# COMPARISON OF SEBAL-BASED EVAPOTRANSPIRATION WITH LYSIMETERIC DATA

# COMPARASION DES DONNEES D'EVAPOTRANSPIRATION UTILISANT SEBAL AVEC DES DONNEES LYSIMETRIQUES

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## ABSTRACT

*There are several algorithms for estimation of crop evapotranspiration such as SEBAL (Surface Energy Balance Algorithm for Land). In this study, SEBAL was used for estimation and evaluation of agricultural crop evapotranspiration by using of MODIS, NOAA, and ASTER imaginary and meteorological data of Kerman province and consequently results were compared with lysimeteric data. Due to hot and dry climate of the study area, optimum value of L (soil adjustment factor) had to be determined. Results show that increasing of L causes increasing of estimated evapotranspiration and minimum errors occurred when L equals to 1. In this case, RMSE was 0.29 and 0.76 by the use of MOSIS and NOAA imaginary respectively. Relative error of evapotranspiration estimation by SEBAL from MODIS, NOAA and ASTER images are 10%, 13% and 3.57% respectively. Errors are introduced by the difference in time of irrigation and different characteristics of cultivated plant in lysimeter data, adjacent farms, around area and interpolation of hourly meteorological data.*

**Key words:** *MODIS, NOAA, ASTER, SEBAL, evapotranspiration, Kerman province, soil adjustment factor, remote sensing.*

## RESUME

*Il existe plusieurs algorithms pour l'estimation de.l'évapotranspiration des culturestelles que SEBAL (Surface Energy Balance Algorithm pour la Terre). Dans cette étude, SEBAL a été utilisée pour l'estimation et l'évaluation de l'évapotranspiration des cultures agricoles à l'aide de MODIS, NOAA, et les données ASTER imaginaireet météorologiques de la province de*

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*Kerman resultants et par consequent ont étécomparés avec les données lysimeteric. En raison de hotness et la sécheresse dezone d'étude, la quantité optimal de L (facteur d'ajustement du sol) ont obtenu de l'être. Les résultats montrent que l'augmentation de L causes plus en plus del'évapotranspiration estimée et le minimum des erreurs s'est produite lorsque la quantité de L est égal à 1. Dans ce cas, RMSE était de 0,29 et 0,76 par l'utilisation deMOSIS et la NOAA imaginaire respectivement. Images d'erreur relative de l'estimation de l'évapotranspiration par SEBAL de MODIS, NOAA et ASTER sont de 10%, 13% et 3.57% respectivement. Les erreurs sont introduites par la différence de temps de l'irrigation et des caractéristiques différentes de plantes cultivées dans les données de lysimètre, les exploitations voisines, autour de la zone et l'interpolation des données météorologiques horaires.*

***Mots clés :** MODIS, NOAA, ASTER, SEBAL, évapotranspiration, province de Kerman, facteur d'ajustement des sols, télédétection.*

*(Traduction française telle que fournie par les auteurs)*

# 1. INTRODUCTION

Usual methods of evapotranspiration (ET) estimation are mostly point based. Since agriculture is the main water consumer in most countries and ET varies spatially and seasonally according to weather and vegetation cover conditions (Hanson, 1991), estimation of the temporal and spatial distribution of ET is essential for managing river basins and water supply systems. This can be achieved by the use of remote sensing data.

In arid and semi-arid regions where rainfall is much less than evaporative demand and agriculture is only possible with surface or groundwater irrigation, accurate estimation of ET can help managing agricultural water use. ET is one of the most important components in hydrology cycle in such regions.

Several algorithms are developed for estimation of ET by the use of remote sensing such as SEBAL (Bastiaanssen et al., 1998), SEBS (Su, 2002), S-SEBI (Roerink and Menenti, 2000 and TSEB (Kustas and Norman, 2000). SEBAL is one of the mostly used algorithms which is applied in several countries and presented acceptable results (Bastiaanssen et al., 2003).

Bastiaanssen et al. (1998, 2003) evaluated SEBAL algorithm and showed that without any calibration procedure the Root Mean Square Error (RMSE) of evaporative fraction varied from 0.1 to 0.2. The accuracy at field scale was 85% and 95% for 1 day and seasonal basis, respectively, and the accuracy of annual ET of large watersheds was 96% on average.

In this research, SEBAL was run by using three satellite images, MODIS, AVHRR and ASTER in Kerman, Iran, a semiarid region. The results were compared with lysimeteric data measured hourly and daily. Also the effect of L factor on estimation of ET is considered.

# 2. MATERIAL AND METHODS

## 2.1 Satellite images

SEBAL and similar algorithms can be run by the use of either visible and near-infrared and thermal infrared images. In this study 14 MODIS images, one ASTER image and 18 AVHRR images are used. The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) covers a wide spectral region with 14 bands from the visible to the thermal infrared with high spatial, spectral and radiometric resolution (ASTER user handbook).

The spatial resolution varies with wavelength: 15 m in the visible and near-infrared (VNIR), 30 m in the short wave infrared (SWIR), and 90 m in the thermal infrared (TIR).

The MODerate resolution Imaging Spectrometer (MODIS) instrument flies on the Earth Observation System's (EOS) Terra and Aqua satellites. It has 36 spectral bands between 0.405 and 14.385 Am whose spatial resolutions range is from 250 to 500 and 1000 m. Table 1 shows the Characteristics of the bands which are used in SEBAL.

The AVHRR is a five spectral wavelength sensor with coverage in the visible and near-infrared solar reflective wavelengths and three spectral bands in the thermal infrared region (Prabhakara, 1974).

Preprocessing of satellite images includes dereferencing and calibration which were made with the use of ENVI (Environment for Visualizing Images) software.

Table1. Characteristics of the bands of MODIS sensor which used in SEBAL

| Range | Band number | bandwidth | Spatial resolution |
|---|---|---|---|
| Red and infrared | 1 | 620-670 | 250(m) |
| | 2 | 841-874 | |
| | 3 | 459-479 | 500(m) |
| | 4 | 545-565 | |
| | 5 | 1240-1250 | |
| | 6 | 1628-1652 | |
| | 7 | 2105-2155 | |
| Termal | 31 | 10.78-11.28 | 1(km) |
| | 32 | 11.77-12.27 | |
| The bandwidths 1 to 7 are in terms of nm.<br>The bandwidths of 31,32 are in terms of µm. | | | |

## 2.2 SEBAL

SEBAL algorithm, calculates evapotranspiration as a residual of surface energy balance for land.

$$R_n = G + H + \lambda ET \quad (1)$$

Where $\lambda ET$ is latent heat flux, Rn is the net heat flux, G is the soil heat flux and H is the sensible heat flux (all the units are w/m$^2$). The ground heat flux is estimated using surface temperature, albedo, and vegetation index (NDVI, SAVI and LAI). Figure1 shows the flowchart of SEBAL approach.

One of the advantages of SEBAL is that it does not need to use a land map. In this case SEBAL uses Soil Adjustment Vegetation Index (SAVI) and Leaf Area Index (LAI) for estimation sensible heat flux. SAVI can be calculated using equation 2:

$$SAVI = \frac{(1+L)(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + \rho_R + L)} \qquad (2)$$

Where L is a non-dimensional correction factor, which range from 0 to 1, from high to low vegetation.

One of the methods of finding L as used in southern Idaho is that the standard deviation (STDEV) between different soil locations or conditions becomes minimum when the L factor reduce the impact of soil wetness on the vegetation index.

L coefficient 4 MODIS images were selected in the dates 6/9/2005, 6/12/2005 15/3/2006 and 20/3/2006; two images before and two after rainfall to decrease the effect of soil moisture and subsequently the effect of soil for achieving the best L in SAVI index. In each image, several pixels have choose which are indicators of dry bare field with bright color, wet bare field with dark color and totally dead grassland from desert area with different soil colors. SAVI was run for each image by the use of L from 0 to 1 and in each L where the standard deviation of SAVI rates was lower; L was selected to the area.

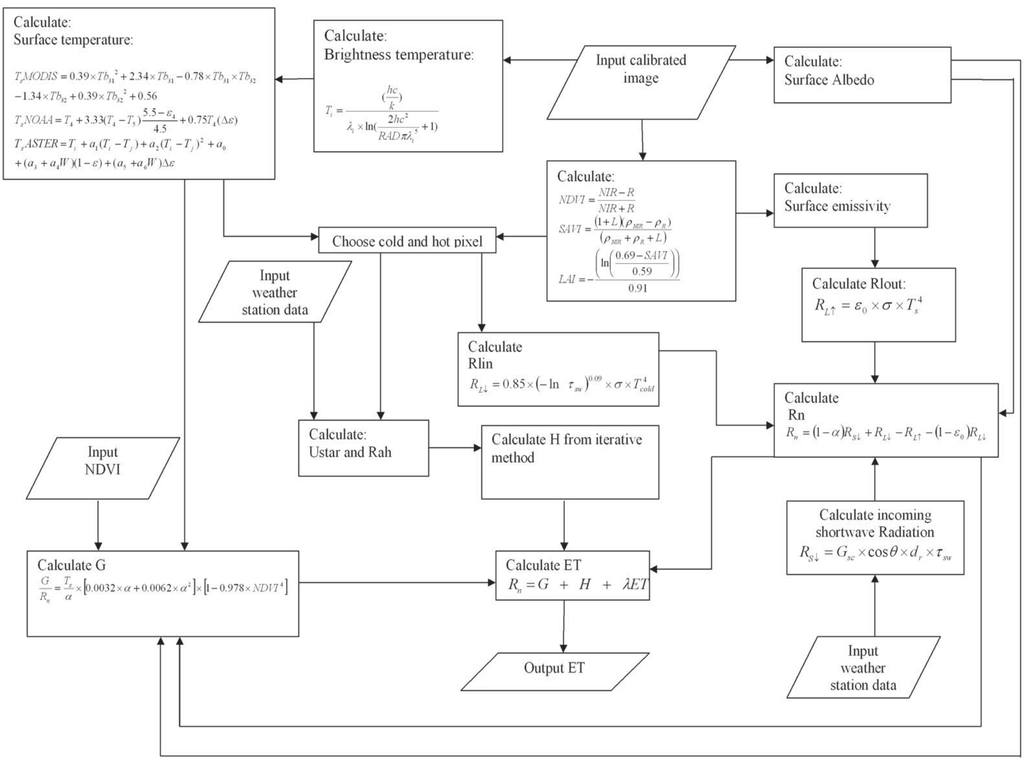



Fig. 1. Flowchart of SEBAL

## 2.3 Site description

Kerman is located in semi arid region according to De Martonne (1926) index of aridity (Bakhtiari *et al*., 2009). The 35-year average annual rainfall of Kerman is 154.1mm. Accordingly average air temperature and average annual relative humidity are 17.1ºC and 32%. Also average air temperatures for hottest and coolest month are 34.7 ºC and 4.6 ºC respectively (Bakhtiari *et al*., 2009). The under cultivation area of wheat in Kerman Township is 6000ha and 99.7% of it is under irrigation. According to importance of wheat production and reduction of groundwater sources, it is afforded to estimate water requirement of this crop by the use of remote sensing. The meteorological data including wind speed, air temperature, reference ET and dew point temperature for calculating humidity are recommended for processing SEBAL, which were collected from meteorological station of Kerman, Iran at 5km from lysimeter site.

Lysimeteric data collected from weighable lysimeter of Bahonar University of Kerman province, located at 57°7′39.8″E, 30°14′23.3″N and average height of 1753.8 (figure 2).

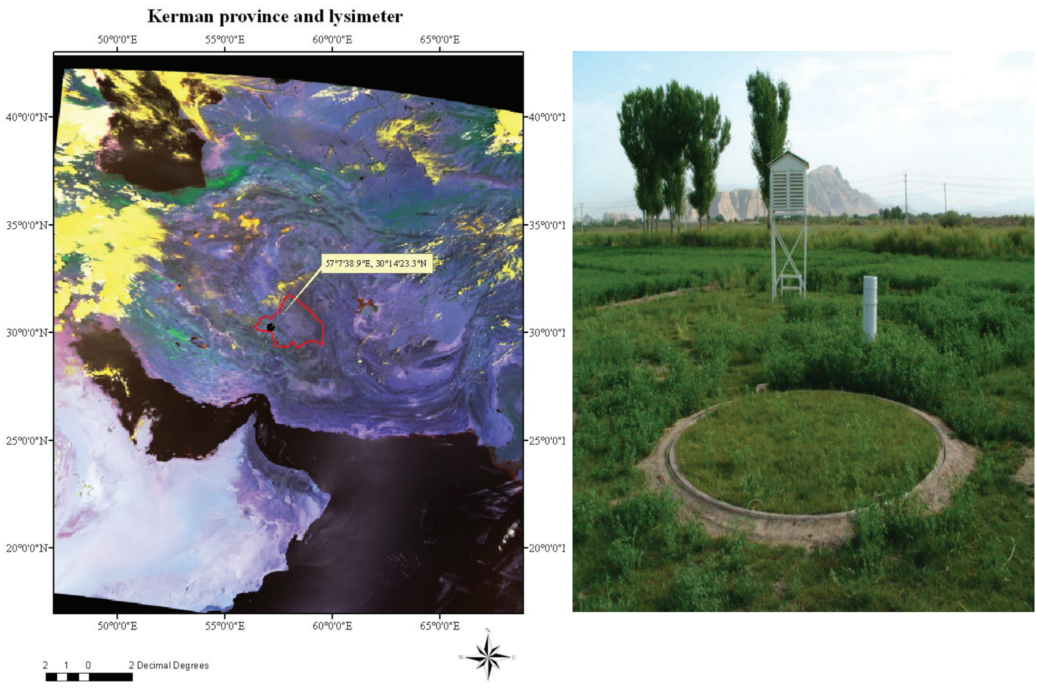



Fig. 2. Kerman province image and location of the Lysimeter

# 3. RESULTS AND DISCUSSION

The results show that whatever L values get larger the standard deviation decrease and the value of L (soil adjustment factor) in such an arid region is seems to be one (figure 3). The other point which is obtained by observing the graphs show that with increasing L, the estimated SAVI and LAI indexes decrease.

Table 2 shows the results of running SEBAL by the use of ASTER images. The decrease of LAI and SAVI causes the increase of estimated ET. In formulation of SEBAL (Waters, 2002), LAI has a direct relation with the momentum roughness. The decrease in the momentum roughness causes the increase in friction velocity and aerodynamic resistance and finally reduction in estimated sensible heat flux and increase in estimated ET. Figure 4 shows these changes more apparently.

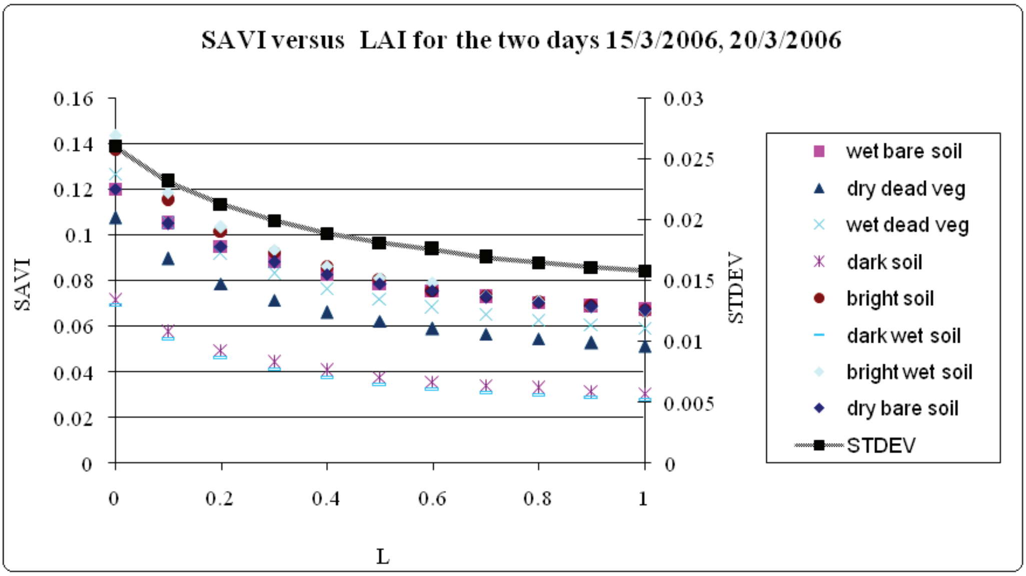
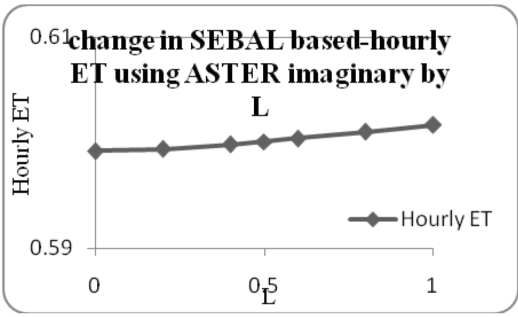



Fig. 3. SAVI versus different L values



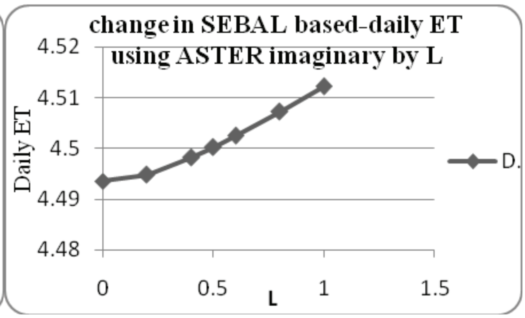




Fig. 4. Change in SEBAL- based ET using ASTER imaginary by changing in L values

SEBAL –based ET variability by L from 0 to 0.5 is more than from 0.5 to 1. So use of L=0.5 does not accompanied by large errors. Totally the change in L even in semi arid region, do not change the value of estimated ET so much, but as in scarce vegetation soil effect must be adjust, increasing LAI may cause decrease in the regions where ET is estimated. This shows that if land use map is not available in scarce vegetation regions, determining L would important. Tables3 and4 show that there is a good agreement between SEBAL-based ET by using MODIS images and measured data. These tables show also the date and the error of the estimated ET versus lysimeter ET. RMSE that shows absolute error (Singh *et al.*, 2006) in predicting ET that reduce obviously from L=0 to L=1(plotted in figure 5). The difference in error between L=0 to L=0.5 is much larger than the difference in error between L=0.5 to L=1 so the L=0.5 can be use trustfully.

Table 2. Hourly and daily SEBAL based ET by using ASTER image and lysimeteric values

| Date 4/30/2007 | Lysimetric value | L | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 0.2 | 0.4 | 0.5 | 0.6 | 0.8 | 1 |
| Hourly (mm/hr) | 0.5156 | 0.5992 | 0.5993 | 0.5998 | 0.6001 | 0.6003 | 0.6010 | 0.6016 |
| Daily (mm/day) | 4.679 | 4.493 | 4.494 | 4.498 | 4.500 | 4.502 | 4.507 | 4.512 |
| Hourly relative error | | 16.19 | 16.23 | 16.32 | 16.37 | 16.43 | 16.55 | 16.68 |
| Daily relative error | | -3.98 | -3.94 | -3.88 | -3.83 | -3.88 | -3.69 | -3.57 |

Table 3. SEBAL based daily ET using MODIS images and Lysimeteric ET

| Date | lysimeteric ET | SEBAL based ET | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | L | | | | | | |
| | | 0 | 0.2 | 0.4 | 0.5 | 0.6 | 0.8 | 1 |
| 5/03/2007 | 0.567 | 0.559 | 0.567 | 0.574 | 0.577 | 0.579 | 0.585 | 0.592 |
| 5/04/2007 | 0.443 | 0.421 | 0.425 | 0.428 | 0.431 | 0.431 | 0.433 | 0.435 |
| 5/07/2007 | 0.466 | 0.433 | 0.440 | 0.446 | 0.448 | 0.450 | 0.453 | 0.456 |
| 5/12/2007 | 0.548 | 0.476 | 0.486 | 0.492 | 0.495 | 0.497 | 0.501 | 0.504 |
| 5/19/2007 | 0.470 | 0.433 | 0.435 | 0.436 | 0.437 | 0.437 | 0.438 | 0.439 |
| | RSME | 0.041 | 0.035 | 0.031 | 0.030 | 0.029 | 0.028 | 0.027 |
| | MAE | 0.035 | 0.028 | 0.026 | 0.025 | 0.025 | 0.024 | 0.024 |
| | CRM | -0.069 | -0.056 | -0.047 | -0.043 | -0.040 | -0.033 | -0.027 |

Table 4. SEBAL based hourly ET using MODIS images and Lysimeteric ET

| Date | lysimeteric ET | SEBAL based ET | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | L | | | | | | |
| | | 0 | 0.2 | 0.4 | 0.5 | 0.6 | 0.8 | 1 |
| 5/03/2007 | 4.812 | 4.202 | 4.264 | 4.314 | 4.336 | 4.357 | 4.401 | 4.451 |
| 5/04/2007 | 4.278 | 3.902 | 3.944 | 3.973 | 3.995 | 3.996 | 4.015 | 4.034 |
| 5/07/2007 | 3.886 | 3.258 | 3.316 | 3.356 | 3.373 | 3.387 | 3.412 | 3.434 |
| 5/12/2007 | 4.431 | 4.310 | 4.398 | 4.456 | 4.479 | 4.499 | 4.536 | 4.567 |
| 5/19/2007 | 4.050 | 3.896 | 3.913 | 3.926 | 3.931 | 3.936 | 3.943 | 3.949 |
| | RMSE | 0.435 | 0.389 | 0.357 | 0.342 | 0.332 | 0.311 | 0.291 |
| | MAE | 0.378 | 0.324 | 0.296 | 0.287 | 0.283 | 0.271 | 0.259 |
| | CRM | -0.088 | -0.076 | -0.067 | -0.063 | -0.060 | -0.054 | -0.048 |

RMSE does not show relative error and it is proportional to mean value. Therefore CRM index that shows relative error was also calculated. The negative and positive quantities of CRM show underestimation and overestimation of model predictions (Singh *et al*., 2006). As is shown in tables 3 and 4 the CRM is negative that shows SEBAL has underestimated evapotranspiration. The differences between lysimeter ET and SEBAL-based ET may be due to:

(1) The time and amount of irrigation inside of lysimeter and around farm was different from the rest of the area because the pixel size of MODIS is much larger than the lysimeter size, and

(2) Interpolation the weather data for estimation meteorological data at satellite image time. An example of running SEBAL on MODIS imaginary is presented in figure 6.

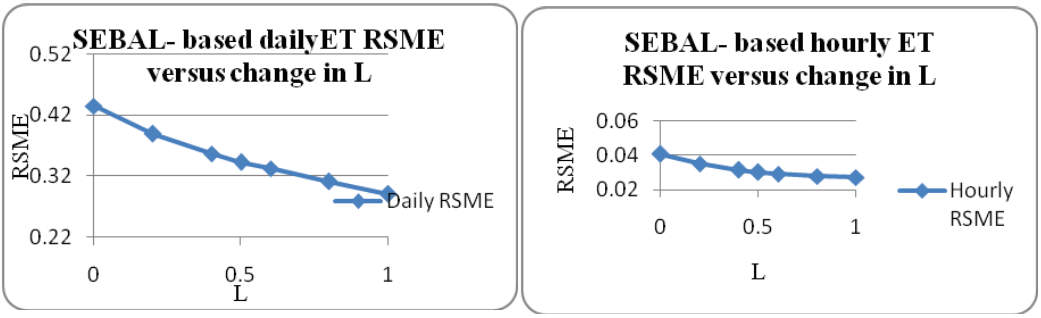



Fig. 5. RSME of SEBAL-based ET using MODIS imaginary

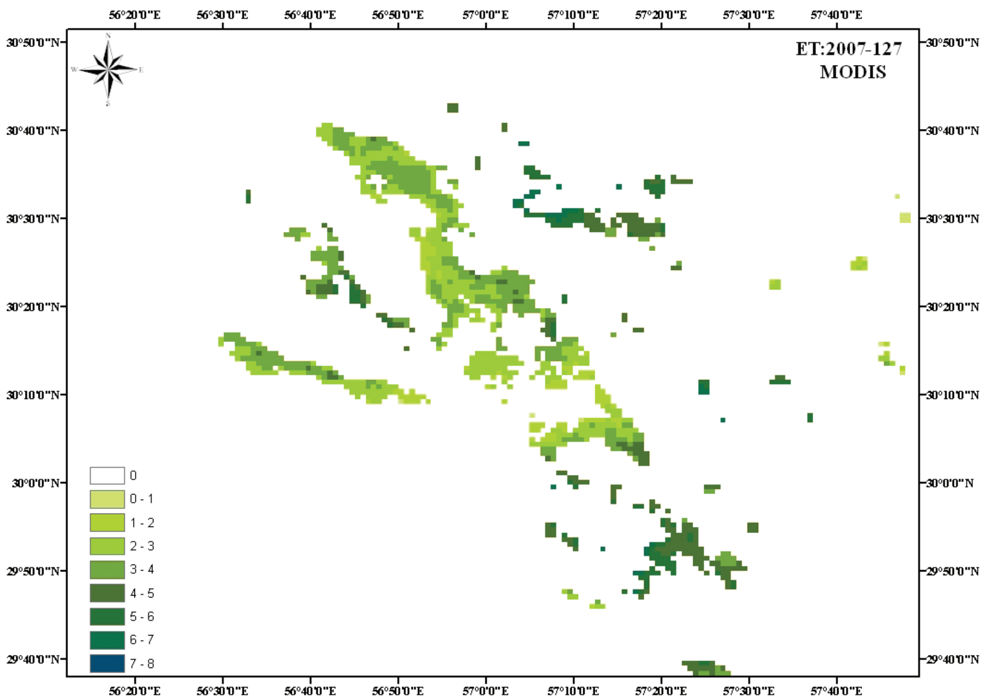



Fig. 6. SEBAL- based daily ET by the use of MODIS imaginary for the day: 5/07/2007

Teillet *et al*. (1997) found that the best bandwidth for computing vegetation indices is in 50nm. The spectral characteristic of the AVHRR in visible and red bands are 100 and 275 nm respectively and it may limits the use of L greater than 0.1 for running SEBAL by using NOAA imaginary (figure 7 shows an example). RMSE was 0.76 for SEBAL-base ET and the CRM was also negative that show underestimation of the model. The relative error for daily and hourly ET was 13 and 20 %( table5). ASTER image has the best result with the relative error of 3% and NOAA image has the worst result with the error of 13%. It is clear that the spectral and spatial resolution of ASTER is much accurate than the other two applied sensors.

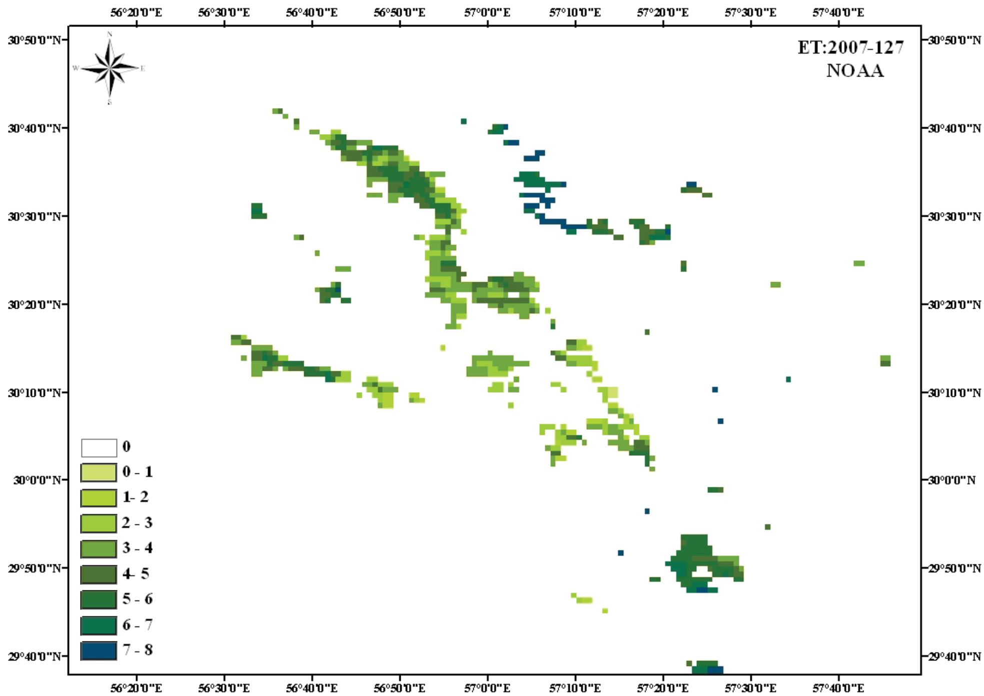
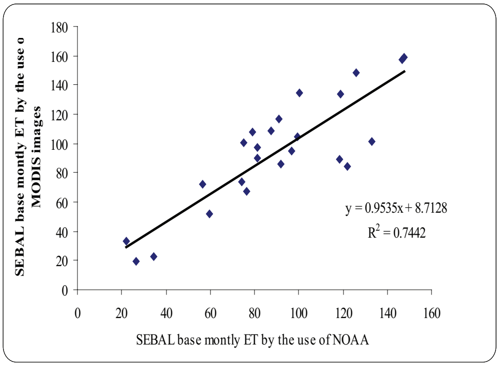



Fig. 7. SEBAL- based daily ET by the use of NOAA imaginary for the day: 5/07/2007

In several studies have shown that the long-term SEBAL-based ET is much accurate (Bastiaanssen et a1. 2005 and Allen et al., 2003). Bastiaanssen *et al*. (2005) found that the accuracy of model reaches from 83% daily to 95% monthly. In the present study the monthly ET was estimated for two months of spring and the results were used for the daily and monthly ET correlation between NOAA and MODIS (Figure 9). The images of 2005.05.04 '2005.05.17 '2006.05.04 '2006.06.15 '2007.05.03 '2007.05.14 were used and the same locations from each image were selected for this purpose. As shown in Figure 3 the correlation coefficient for daily and monthly ET was 0.88 and 0.74.



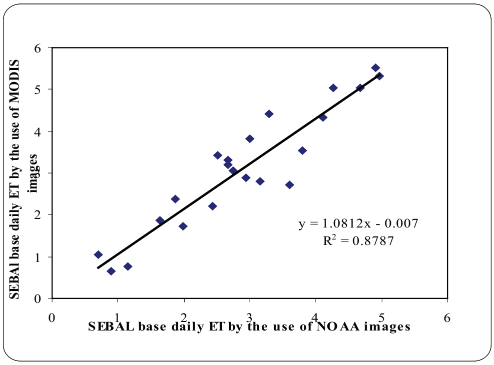




Fig. 8: Relations between SEBAL base ET y the use of NOAA and MODIS images

Table 5. Application of SEBAL by the use of NOAA image

| Date | Hourly lysimeteric value | Hourly SEBAL-base ET | Daily lysimeteric value | Daily SEBAL-base ET | Relative error of hourly ET | Relative error of daily ET |
|---|---|---|---|---|---|---|
| 4/20/2007 | 0.5770 | 0.5566 | 6.1900 | 5.0166 | -4% | -19% |
| 4/22/2007 | 0.4366 | 0.4584 | 5.0061 | 4.2354 | 5% | -15% |
| 4/30/2007 | 0.5157 | 0.7662 | 4.6796 | 4.5348 | 49% | -3% |
| 5/1/2007 | 0.3452 | 0.4403 | 4.3873 | 3.7602 | 28% | -14% |
| 5/3/2007 | 0.4741 | 0.5391 | 4.8118 | 4.6946 | 14% | -2% |
| 5/4/2007 | 0.4430 | 0.3785 | 4.2780 | 3.3115 | -15% | -23% |
| 5/7/2007 | 0.4658 | 0.3868 | 3.8856 | 3.1780 | -17% | -18% |
| 5/8/2007 | 0.3487 | 0.2003 | 2.0710 | 1.9122 | -43% | -8% |
| 5/12/2007 | 0.5483 | 0.4292 | 4.4313 | 4.0226 | -22% | -9% |
| 5/13/2007 | 0.4957 | 0.5114 | 4.6904 | 4.4136 | 3% | -6% |
| 5/14/2007 | 0.4289 | 0.5757 | 3.6029 | 4.4182 | 34% | 23% |
| 5/15/2007 | 0.4361 | 0.3957 | 4.1672 | 3.7440 | -9% | -10% |
| 5/21/2007 | 0.7916 | 0.4463 | 5.9022 | 4.2527 | -44% | -28% |
| RMSE | 0.143085196 | | 0.767985815 | | | |
| MAE | 0.108601334 | | 0.633834092 | | | |
| CRM | -0.035197777 | | -0.128348462 | | | |

# 4. CONCLUSIONS AND RECOMMENDATIONS

In this study SEBAL was conducted in Kerman region in Iran. The results of this study showed:

1. Good precision of model prediction in daily and hourly ET. This research has shown that where low-resolution images also can estimate ET with sufficient confidence. One problem

with estimating ET using images with low resolution is heterogeneous vegetation in each pixel that create the difference between the values of estimated and actual ET. However application of low resolution images is cost-effective.

2. SEBAL –based ET variability by L from 0 to 0.5 is higher than from 0.5 to 1. So use of L=0.5 do not accompanied by large errors. Totally the change in L even in semi arid region, do not change the estimated ET so much.

3. Among the applied images, estimated ET by NOAA data has the highest error. Plant has the higher reflection in infrared spectrum, while the soil also reflected in the considerable range. The bandwidth of NOAA Images in this spectrum can be effective in this case. MODIS sensor spectral feature vary with NOAA and led to more accuracy in estimated ET. Using soil adjustment factor for each area can adjust the effect of soil that causes some error, because its effect in reducing the RMSE in estimating daily ET by MODIS images to up to 0.14 is well evident.

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