COMPARISON OF SEBAL AND METRIC-BASED EVAPOTRANSPIRATION MODELS IN A SEMI-ARID REGION

*Mohammad Mokhtari *[a], Ibrahim Busu [a] and Kave Deilami [c]*

[a] PhD student, Department of Remote Sensing, Faculty of Geo-information science and engineering, University Technology of Malaysia (UTM), Malaysia; Tel:+60173472496
E-mail:mokhtari.mh@gmail.com

[a] Associate professor, Department of Remote Sensing, Faculty of Geo-information science and engineering, University Technology of Malaysia (UTM), Malaysia; Tel:+60197510310
E-mail: Ibusu@utm.my

c MSc student, Department of Remote Sensing, Faculty of Geo-information science and engineering, University Technology of Malaysia (UTM), Malaysia; Tel:+60177174146
E-mail: kaveh.deilami@utm.my

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ABSTRACT: This study compares the result of evapotranspiration (ET) estimates of the pistachio orchard from surface Energy Balance for Land (SEBAL) and Mapping Evapotranspiration at high Resolution with Internal Calibration (METRIC) models in a semiarid region by using LANDSAT satellite TM5 data. The results showed similarity of ET estimate from both energy balance models at the satellite overpass time, although slight deviation especially at high ET values was observed on daily basis. This is due to differences in calculation of sensible heat and the assumptions of SEBAL and METRIC in extrapolating instantaneous to the daily basis. However, minimum ground data requirement is the major advantage of the SEBAL over the METRIC model. Although, METRIC requires high quality weather data from the ground station located nearby the study area, it takes into account daily variability of climatic parameter via the use of REF_{ET} for extrapolating ET. Therefore, METRIC has priority over the SEBAL where climatic condition varied during the day. Nevertheless, the study has considered both models feasible for estimation of ET from satellite data in the study area. In this study, the maximum value, the sum and ET range by METRIC was higher than SEBAL. The same standard error of mean was observed for SEBAL and METRIC in this study.

INTRODUCTION

During the last decades, there has been increasing need for the accurate estimation of plant water requirement in agricultural sector where large volume of water is consumed. In general the amount of water consumed by plant is considered as water evaporated from the soil and transpirated by plant. Traditionally evapotranspiration (ET) is estimated from point-based ET models such as Penman-Monteith, Priestly-Taylor, Hargreaves, Blaney–Criddle and crop coefficient approach. However, estimation of spatial distribution of ET over the large area is restricted due to wide-spread distribution of weather stations (Ramos, Cratchley et al. 2009). On the other hand, crops have different crop coefficient in different stage, therefore, estimation of crop coefficient and crop stages because of large crops population in the nature is difficult (Allen, Tasumi et al. 2005; Kjaersgaard, Gowda et al. 2009).

Satellite-based estimation of evapotranspiration (ET) have been reported to be essential for spatially evaluation of plant water requirement and water use regulation, particularly in the area with abundant water resources (Bastiaanssen, Molden et al. 2000; Gao and Long 2008; Gowda, Chavez et al. 2008; Kamble and Irmak 2008). Therefore, several satellite-based ET models have been developed and evaluated in different climatic conditions during the last couple of years. Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen, Menenti et al. 1998), Surface Energy

Balance System (Su 2002), Simplified Surface Eenergy Balance Index ((Roerink, Su et al. 2000), Surface Energy Balance Index (Meneti and Chodhury 1993), Two Source Energy Balance (Norman, Kustas et al. 1995) and Hybrid model (calculates net radiation through SEBAL and surface temperature, latent heat flux and sensible heat flux from TSEB (Melesse and Nangia 2005) are the residual methods that calculate energy balance component from different data sources. Energy balance models solve the energy balance of land surface for latent heat flux at the satellite overpass time. Estimated instantaneous latent heat flux then is considered as energy consumed for evaporation and transpiration. Estimated ET at the overpass time of satellite data is extrapolated to 24h ET and interpolated between two consecutive satellite data by means of weather data in order to estimate seasonal ET.

SEBAL as an energy balance model has been examined in more than 30 countries under various climatic condition and results proved the reliability of the estimates (Rossi, Vega et al. 2007; Ramos, Cratchley et al. 2009). The accuracy of the model reported to be 67% to 95% for instantaneous ET and 70% to 98% on daily basis (Bastiaanssen, Noordman et al. 2005). METRIC as a variant of SEBAL similarly estimates actual ET from residual part of the energy balance model. The efficiency of METRIC in estimation of actual ET has been proven by several researcher in previous studies (Allen, Tasumi et al. 2005; Tasumi, Trezza et al. 2005; Trezza 2006; Conrad, Dech et al. 2007; Hendrickx, Kleissl et al. 2007; Mishra, Clay et al. 2008; Chavez, Gowda et al. 2009; Folhes, Rennó et al. 2009). The error of ET estimates via METRIC has been reported to be 10 to 20% for daily basis and 1 to 4% for seasonal estimate (Gowda, Chavez et al. 2008). However, although good agreements have been found in the last between estimated ET by METRIC and that from ground measurement, but the performance of this method require to be evaluated under different agro-climatic conditions (Chavez, Gowda et al. 2007).

1. ALGORITHMS COMMONALITIES

The general form of an energy balance model can be presented as eq.1 (Jiang and Islam 2001). The residual part of the energy balance model is considered as energy utilized for evaporation of water from the soil surface and transpiration from plant canopy.

$$LE = R_n - G - H \tag{1}$$

Where LE is the latent heat loss (W m-2) calculated as a residual of the energy balance equation at the time of the satellite overpass, R_n is net solar radiation (W m-2) (eq.2), G is soil heat flux (W m-2), H is sensible heat (W m-2):

$$Rn = Rns - Rnl \tag{2}$$

Where Rns is net short-wave radiation (W m-2) calculated by subtracting incoming Rns by outgoing Rns, Rnl is net long wave radiation (W m-2) calculated by subtracting incoming Rnl by Rnl. They can be estimated by the TIR-based satellite imagery (Algorithms for extracting information from remote thermal-IR observations of the earth's surface.)

The solar radiation can either be estimated by satellite data (Allen, Tasumi et al. 2007) or can be measured at ground station using Pyranometer. An Albedo-based function is used to calculate Rns from satellite image:

$$Rns = (1 - \alpha) Rs \tag{3}$$

Where α is surface Albedo calculated from visible-near infrared and shortwave bands of image. For the Landsat TM 5 data that has been utilized in this study to develop energy balance model following equation is used (Liang 2004; Folhes, Rennó et al. 2009):

$$\alpha = 0.356\alpha_1 + 0.13\alpha_3 + 0.373\alpha_4 + 0.085\alpha_5 + 0.072\alpha_7 \tag{4}$$

Where α_{1-7} are the surface reflectances's of LANDSAT spectral bands. The area with higher Albedo value increase outgoing shortwave radiation and consequently the available Rn is decreased in this area.

Air emissivity and surface emissivity are used to calculate incoming and outgoing long wave radiation respectively from surface temperature using Stephan-Boltzman equation:

$$R_{L\downarrow} = \varepsilon_a \sigma T_a^4 \tag{5}$$

$$R_{L\uparrow} = \varepsilon_o \sigma T_s^4 \tag{6}$$

Where $R_{L\downarrow}$ and $R_{L\uparrow}$ are the incoming and outgoing long wave radiation, ε_a is the air emissivity, ε_o is the surface emissivity, σ is the Stephan-Boltzman constant ($5.67*10^{-8} Wm^{-2}K^{-4}$), T_a and T_s are the air and surface temperature in Kelvin. T_a is measured at ground station and T_s is calculated from satellite image thermal band(s). In case of using LANDSAT TM data band 6 (Rad_6) in radiance is utilized to calculate T_s :

$$T_s = \varepsilon_o^{-0.25} * Rad_6 \tag{7}$$

Using equation 2 through 7, the net radiation is calculated. The same procedure also is followed by METRIC and SEBAL in order to calculate soil heat flux as is explained bellow:

$$G = (T_S - 273.15)(0.0038 + 0.0074\alpha)(1 - 0.98NDVI^4)R_n \tag{8}$$

Where; T_S is the surface temperature in Kelvin using thermal band, α is surface Albedo and NDVI is vegetation index calculated from Red and near-infra red spectral bands. In case of using LANDSAT data band number 3 and 4 are used to calculate NDVI:

$$NDVI = \frac{\alpha_4 - \alpha_3}{\alpha_4 + \alpha_3} \tag{9}$$

2. ALGORITHMS DIFFERENCES

In general, aerodynamic heat transfers to the air H it is calculated from temperature difference between surface aerodynamic temperature and air temperature at a reference height (Brutsaert 1982). In order to calculate H in most of the energy balance models, temperature differences (dT) between near surface temperature and air temperature at a reference height is used.

$$H = \rho C_p \frac{dT}{r_{ah}} \tag{10}$$

Where ρ is air density (kgm^{-3}), C_p is air specific heat at constant pressure (≈1004 $Jkg^{-1}k^{-1}$), r_{ah} is the aerodynamic resistance to heat transfer and dT(k) is the temperature differences between near surface and reference heights (0.1 and 2m) using wind speed extrapolated to some blending height above the ground surface (100 to 200 m) (eq.11). Assuming linear relationship between dT and radiometric surface temperature Ts, dT is determined for each pixel of image in both METRIC and SEBAL (eq.12).

$$r_{ah} = \frac{LN(z_2 / z_1)}{u^* k} \quad (11)$$

Where; z_1 and z_2 are the height above zero plane displacement height of vegetation that is set to 0.1 m for each pixel and z_2 is the reference height just above the plant canopy set to 2 m, u^* (ms^{-1}) is the friction velocity calculated from the logarithmic wind law for neutral atmospheric conditions (Allen, Tasumi et al. 2007) and K is Von Karman's constant equal to 0.41. An iterative solution is used to calculate r_{ah} and corrected value of u^* is calculated. Detail of iteration process can be found in Allen et al. (2007).

$$dT = a + bT_S \quad (12)$$

a and b is determined iteratively using two dT value and their associated T_S values from two extreme pixels, hot and cold pixels.. SEBAL and METRIC are different in defining two extreme points. Cold pixel is selected from crop surface with full vegetated area. In this pixel the surface temperature (Ts) is assumed to be close to air temperature and dT and H are assumed to be zero. The hot pixel is a dry bare agricultural field where LE is assumed to be 0. Therefore, all available energy considered as H. The two pixels tie the calculations for all other pixels between these two points (Allen, Tasumi et al. 2005).

Similar approach is followed for selection of hot pixel in SEBAL and METRIC. In SEBAL cold pixel is selected from area having deep water body. But in METRIC cold pixel is selected from full vegetated area and ET in this area assumes to be 5% greater ET than the ET_{ref} due to higher surface wetness compare to other vegetation field:

$$dT_{cold\_METRIC} = \frac{(R_n - G - kET_{ref})r_{ah}}{\rho C_p} \quad (24)$$

$$dT_{hot} = \frac{(R_n - G)r_{ah}}{\rho C_p} \quad (25)$$

where; ET_{ref} is hourly reference ET that is estimated from standardized ASCE Penman–Monteith equation for alfalfa reference (ASCE-EWRI 2004), k is an empirical value and is set to 1.05, r_{ah} is aerodynamic resistant for heat transfer calculated for the hot and cold pixels, ρ is air density kgm^{-3} and C_p is air specific heat at constant pressure. Consequently, from the pair of dT value at cold and hot pixel, a and b in eq. 12 is determined and the result is applied to all pixels on the satellite image. According to eq. 1 LE at satellite overpass can be calculated once the G, Rn and H were determined. The next major difference between SEBAL and METRIC is the method of converting instantaneous ET value to the daily basis. SEBAL uses evaporative fraction in order to estimate daily ET (eq. 16), whereas, METRIC utilizes ET_{ref} calculated from ground-based data through ASCE Penman-Monteith method.

$$\Lambda = \frac{LE}{Rn - G} \quad (15)$$

Where LE is the latent heat flux (Wm^{-2}), Rn is the net radiation (Wm^{-2}) and G is the soil heat flux (Wm^{-2}).

$$ET_{24} = \Lambda \times [Rn_{24} \times ((2.501 - 0.002361 \times T_0) \times 10^6 \quad (16)$$

Where Λ is the evaporative fraction, R_{24} is the daily net radiation and T_0 is the surface temperature,

$$ET_{ins} = 3600\frac{\lambda E}{\gamma \rho_w} \tag{17}$$

Where; ET_{ins} is instantaneous ET (mmh^{-1}), 3600 converts from second to hours, ρ_w is density of water (1,000 kgm^{-3})and γ is latent heat of vaporization Jkg^{-1} that is computed from:

$$\gamma = (2.501 - 0.00236 \times (T_s - 273.15)) * 10^6 \tag{18}$$

In order to convert hourly ET to the daily basis, reference ET fraction is computed by dividing ET_{ins} to the ET_r calculated from weather data via standardized ASCE Penman–Monteith equation.

$$ET_r f = \frac{ET_{ins}}{ET_{ref}} \tag{19}$$

Then, the same fraction is used to calculate hourly ET and the results are accumulated (Allen, Tasumi et al. 2007)

3. CASE STUDY RESULT AND DISCUSSION

The study was conducted at the semi-arid region, South-west of Yazd city in Bahadoran area, Iran (fig. 1, Left). This area expands from longitude of 54° 51′ to 54° 59′ in east and latitude of 31° 29′ to 31° 17′ in north and covers about 7000 ha. Pistachio (Pistachio vera L.) is the dominant cropping pattern in this area (over the 97%) The study compares two energy balance algorithm and their application and the results are statistically evaluated.

The comparison of the METRIC and SEBAL is shown in fig. 1(Right). As shown in this figure ET underestimated at high ET rate. It can be due to different approaches in selecting cold pixel. The cold in SEBAL is selected from a deep water body, while in METRIC it is selected from fully covered vegetated area. In addition the variation of the wind speed during the day, especially afternoon time increases the ET rate. However, this is not taken into account by SEBAL.

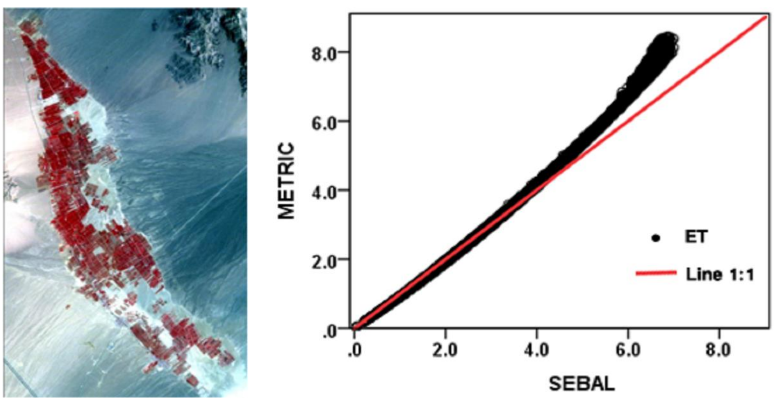

Figure 1: Study LANDSAT 5 TM satellite Image acquired on July 17 2010 (FCC of 4,3,2,) (Left) comparison between SEBAL and METRIC (Right)

Unlike METRIC, SEBAL requires limit numbers of weather data. Therefore, this method is proposed to be used in the area with poor ground station or weather data. However, METRIC takes into account daily weather variability, although high quality hourly weather data collected nearby to the area for calculation of reference evapotranspiration (RefET) through ASCE Penman-Monteith method are required. The detailed statistical information of METRIC and SEBAL ET estimates are shown in the following table1:

Table 1: Statistic results of the comparison

Statistic parameter	ET_METRIC	ET_SEBAL
Mean	3.77	3.60
Std. Error of Mean	0.0057	0.0048
Std. Deviation	1.76	1.47
Variance	3.11	2.18
Skewness	0.526	0.349
Kurtosis	-0.656	-0.847
Range	8.43	6.99
Minimum	0.00	0.00
Maximum	8.43	6.99
Sum	351748.07	335847.76

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