Calculation of Real Evapotranspiration by the Application of Metric Method on Landsat-8 Data

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Abstract. In geological remote sensing approaches for estimating evapotranspiration, METRIC method is among the most modern and precise approaches that many positive experiments have been reported regarding its applicability. In this study, the value of actual evapotranspiration (ET) occurred in Marvdasht farmlands, Fars province, Iran, was calculated instantaneously (hourly) and daily (24 hours), at 24 April 2017 using METRIC method and Lansat-8 data. In order to accuracy assessment of the results, estimated values were compared to the values calculated with Penman Monteith method in places that covers by alfafa crop. Our observations showed that ET values obtained via METRIC model on average, have 0.51mm difference in estimations, comparing to the Penman Monteith method.

1. Introduction
During the evapotranspiration process, a high volume of water from soil in the form of evaporation, and from subsoil in the form of transpiration from vegetation, moves to the atmosphere [1]. Constant survey of water consumption for irrigation in term of management of water rights, irrigation planning, water consumption efficiency management, and setting hydro-climatology balance is a very important issue. In addition, the differences between actual and potential evapotranspiration, as a measure of water shortage in high spatial resolution, has many applications including agricultural and water resources studies. Furthermore, soil moisture derived by actual evapotranspiration is a valuable input for precipitation-runoff models [2-5].

METRIC model was developed in order to have relatively more accurate evaluations of evapotranspiration in higher resolution (30 meters) in comparison with more general models, and to calculate the effects of horizontal movements of regional air masses [6,7]. METRIC model has some important advantages over older satellite energy-balance methods such as SEBAL. One important advantage is calibration is done via considering the relation between reference evapotranspiration and evaporation component. The other advantage of METRIC model is the crop conditions curve, as the metric method does not require the information about crops growing steps and crop types. However, using METRIC energy-balance model, evapotranspiration as a result of water shortage can be recognized. The innovative component of METRIC model is that in energy balance modelling, near-surface temperature gradient (dT) is used, which is an index of radiometric surface temperature. This
omits the requirement of the calibration of absolute surface temperature, which is a significant limitation in evaluation of evapotranspiration using satellites [1,8,9]. In METRIC model of calibration of sensible heat (H) calculation using temperature gradient, the requirement of atmospheric correction of surface temperature and measurement of surface albedo are removed by using radiative transfer models. In addition, internalized calibration decreases the effects of biases in the estimation of aerodynamic stability corrections and surface roughness. This model is distinguished with SEBAL, using reference evapotranspiration based on meteorology data to create conditions of energy balance in one pixel (cold pixel) [10-12]. Due to the lack of Lysimeter and measurement columns of surface fluxes in the study area, evaluation of the results derived by METRIC algorithm by comparison with real data was not possible. Thus, we tried to verify the results using the established Penman-Monteith method based on FAO-56 standards.

2. Study Area
The region studied in this research includes agricultural lands around Marvdasht, Fars Province, Iran. Geographically, the study area is located between northern latitudes 29° 47′ 00″ and 30° 18′ 00″, and eastern longitudes of 52° 25′ 00″ and 53° 10′ 00″, showed in Figure 1. From climatological point of view, the information and datasets collected by 5 synoptic stations of Safashahr, Arsanjan, Persepolis, Ardekan and Shiraz, with 18.7 centigrade and 986 mm of precipitation in a 35-years period from 1984 to 2019 were considered [13,14].

3. Materials and Methods
This section provides two main subsections discussing the datasets used and the methods applied. Flow chart of the methodology is depicted in Figure 2. In this research, the algorithms, methods, calculations and data processing were done via different software packages. ENVI was used for pre-processing of satellite imagery; ArcGIS and Python scripts were used for calculations, and Google Earth was used for field observations and verifications.
3.1. Remote Sensing Data

In order to calculate actual evapotranspiration per satellite image pixel, METRIC model needs different information, including multi-spectral satellite data, satellite imagery’s metadata file, meteorological measurements of the stations, and Digital Elevation Model (DEM) [1].

3.1.1. Landsat-8 Satellite. Landsat-8 satellite which launched to the space in 2013, has two sensors including Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). OLI has 9 bands in visible and near-infrared (VNIR) and short-wave infrared (SWIR) ranges, which includes bands 1 to 7, and 9 with spatial resolution of 30 meters. EarthExplorer (USGS) was used as the source of Landsat-8 data. Thermal infrared sensor of Landsat-8 has two bands with spatial resolution of 100 meters, which are band 10 and 11 form the datasets of Landsat-8 satellite. In METRIC model, to calculate land surface temperature (LST), only band 10 is used. It is not recommended that band 11 be used for the split-window technique (USGS).

3.1.2. ASTER Sensor’s Digital Elevation Model. Advanced Spaceborne Thermal Emission and Reflection Radiometer, is an American-Japanese sensor and one of the five remote sensing tools onboard the Terra satellite, which was launched in 1999 by NASA. This sensor has 4 bands within visible and near-infrared range. By using its band 3 in nadir view and band 4 in backward looking, the Global Digital Elevation Model (GDEM) was created with spatial resolution of 0.000278 degrees, equal to rectangular pixels with dimensions of 26.93 by 30.79 meters [15,16].

3.2. METRIC Model Theoretical Concepts

The basic theory of METRIC method was developed by Allen et al. (2007) [1]. In general, ET from satellite imagery in METRIC model is derived by exploiting an energy balance on the surface of the Earth. Where the consumed energy by the ET process is calculated as a residual of surface energy:

\[ \text{ET} = \text{Net Radiation} - \text{Sensible Heat Flux} - \text{Latent Heat Flux} - \text{Soil Heat Flux} \]
\[ LE = R_n - G - H \] \hspace{1cm} (1)

Where, \( LE \) is latent heat flux, \( R_n \) is net radiation flux on Earth’s surface, and \( G \) is the soil heat flux, all in Watt per square meter.

3.2.1. Net Radiation Flux. Net radiation or Net radiation flux is the equilibrium of incoming and outgoing energies over the atmosphere. These energies, directly or indirectly, are the results of nuclear interactions occurring on the solar surface, and is equal to the total available energy for occurrence of the Earth’s surface and atmospheric processes [17]. Net radiation flux (\( R_n \)) is the radiant energy on a surface which is segmented via \( G \), \( H \), and \( LE \):

\[ R_n = R_{s\downarrow} - \alpha R_{s\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1 - \varepsilon_0) R_{L\uparrow} \] \hspace{1cm} (2)

Where, \( R_{s\downarrow} \) is Incoming short-waves solar radiation, \( R_{L\downarrow} \) is Incoming long-waves solar radiation, and \( R_{L\uparrow} \) is outgoing long-waves solar radiation from surface, all in Watt per square meters. \( \alpha \) is surface albedo, and \( \varepsilon_0 \) is broad-band surface thermal emissivity, which is a dimensionless parameter.

3.2.2. Soil Heat Flux. Net Radiation Flux can be defined as the amount of thermal energy which can be transmitted in time units after being saved in soil texture, due to the conduction [18]. Calculation of the numerical value of soil heat flux (Watt/m2) in the METRIC method is done by using equation 3, provided by Bastiaanssen (2000) [10]:

\[ \frac{G}{R_n} = (T_s - 273.15)(0.0038 + 0.0074\alpha)(1 - 0.98(NDVI)^4) \] \hspace{1cm} (3)

Tasomi (2003) also provided equations 4 and 5 in order to calculate this parameter, and to enhance the results of using METRIC method [19]:

\[ \frac{G}{R_n} = 0.05 + 0.18e^{-0.521LAI} \hspace{1cm} \text{for} \hspace{0.5cm} LAI \geq 0.5 \] \hspace{1cm} (4)

\[ \frac{G}{R_n} = 1.8(T_s - 273.15)/R_n + 0.084 \hspace{1cm} \text{for} \hspace{0.5cm} LAI < 0.5 \] \hspace{1cm} (5)

Where, \( T_s \) (surface temperature) is in Kelvin, and Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) are dimensionless.

3.2.3. Sensible Heat Flux. The critical difference between METRIC and SEBAL methods is in the way of calibration in evaluation of sensible heat flux (\( H \)). In both of the methods, calculation of the sensible heat flux of the surface is done using an aerodynamic function:

\[ H = \rho_{\text{air}} \cdot C_p \cdot \frac{dT}{r_{ah}} \] \hspace{1cm} (6)

Where, \( \rho_{\text{air}} \) is the air density in kg/m³, \( C_p \) is the specific heat of air at constant pressure, which is equal to 1000 (J/kg.K), \( dT \) is the indicator of temperature difference in Kelvin between two elevations near surfaces of \( z_1 \) and \( z_2 \), and \( r_{ah} \) is the aerodynamic resistance (m/s) available for the heat transfer between \( z_1 \) and \( z_2 \), which are considered 0.1 and 2 meters [20,21].

3.2.4. Instantaneous Evapotranspiration. Actual evapotranspiration happened at the moment of satellite passage, is derived by the following equation:

\[ ET_{\text{inst}} = \frac{3600 \cdot LE}{\lambda} \] \hspace{1cm} (7)
Where, \( LE \) is the latent heat energy (Watt/m\(^2\)) spent for the evapotranspiration process, and \( \lambda \) is the latent heat of vaporization in J/kg. The multiplication by 3600 is for conversion of the moment (a second) to the hour scale.

3.2.5. Daily Evapotranspiration. In METRIC model, daily evapotranspiration is calculated by using reference evapotranspiration in a 24-hours period, and a parameter named reference evapotranspiration fraction, which is derived by the following equation:

\[
ET_r F = \frac{ET_{inst}}{ET_r}
\]

(8)

Where, \( ET_r \) is the reference evapotranspiration. In METRIC model, evaluation of the actual evapotranspiration in 24 hours, assuming constant instant \( ET_r F \) at the point of satellite passage, is compared with its mean over the one-day period, via the following equation:

\[
ET_{24} = C_{rad} (ET_r F \times ET_{r,24})
\]

(9)

Where, \( C_{rad} \) is the correction index for evaluated daily evapotranspiration. The numerical values for this index are between 0 and 1. It should be considered as 1 for the flat areas without topographical changes.

4. Results and Discussion
In order to evaluate net radiation flux (equation 3), parameters including incoming short-waves solar radiation, surface albedo, incoming and outgoing long-waves solar radiation, and broad-band surface thermal emissivity were calculated. The evaluated net radiation flux for the agricultural areas near Persepolis synoptic station are provided via Figure 3-a. Calculation of soil heat flux for the study area using Equations 5 and 6 were done, and then using the derived net radiation flux, the value of \( G \) was found. Figure 3-b shows the soil heat flux calculated for the study area. In the process of evaluating the actual evapotranspiration, occurred at the surface, via the METRIC method, calculation of the sensible heat flux parameter within the energy balance equation can be considered as the most sensitive part. This sensitivity happens because of the effects of different elements and the conversions while its calculation, which finally defines the accuracy of calculated actual evapotranspiration [22]. In this research, determination of the locations of hot and cold pixels was done with a high sensitivity, which means that the location of those pixels were selected from the regions where have the minimum area of 5-by-5 pixels of the satellite image with almost the same characteristics. Figure 3-c shows the sensible heat flux calculated for the study area.

![Figure 3](image-url)

(a) (b) (c)

Figure 3. a) Net radiation flux; b) Soil heat flux; and c) Sensible heat flux in Watt/m\(^2\).

4.1. Instantaneous Evapotranspiration
Evaluation of the actual evapotranspiration occurred at the time of satellite passage, is possible with calculation of the consumed energy (LE) during evapotranspiration. This amount of energy which is the output of energy balance equation, is measurable via calculation of three parameters including net
radiation, soil heat flux and sensible heat flux using Equation 8 [23]. Figure 4-a depicts the occurred instantaneous evapotranspiration within the study area.

4.2. Daily Evapotranspiration
Actual evapotranspiration occurred in the 24-hours period is measurable via the reference evapotranspiration fraction, using Equation 9. Figure 4-b shows the daily evapotranspiration (ET$_{24}$) for the study area.

![Figure 4](image)

**Figure 4.** a) Instantaneous evapotranspiration (mm), and b) Daily evapotranspiration (mm).

4.3. Accuracy Evaluation
In this study, due to the unavailability of the Lysimetric data of the study region, and in order to evaluate the achieved results, a comparison is done between the daily evapotranspiration and the values calculated by Penman-Monteith method in accordance with FAO-56 standards within the regions of pixels where at the passage time of the satellite, were covered by alfalfa. This approach on accuracy evaluation was previously used by Tasumi (2019) [19]. For this purpose, after field surveys and filling questionnaires by the local farmers at 11 points where the plantation of alfalfa were verified, using the Penman-Monteith method and the data of Persepolis synoptic station, reference evapotranspiration was calculated, and the results were compared with those of the METRIC method. The comparative results of the accuracy evaluation are shown in Table 1, in which it is shown that the evapotranspiration derived by the METRIC method has the average difference of 0.51 mm with the calculated values by the Penman-Monteith method.

| Check-point Station No. | FAO-56 Data (mm) | METRIC Data (mm) | Difference (mm) |
|-------------------------|------------------|------------------|-----------------|
| 1                       | 5.91             | 6.34             | + 0.44          |
| 2                       | 5.76             | 6.23             | + 0.47          |
| 3                       | 6.11             | 6.48             | + 0.37          |
| 4                       | 6.02             | 6.36             | + 0.34          |
| 5                       | 5.21             | 4.69             | - 0.52          |
| 6                       | 5.43             | 4.57             | - 0.86          |
| 7                       | 5.64             | 5.23             | - 0.41          |
| 8                       | 5.81             | 5.11             | - 0.70          |
| 9                       | 4.97             | 5.56             | + 0.59          |
| 10                      | 5.08             | 5.61             | + 0.53          |
| 11                      | 5.01             | 5.49             | + 0.48          |
| 12                      | 5.84             | 6.33             | + 0.49          |
| 13                      | 4.78             | 5.32             | + 0.54          |
5. Conclusion
Using satellite imagery to calculate evapotranspiration, has different applications, including water efficiency for agricultural lands, energy balance investigation, and irrigation development management. METRIC model used collected data of Landsat-8 satellite or other satellites with high spatial resolution sensors installed on them, which collect data of thermal radiation, visible and near-infrared on the Earth’s surface. This study was an attempt to calculate actual evapotranspiration via METRIC method, using pixel-by-pixel approach at the moment of satellite imaging. The results showed that using Landsat-8 satellite imagery and the METRIC algorithm are potentially appropriate tools to evaluate actual evapotranspiration, and the outcome can be considered as a basis of planning and management of the regions.

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