley CR, Kay J, Casterad MA, Martínez-Cob A, and Dominguez R, Evaluation of satellite evapotranspiration estimates using ground-meteorological data available for the Flumen District into the Ebro Valley of NE Spain. Agricultural water management. 2009;96(4):638-652.
14. Lin W, van de Velde R, Su Z. Satellite based regional scale evapotranspiration in the Hebei Plain, Northeastern China. Proceedings of Dragon. 2006;1:2004-2007.
15. Su H, McCabe M, Wood E, Su Z, Prueger J, Modeling evapotranspiration during SMACEX: Comparing two approaches for local-and regional-scale prediction. Journal of Hydrometeorology. 2005;6(6):910-922.
16. Shan X. Regional evaptranspiration over arid inland Heihe river basin in Northwest China. International Institute for Geo-information Science and Earth Observation (ITC), Enschede, The Netherlands. MSc thesis; 2007.
17. Temesgen E. Estimation of evapotranspiration from satellite remote sensing and meteorological data over the Fogera Floodplain–Ethiopia. International Institute for Geo-information Science and Earth Observation (ITC), Enschede, The Netherlands. MSc thesis; 2009.
18. Gebreyesus MG. Validation of RS approaches to model surface characteristics in hydrology: A case study in Guarena Aquifer, Salamanca, Spain. International Institute for Geo-information Science and Earth Observation (ITC),

Enschede, The Netherlands. MSc thesis; 2009.

19. Allen R, Tasumi M, Trezza R, SEBAL (Surface Energy Balance Algorithms for Land). Advanced Training and Users Manual-Idaho implementation. Version 1. 2002;97.

20. Oberg JW, Melesss AM. Evapotranspiration dynamics at an ecohydrological restoration site: An energy balance and remote sensing approach. JAWRA Journal of the American Water Resources Association. 2006;42(3):565-582.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=958&id=24&aid=8785