EVALUATION OF SEBAL AND METRIC BASED EVAPOTRANSPIRATION IN ARID REGION OF SAMAIL, OMAN

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KEY WORDS: Remote Sensing, Landsat-8, Heat Flux

ABSTRACT

Crop water requirement of any crop needs accurate estimation especially, in arid regions where scares water, high temperature and scattered low amount of rain are dominating the climate conditions. Traditional climatological and meteorological point-based methods showed limited capabilities in accurately estimating actual evapotranspiration (ETa) over different scales of covering area. Surface Energy Balance Algorithm for Land (SEBAL) and Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC) models provide primarily applied remote sensing methods to estimate ETa on both, regional and local scale. This study analyzed the performance of both models in arid region of Samail, Oman. Results from the study shown that SEBAL model was overestimating ETa but not significantly, as compared to METRIC and modified Penman-Monteith (PM) models. The difference between ETa values estimated by SEBAL and METRIC was due to difference of calibration of ETa on the daily basis as SEBAL uses total daily Net Radiations (Rn_{24}) and METRIC use cumulative reference evapotranspiration (ET_{r24}). Moreover, METRIC model considered local weather conditions more than SEBAL model. This study concluded that METRIC model can produce ETa maps of high spatial and temporal resolution on local scale for the study area. On the other hand, SEBAL model can be applied on the global scale or in areas with less available metrological details.

1. INTRODUCTION

There is an increase in the need for the accurate estimation of plant water requirement especially in arid regions and countries like, Sultanate of Oman, where scares water, high temperature and scattered low amount of rain are dominating the climate conditions. Amount of water consumed by plant is referred as evapotranspiration which is a combination of water evaporated from soil and transpired by plant. Traditionally, actual evapotranspiration (ETa) was estimated by point-based model such as Penman-Monteith, Priestly-Taylor, Blaney-Criddle, Hargreaves and Crop Coefficient Approach in addition to field measuring instruments such as hydrometers (Mokhtari et al., 2011). Drawbacks of the traditional methods include the fact that ETa is estimated on local scale, providing single point data while hydrometers are costly and laborious to be applied on large scale. Traditional climatological and meteorological point-based methods are unable to accurately estimate ETa over large area (Sun et al., 2011). Moreover, since each crop has different crop factors depending on its types and growing stages, it is difficult to estimate for a large agricultural area (Allen et al., 2005). In this perspective, remote sensing is used to estimate ETa. By which, ETa can be estimated on pixel-by-pixel scale over any area size, small or large (Morse et al., 2005; Trezza, 2006; da Silva et al., 2008; Irmak and Kamble, 2009; Singh and Senay, 2016). Remote sensing techniques have been used by various researchers to estimate ETa using different energy models (Bastiaanssen et al., 1998; Su, 2002; Allen et al., 2005; Jana et al., 2016). Among vast field of remote sensing, Surface Energy balance Algorithm for Land (SEBAL) and Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC) are primarily applied methods to estimate ETa on both, regional and local scale.

SEBAL model was formulated by Bastiaanssen et al., (1998a) to estimate ETa from the crop cover and has been utilized in more than 30 different climatic conditions (Mokhtari et al., 2011). SEBAL has been applied in different climatic regions utilizing satellite imagery that performed well with acceptable outcomes (Zamani and Rahimzadegan, 2018). SEBAL model was applied in Malayer city of Iran to estimate ETa using different satellite imagery. Results shown that SEBAL model was more accurate to estimate ETa using low spatial resolution satellite imagery (Nouri et al., 2017). SEBAL model was also applied in Doon valley of India and successfully estimated ETa for different crop cover and concluded that SEBAL model can be used a quick method to estimate ETa in the absence of in-situ hydrological data (Jana et al., 2016). SEBAL model applied in western US for water rights and designing; resulted as on effective, precise and cheap model to make an estimate of ETa over a large area (Allen and Morse, 2003).

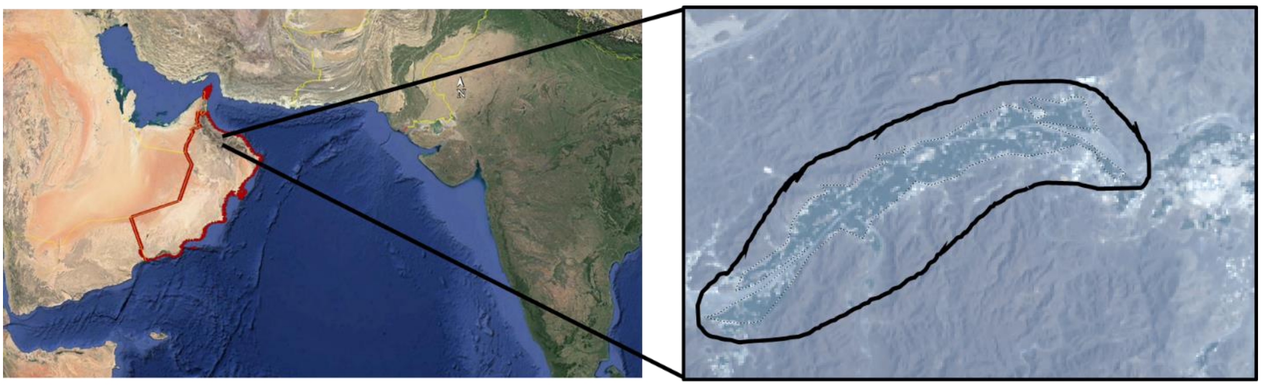
On the other hand, METRIC model was modified from SEBAL model by Allen et al., (2005) to estimate ETa for different land cover using local meteorological data. METRIC model was used to access the ETa over crops and natural vegetation covers and resulted an acceptable relation with value of R^2 greater than 0.88 with ground observations (Oliveira et al., 2018). METRIC model was also applied to estimate ETa on monthly, seasonally and annually basis over agricultural crop cover using Landsat-5 and Landsat-7 satellite imagery. The study resulted that there is 10 to 20 percent of variation of ETa estimates between METRIC model and ETa derived from micrometeorological stations (Huntington et al., 2018). METRIC model has been also applied under different climate circumstances and produced a satisfactory results with an error less than 20 percent (Allen et al., 2007; Numata et al., 2017; Bhattarai et al., 2017; Oliveira et al., 2018).

The main aim of this study was to analyze the performance of SEBAL and METRIC in estimating actual evapotranspiration in arid region of Samail in the sultanate of Oman.

2 MATERIAL AND METHODS

2.1 Study area and Imagery acquisition

The study was carried at a hot and arid region of Samail, Oman (Fig. 1). The study area expands from longitude of 57° 58' 59.99" and latitude of 23° 17' 60.00". The selected study area is cultivated with Date palm trees as a major crop cover. The SEBAL and METRIC models were applied on study area using Landsat-8 OLI/TIRS satellite imagery. The satellite images were acquired on clouds-free dates; 15 January, 5 April, 21 April, 8 June, 10 July, 11 August, 27 August, 12 September and 14 October during 2015.



Longitude 57° 58' 59.99"
Latitude 23° 17' 60.00"

Figure 1: Location of study area: Samail, Oman

2.2 SEBAL Vs. METRIC

SEBAL (Fig 2) and METRIC (Fig 3) models works based on energy balance principle that is a residual of heat flux used by soil surface and plant stomata for evaporation and transpiration, respectively. Both models calibrate ET to daily values. SEBAL model uses daily potential ET ($ET_{p_{24}}$) (Eq. 1) while, METRIC uses daily cumulative ET (ET_{r24}) values (Eq. 2) to calibrate Eta

$$ET_a = ET_{p_{24}} \times \mathrm{EF} \tag{1}$$

$$ET_a = ET_{r\_24} \times \mathrm{ETrF} \tag{2}$$

Where EF is Evaporative fraction which is estimated as formulated in Equation (3) that is followed by (Mkhwanazi and Chávez, 2013)

$$\mathrm{EF} = \frac{Rn-G-H}{Rn-G} \tag{3}$$

and ETrF is reference evaporative fraction (Eq. 4) that is estimated as a ratio of ET estimated by satellite imagery at the time of satellite imagery was taken and reference evapotranspiration calculated for the reference crop.

$$ETrF = \frac{ET_{inst}}{ET_r} \tag{4}$$

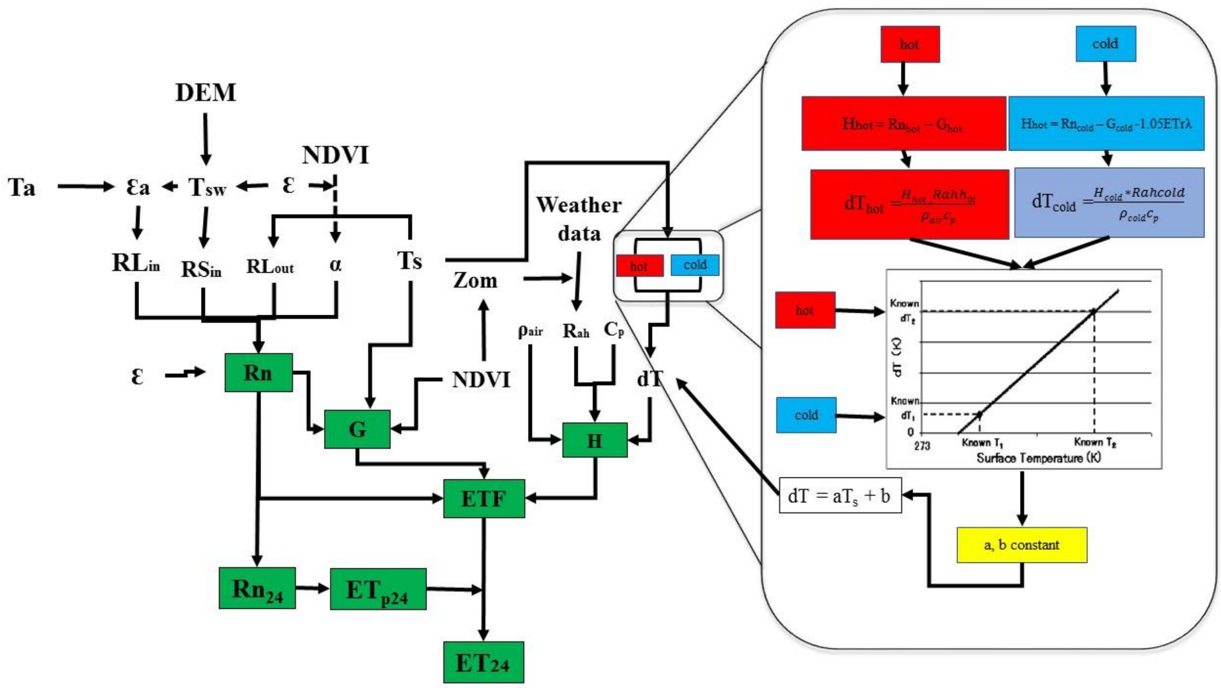


Figure 2: Schematic flowchart for energy balance SEBAL algorithm.

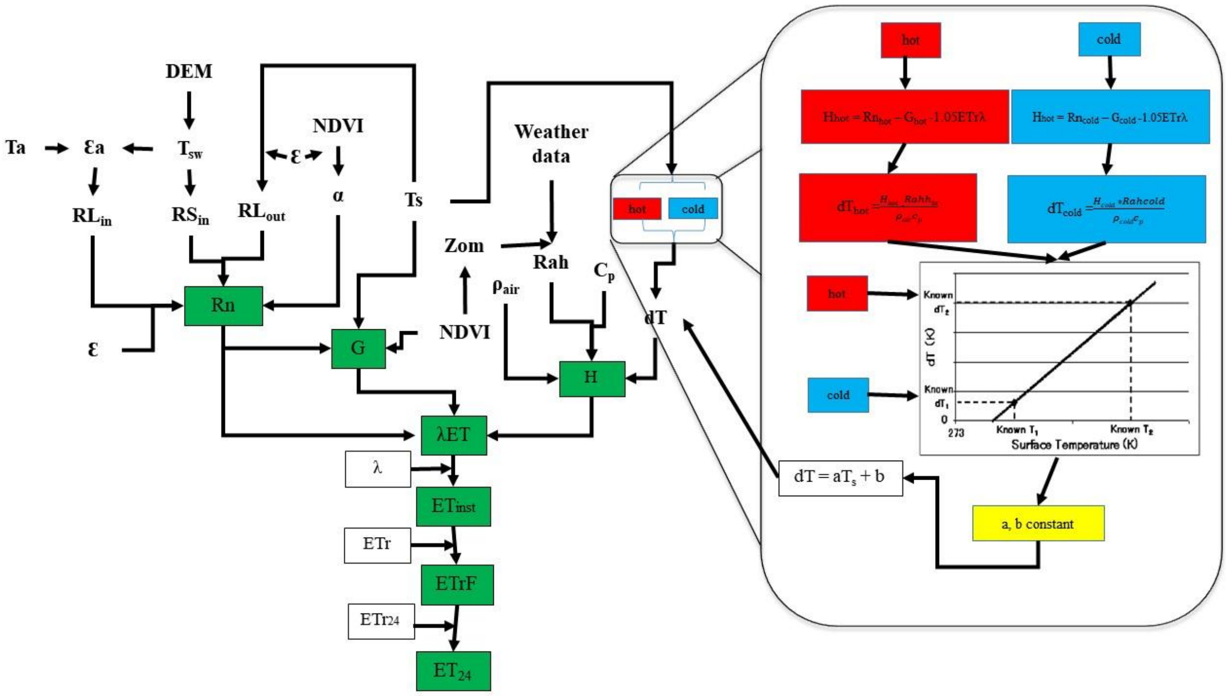


Figure 3: Schematic flowchart for energy balance METRIC algorithm.

First step for both of the models is the estimation of Net radiation (R_n) that is net difference between incoming and outgoing longwave/shortwave radiations (Jana et al., 2016). Followed by estimating surface albedo using visible, near infrared and shortwave bands of image. Thermal bands, on the other hand, were used to estimate surface emissivity (ε) (Silva et al., 2016). Then the incoming shortwave radiations and incoming longwave radiations were collected where needed. Air temperature values were calculated following (Bastiaanssen et al., 1998b; Widyasamratri et al., 2013).

The second step was the estimation of Soil heal Flux (G) using Rn, Land surface temperate (LST) , Albedo and NDVI (Bastiaanssen et al., 1998a)

$$\frac{G}{Rn} = \frac{LST}{\sigma} \times (0.0032r_0 + 0.0032r_o^2) \times (1 - 0.978 \times NDVI^4) \quad (5)$$

Where σ is surface albedo, r_o is day time average surface temperature and NDVI is Normalized Difference Vegetation Index.

The heat transport to air (R_{ah}) is calculated using temperature difference at two different heights; one at the zero-plane height of surface (Z_1) while the other one is at a reference height (Z_2) ranging from 100-200 meter.

$$r_{ah} = \frac{ln(\frac{z_1}{z_2})}{u_* K} \quad (6)$$

The value of temperature difference dT is estimated on each pixel by selecting two extreme conditions called hot and cold conditions. The criteria of selection of these extreme conditions differ in each of the models differentiating each model.

$$dT = a + bT_s \quad (7)$$

Where, *a* and *b* area constants that are calculated using iteration process on selected extreme conditions. The selection of these extreme conditions changes from SEBAL to METRIC. Both of hot and cold pixels are selected using the surface temperature and vegetation indices. Hot pixel is selected where there is no vegetation/bare soil and hence no ETr value. The values of ETr is estimated by PM model using local weather data. In SEBAL, cold pixel is selected from an area having water surface. But is METRIC, cold pixel is selected from an area having full vegetation. METRIC uses an increment of five percent allocated to the ETr value of that pixel because pixel has more vegetation as compared to the whole study area. After selection of these conditions, an iterative process in initiated and values of a and b constant are calculated for each iteration step. The new value of dT is calculated while selected conditions act as boundary conditions for each iteration process. Once the correct value of dT and Rah area estimated after iteration process, value of H is estimated using equation (6). Then, values of EF and ETrF are calculated using Rn, G and H. Hence, values of ETa for each model is computed.

3 RESULTS

The hot and cold pixel were selected within the study area to make the iteration process more precise. Hot pixel was selected from bare soil for both SEBAL and METRIC while cold pixel was selected from fully vegetated cover area. Results from both models were validated against the values obtained by modified Penman-Monteith (PM) model followed by Allen et al., (1998). Results from the study shown that (Fig. 4) SEBAL model was over estimating ETa as compared to ETa estimated by METRIC. SEBAL model requires less weather data as compared to METRIC which makes SEBAL easier to be applied with the limitation of weather data availability. Statistical analysis Table 1) showed that there were no significant differences between ETa values estimated by SEBAL and METRIC model as the value of P is 0.05. The statistical analysis also resulted that mean values of SEBAL model is higher as compared to PM and SEBAL model as SEBAL model uses only R_{n24} values to extrapolate the ETa values on daily basis. The analysis also showed same amount of error generated by both PM and METRIC model. As METRIC model uses more local weather data, it is suggested to be applied on local scale to estimate ETa with high spatial and temporal resolutions. On the other hand, SEBAL model can be useful on regional scale because as it is less complex and easy to use.

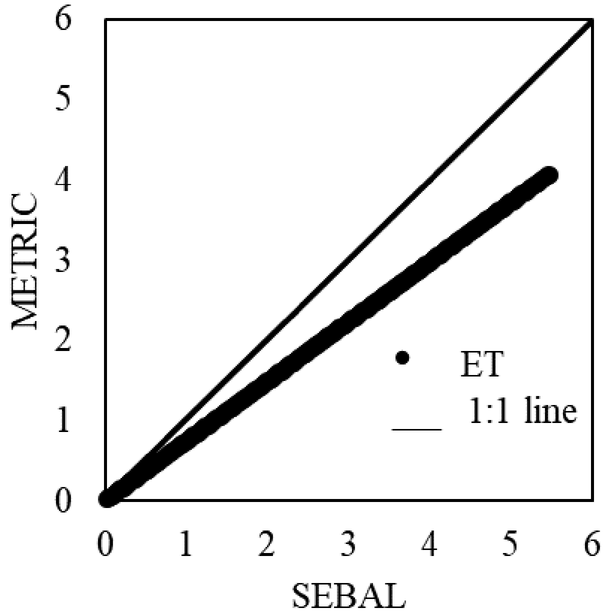


Figure 4: Comparison between SEBAL and METRIC model.

Table:1 Statistical parameters for SEBAL, METRIC and PM models

Statistical Parameters	PM	SEBAL	METRIC
Mean	5.17	5.35	4.95
Standard Error	0.55	0.19	0.50
Median	5.65	5.49	5.17
Standard Deviation	5.17	0.56	1.51
Sample Variance	0.55	0.32	2.29
Kurtosis	5.65	0.16	-1.18
Skewness	-0.48	0.45	-0.14
Range	4.42	1.83	4.16
Minimum	2.68	4.58	2.78
Maximum	7.10	6.41	6.93
P value	0.82		

4 CONCLUSION

In this study, two remote sensing models namely SEBAL and METRIC were used to estimate ETa for the arid region of Samail, Oman. The basic criteria for selection of hot and cold pixel can affect the performance of these models as these pixels act as a boundary condition in the estimation of sensible heat fluxs. Another difference between the two models was found in the calibration of ETa on daily basis. The study also found although SEBAL model gave over estimation values of ETa as compared to METRIC and PM model, this difference was not statistically significant. From this study it is suggested to use METRIC model on local scale to produce ETa maps of high spatial and temporal resolution. However, SEBAL model can be applied on the global scale or in the area with less metrological details.

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