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Estimation of Water Requirement of Olive Orchards with Satellite Images (Case Study: Tarom)

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ABSTRACT: Knowing water requirement or the actual amount of evapotranspiration for agricultural lands is an appropriate tool and technique for water resource management. Estimation of actual evapotranspiration from field observations is a time-consuming and difficult task. In this regard, remote sensing methods are powerful tools for the assessment of water consumption in a regional scale. In this study, MODIS (land bands 1-7, and thermal bands) and SEBAL algorithm were used to extract water requirement of olive in Tarom County from December 22, 2011 to August 23, 2013. Results from SEBAL algorithm were compared with Penman-Monteith method. Findings indicated that the root mean square error (RMSE) in the estimation of daily evapotranspiration by MODIS and Penman-Monteith method was 0.98.

Keywords: Water Requirement, SEBAL Algorithm, Penman-Monteith, Olive, Tarom County.

INTRODUCTION

Irrigation planning is an important aspect for successful production of high-quality crops (Intrigliolo and CASTEL, 2008). To achieve an optimal irrigation planning, access to a reliable method for the determination of water consumption, i.e. daily evapotranspiration (ET), is essential. To this end, remote sensing methods are powerful tools for ET estimation in studying water consumption in a regional scale (Gowda *et al.*, 2008). Since 90s, the most common energy balance-based remote sensing algorithms for ET estimation were the Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen *et al.*, 1998) and the Surface Energy Balance System (SEBS). The SEBAL algorithm was introduced by Bastiaanssen *et al.* (1998) to determine water and energy fluxes. It is capable of computing evapotranspiration using satellite images. An advantage of SEBAL is that it requires quantitative data for the calculation of pixel-based actual evapotranspiration and covers vast areas (Bashir *et al.*, 2008). This algorithm calculates instant and 24-hour surface heat fluxes. The required data are satellite images from visible, near infrared, and thermal infrared bands, as well as meteorological data such as temperature and wind speed. Satellite radiations change to the surface properties such as surface albedo, leaf area index (LAI) and surface temperature. SEBAL does not need any data related to the land use, soil type, or hydrological conditions. It has been validated in some projects and studies in different parts of the world including southern basin of California (Thoreson, 2009), West Bank (Khalaf & Donoghue, 2011), eastern Amazon (Ferreira et al., 2013), and tropical regions of Brazil (Ferreira et al., 2012), using dual crop coefficient approach (FAO 56), data from Penman-Monteith method, data from LBA project , and results from MGB-IPH hydrological model, respectively. Results from those studies showed that SEBAL was reliable in the estimation of water consumption.

In terms of exploiting remote sensing methods in the estimation of olive evapotranspiration, studies by Poças *et al.* (2014) in the Southern Portugal, Er-Raki *et al.* (2010) and Hedges *et al.* (2008) in Morocco can be mentioned. In this regard and based on previous studies indicating the capability of remote sensing algorithms in the estimation of water requirement, SEBAL has been used to estimate the evapotranspiration of olive orchards in Tarom County from December 22, 2011 to August 23, 2013.

MATERIALS AND METHODS

In this study, first, meteorological data were collected, and a general understanding of vegetation and position of olive orchards in the region was obtained. Then, using meteorological data, the evapotranspiration of olive was estimated from December 22, 2011 to August 23, 2013, using Penman-Monteith Method.

In the next stage, high-quality MODIS satellite images within the desired period were captured under non-cloudy condition from http://earthexplorer.usgs.gov. Then, the amount of water consumption in olive orchards was obtained by applying SEBAL algorithm on the captured images.-Finally, the output of the SEBAL algorithm for MODIS images were compared with the results of Penman-Monteith method within the desired period.

Site of the Study: Tarom Country, with Ab Bar as its county center and an area of 2,235 square kilometers, is one of the seven counties of Zanjan Province. It is located at 37º10'E longitude and 36º40'N latitude in the north of Zanjan (100 kilometers from it).

In this study, statistics provided by the meteorological station of Tarom Research Center was used to validate the results of SEBAL algorithm within the desired period. This station is located in Tarom Research Center Complex in Gilvan in Tarom County.

The Energy Balance Equation in SEBAL Algorithm: SEBAL is a remote sensing flux algorithm that calculates the components of energy balance and considers ET as the remainder of the balance equation. Fig.1 represents the components of Energy Balance Equation.

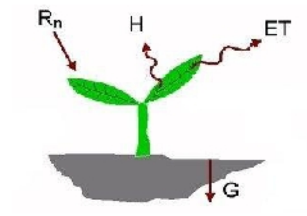

Fig.1. Components of Energy Balance Equation.

$$LE = R_n - G - H \quad (1)$$

where, R_n is net radiation flux density (Wm^{-2}); G is the net heat flux of the soil (Wm^{-2}); H is the sensible heat flux (Wm^{-2}); and Eλ is the latent heat flux (Wm^{-2}) that can be converted into ET (mm/dd) through latent heat of vaporization λ (Jkg^{-1}). In this study, Rn, Eλ, and H are considered positive when they are moving towards the surface, from the surface towards atmosphere, and from surface to the deep soil, respectively.

To implement SEBAL, reflectance information of images in visible, near infrared, middle infrared, and thermal infrared bands are required. Fig. 2 shows the main process of SEBAL algorithm calculation.

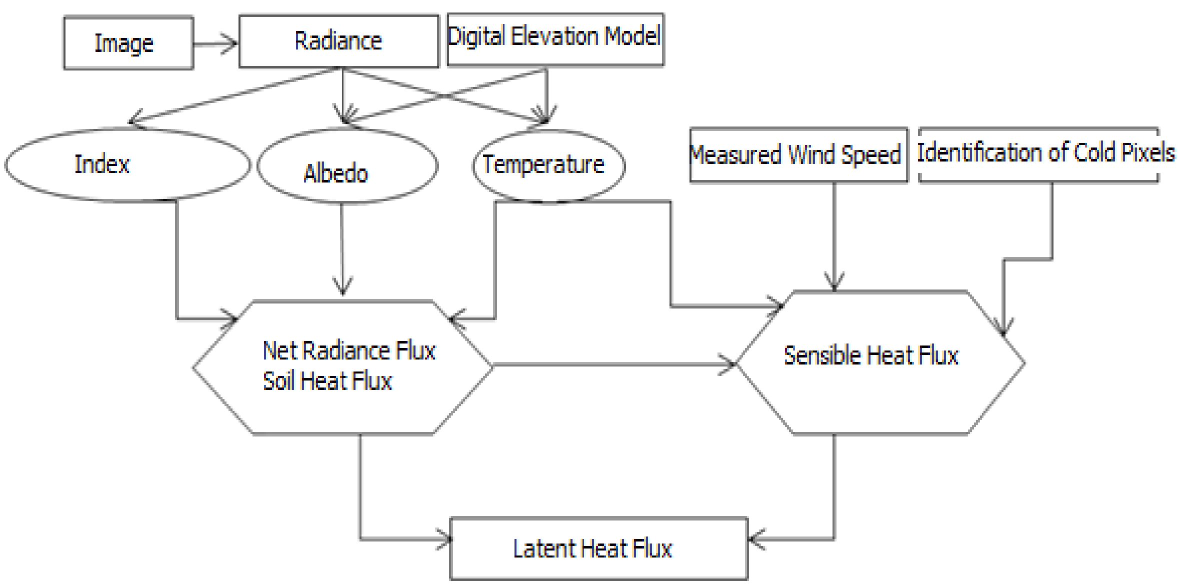

Fig. 2. The main view of computational process in determination of evapotranspiration, using SEBRAL algorithm.

The preparation stages of data include preprocessing, geometric correction of images for different bands, and extraction of researching region in different bands with ArcGIS 10, ERDAS Imagine 9.1, and Idrisi Selva. The computational pattern and processes of SEBAL are presented in Fig. 2. This pattern can be used for computing Eλ, R_n, G, H, evaporative component (Λ), actual evapotranspiration, and 24-hour actual evapotranspiration.

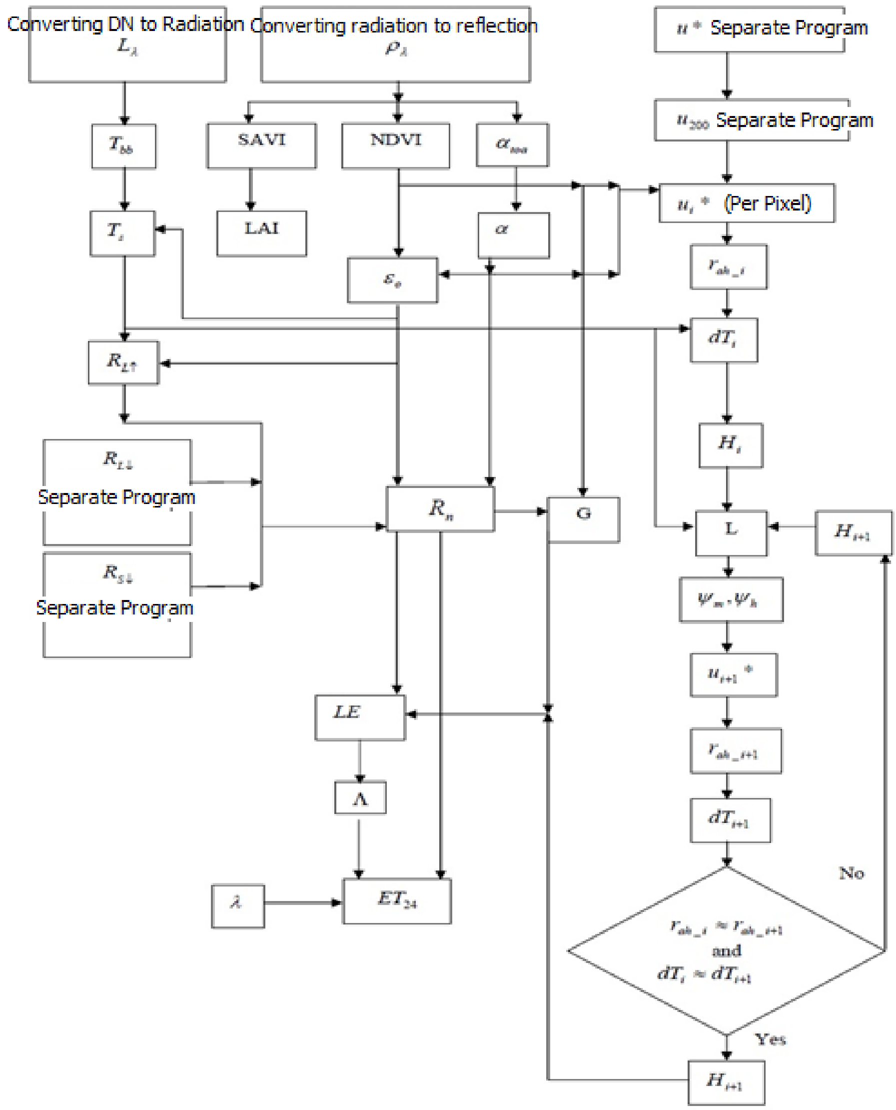

Fig. 3. Computational pattern and processes of SEBRAL

The Penman-Monteith Method for the Determination of evapotranspiration in Regional Scale: The actual evapotranspiration can be computed with the help of meteorological data, where empirical equations for such estimations are developed. The Penman-Monteith equation is:

$$PE = \frac{0.408\Delta(R_n - G_0) + \gamma \frac{900}{T_a + 273.16} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

Where PE is the reference evapotranspiration (mm/day), R_n is surface net radiation (MJ m^{-2} day^{-1}), G is the net heat flux of the soil (MJ m^{-2} day^{-1}), Ta is mean daily temperature (°C) at the height of 2m, U2 is wind speed ($^{-1}$) at the height of 2m, ea is the actualvapor pressure (kPa), es - eais atmospheric vapor pressure deficit (kPa), is the slope of the vapor pressure curve (kPa °C), and is hygrometric constant (kPa °C). The amount of daily evapotranspiration was computed with Penman-Monteith equation for the days this parameter was captured with satellite images. In this method, evapotranspiration potential was computed first with meteorological parameters in Tarom Olive Research Station, and then the actual evapotranspiration was obtained from the multiplication of the former by the olive crop coefficient in different growth period. $Etc = ET_0 * k_c$ (3)

The annual values of olive crop coefficient for semi-moist conditions are presented in Table 1. Validation of SEBAL Results Using Penman-Monteith Method: For the analysis of computational data, four statistical indices have been employed, as follows: The Mean Bias Error (MBE), Root Mean Square Error (RMSE), Agreement Index (AI), and Relative Nash-Sutcliffe Efficiency (NR). The Relative Nash-Sutcliffe Efficiency assessed the model performance by comparing the accuracy of estimated values with the observed values mean of correct and actual data set. The equations of the desired indices along with the optimal values of each index are presented in Table 2.

Table 1: The crop coefficient in different growth stages.

	Development Stages					Region
	Primary School	Development	Mid	Final	Winter	
Period (in days)	30	90	60	90	60	Mediterranean
Crop Coefficient (k_c)	0.65	0.7	0.7	0.7	0.5	

Table 2: Equations of statistical indices.

Statistical Parameters	Symbol	Equation	Optimal State
Mean Bias Error	MBE	$MBE = \frac{1}{n}\sum_{i=1}^{n}(E_i - O_i)$	0
Root Mean Square Error	RMSE	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_i - O_i)^2}$	0
Agreement Index	AI	$AI = 1 - \left[\frac{\sum_{i=1}^{n}(E_i - O_i)^2}{\sum_{i=1}^{n}\left[\lvert E_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert\right]^2}\right]$ *	1
Relative Nash–Sutcliffe Efficiency	Nr	$Nr = 1 - \frac{\sum_{i=1}^{n}(E_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$	1

*n, O, and E stand for the sample size, observational and estimated values, respectively, and $\bar{O}$ is the mean observational values

RESULTS AND DISCUSSION

The temporal and spatial distribution of evapotranspiration obtained from MODIS images and climatic data: Distribution of evapotranspiration in 16-day periods is presented in Fig.4, using MODIS images in Olive Research Center of Tarom and climatic data. These data was obtained from the images of desired geographical region.

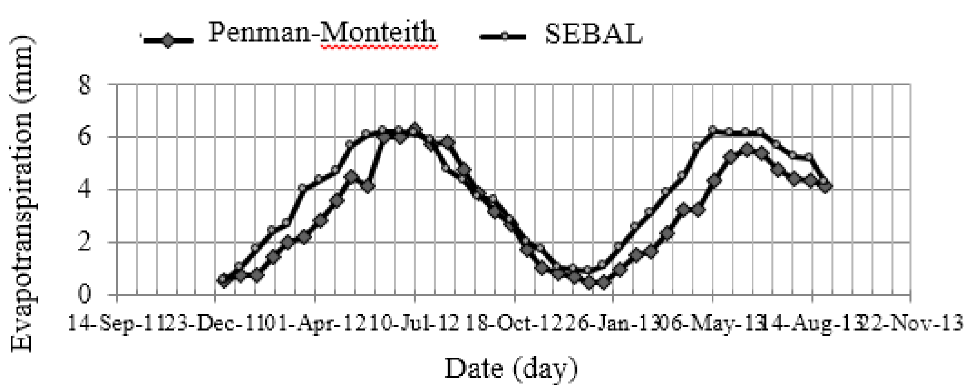

Fig. 4. Temporal distribution of actual evapotranspiration in a 16-day period with SEBAL and Penman-Monteith methods.

At this point, the maximum evapotranspiration was observed in SEBAL method, using MODIS images, from about May 4, 2012 to about August 5, 2012 (Etc =5.9 mm/), and from about May 5, 2013 to about September 6, 2013 (Etc = 6 mm/d).

Statistical analysis of SEBAL results with Penman-Monteith method: Statistical comparative results of Penman-Monteith method in Olive Research Center of Tarom obtained from MODIS images within the mentioned period showed that MBE was positive and equal to 0.71. This indicates that the estimated EF obtained by applying SEBAL algorithm to satellite images was higher than the observational values from Penman-Monteith (Table 3). The value of Nash-Sutcliffe and Agreement Indices were 0.73 and 0.88, respectively. Regarding that their values were approximately close to one, thereby SEBAL gives appropriate estimation relative to Penman-Monteith data, indicating good agreement between them. The RMSE index was obtained as 0.98, implying relatively higher accuracy of SEBAL than Penman-Monteith in the determination of ET (Table 3).

Table 3: Summary of statistical indices.

Index	Value
Mean of SEBAL Method (MODIS)	3.87
Standard Deviation of SEBAL Method (MODIS)	1.91
Mean of Penman-Monteith Method	3.16
Standard Deviation of Penman-Monteith Method	1.9
MBE	0.71
RMSE	0.98
AI	0.88
Nr	0.73

CONCLUSION AND RECOMMENDATIONS

The main goal of the study was to investigate and assess water requirement or actual evapotranspiration of olive orchards in growth season, using remote sensing and satellite images, as well as comparing the results of this method with those of Penman-Monteith. To this end, MODIS images were used as the main data for the estimation of desired parameters. The results from the estimation of olive evapotranspiration, using SEBAL algorithm, were compared and validated with the findings of actual evapotranspiration obtained from the Penman-Monteith method. In this comparison, the values of statistical indices (Nr, RMSE, AI, and MBI) were used as validation parameters. The values of these indices for the first comparison of MODIS results were 0.98, 0.73, 0.88, and 0.71, respectively. The error rate of SEBAL method (using MODIS images), relative to Penman-Monteith method, was estimated as 22%. In general, the estimated values, using MODIS images, were higher than the actual evapotranspiration obtained with Penman-Monteith method.

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