Evaluation of SEBAL Model for Evapotranspiration Mapping in Iraq Using Remote Sensing and GIS

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Abstract
Evapotranspiration is one of the major parameter in the hydrologic cycle. Standard measurements of this parameter is quite complex due to various factors such as variation of precipitation amount, spatial variation by latitude and longitude and changes in environment and specific site conditions. Although of this complexity, various methods were developed to estimate actual and potential Evapotranspiration such as Surface Energy Balance Algorithm for Land (SEBAL) method. SEBAL model calculates heat latent flux mostly from remotely sensed data. This paper aims to evaluate the SEBAL model for actual Evapotranspiration estimation in Al-babil city in Iraq using a SEBAL toolbox developed for ArcGIS software. The toolbox was evaluated with two reference actual Evapotranspiration datasets from Al-babil metrological stations. Overall accuracy of \( R^2 = 0.86 \) for the first dataset on March and \( R^2 = 0.85 \) for the second dataset on September were achieved. The result of this research indicates that the SEBAL model is effective for estimating actual Evapotranspiration in the studied area.

Keywords: Actual Evapotranspiration, GIS, Remote Sensing, SEBAL.

Introduction
Accurate estimation of Evapotranspiration (ET) using remote sensing and GIS techniques requires understanding effects of the input parameters to the model and used satellite data on the accuracy of the results. Reference [1, 2] described the key principles of the SEBAL model and summarized its accuracy under several climatic conditions at both field and catchment scales over more than 30 countries around the world. The typical accuracy at field scale was achieved 85% for 1 day and 95% for seasonal basis. The accuracy of annual ET of large watersheds was found to be 96%. Based on the accuracies achieved from the study, the author concluded that SEBAL can be applied and implemented for solving water resources and irrigation problems. Likewise, Reference [3] studied the effects of surface heterogeneity on performance of SEBAL modeling. In the study, two data sources were used; Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat ETM+. The research suggested that landscape heterogeneity influence the remotely sensed predictions of heat fluxes. In addition, Reference [4] investigated the sensitivity of the SEBAL model parameters for mapping winter wheat ET in South China. Based on the fact that the SEBAL model works well only for areas where sunny days dominate and with a relatively pollution-free atmosphere. The MODIS data used in the study and it was concluded that a small change in the sunshine duration parameters effects significantly the seasonal ET interpolation. The SEBAL model is highly sensitive to the sunshine duration parameters and a modification of SEBAL model important to improve the results of temporal interpolation. Furthermore, Reference [5, 6] evaluated the impacts of varying input variables and spatial resolution of satellite sensors on sensible heat flux (H) estimated from the SEBAL model. Sensitivity analysis of SEBAL was conducted by varying its input variables using MODIS data for 29 cloud-free days in 2007 covering the Baiyangdian watershed in North China. Results of sensitivity analysis indicated that the (H) estimates from SEBAL are most sensitive to temperatures of hot and cold pixels and available energy of
the hot pixel. Using high spatial resolution images, \((H)\) can be smaller than that using low spatial resolution images.

Another important study about SEBAL model conducted by Reference \([6, 7]\) and they discussed the theory of the SEBAL model which was originally derived for Egypt, Spain and Niger. The study calibrated and validated the SEBAL algorithm using images covered the semi-arid region of the Low-Middle Sao Francisco River basin, North-eastern Brazil, from 2001 to 2007. Measured parameters included surface albedo, surface temperature, atmospheric and surface emissivity, soil heat flux, surface roughness, net radiation, air temperature gradients, sensible heat flux, latent heat flux, evaporative fraction, and photosynthetically active radiation. The results of the study indicated that it is essential to distinguish instantaneous and daily time scales. For instantaneous values it was required to apply the hot and cold pixel calibration for every individual image. For daily scale, the values of the instantaneous evaporative fraction needed to be adjusted. The research also showed that it is useful to use curves of the ratio of actual to reference Evapotranspiration instead the average values of the pixel with the lowest and highest surface temperatures in the calibration processes as this ratio changes during the year. Others tried to modify the original SEBAL model for accurate estimation of Evapotranspiration. Reference \([8, 9]\) demonstrated the modified surface energy balance algorithm for land (M-SEBAL). The aim of their study was to reduce ambiguity in flux calculation by SEBAL due to the subjectivity in extreme pixel selection. Results showed that M-SEBAL is capable of reproducing latent heat flux in terms of an overall root-mean-square difference of 41.1 Wm2. The retrieval accuracy of SEBAL was generally lower than M-SEBAL, depending largely on the selected extremes. Spatial distributions of heat flux retrievals from SEBAL were distorted to a certain degree due to its inherent rectangular framework.

SEBAL is suitable for assessing irrigation system performance, assessing crop water productivity, and other natural resource applications. Reference \([10]\) evaluated estimation of water balance components in arid-mountainous catchment of Manshad in Yazd province of Iran, during the estimation of water balance components in arid-mountainous natural resource applications. Reference \([10]\) evaluated performance, assessing crop water productivity, and other SEBAL is suitable for assessing irrigation system performance, assessing crop water productivity, and other

\[ R_n = LE + H + G \]  

(1)

Where \( LE \) latent heat is flux (ET in energy units), \( R_n \) is net radiation at the surface, \( H \) is sensible heat flux to the air, and \( G \) is soil heat flux (W m\(^{-2}\)).

**Figure 1: Surface Energy Balance [12]**

**SEBAL Toolbox Development**

Based on theory of the SEBAL model described by Reference \([12, 13]\), a conceptual diagram was first drown to make the toolbox design and development easier. The main parameters of this model are: net radiation, soil heat flux, sensible heat flux and latent heat flux; therefore, the toolbox was designed to have four main sub-tools to produce a raster layer for each of the four mentioned parameters. In each tool, a second diagram was designed to calculate the parameter based on the input data usually from remotely sensed images and climate recording. The toolbox uses preprocessed remote sensing data, so the one must correct satellite images for geometric, radiometric and atmospheric conditions before to proceed with the latent heat flux estimation for accurate results. The following sections describe each parameter of the SEBAL model and its development in the GIS environment.

**Net Radiation Model**

The Fig. 2 shows the net radiation model developed in GIS model builder. The model has three inputs which they are: a corrected Landsat image, land surface temperature, digital elevation model, and climate data as parameters. Then the model calculates surface albedo and NDVI from the corrected satellite image. Land surface temperature was calculated using ENVI software and in the model it was considered as one of
the input data. After that, NDVI layer was used to calculate the surface emissivity. The surface albedo was then corrected for the elevation variations using the digital elevation model. Surface emissivity was then used to estimate the outgoing long wave radiation. On the other hand, digital elevation model was used to calculate atmospheric transmissivity and then atmospheric emissivity. While climate data were used for near surface temperature layer establishing to be used after that with atmospheric emissivity to estimate the incoming long wave radiation. The incoming shortwave radiation was estimated based on the atmospheric transmissivity and the outgoing shortwave radiation was estimated from the corrected surface albedo and the incoming long wave radiation. Finally, the four radiation components, incoming and outgoing were used to estimate the net radiation.

**Sensible Heat Flux Model**

One of the most complex computation in the SEBAL model is the sensible heat flux which affects by the wind stability. The model uses NDVI and corrected surface albedo to calculate the momentum roughness length which was then used to estimate the friction velocity. The friction velocity after that was used to calculate the wind speed at 200m and then the friction velocity estimated based on the 200m wind speed. The new friction velocity was then used to predict the aerodynamic resistance which needs to be corrected for weather instability. After the aerodynamic was corrected for weather instability using seven iterations and the Monin-Obukhov length formula. Then the model establishes a relationship between the surface temperature and the temperature difference of two heights for two carefully selected anchor pixels (hot and cold). The two selected pixels have known evapotranspiration, soil heat flux and surface temperature, so the temperature difference (dT) was estimated and used to establish the regression model with the surface temperature. After that, the developed regression model was used to estimate the (dT) for each pixel in the study area.

Having estimated the aerodynamic resistance, dT, and weather parameters, the sensible heat flux was estimated in the model. Fig. 4 shows the flowchart for the estimation of the sensible heat flux.

**Reference ET Faction Model**

The final step in the SEBAL model is to estimate the reference ET faction (ETrF). This is done by using the three layers estimated before, net radiation, soil heat flux and sensible heat flux together with the constant value of vaporization as shown in Fig. 5. First, latent heat flux was estimated then the instantaneous ET was estimated to be used with reference ET (from weather data) to estimate the final ETrF in this model. This would be used for extending the ET for 24 hours or for seasonal periods.
Results and Discussion
The statistical analysis for the SEBAL performance evaluation based on (11 sample points) well distributed over the study area Fig.6. It is not easy to directly assess the accuracy of SEBAL model based on the results obtained in the literature. This is because there is no standard method for presenting the results, validation methods and their associated accuracies vary from study to study. thus, the comparison between the actual evapotranspiration estimated from SEBAL model and two datasets collected in the field. the first dataset was acquired on March which is wet season and the second dataset was acquired on September which is a dry season in Iraq. Actual evapotranspiration as estimated from SEBAL model and remote sensing data ranged from (1.44 to 2.32 mm/day) in March and (7.18 to 8.94 mm/day) in September. while the values of the field measurements ranged from (2.63 to 2.74 mm/day) in March and in September the values were (8.15 to 9.10 mm/day).

Regression analysis and Pearson correlation are standard procedure for comparing one dataset against another dataset. this method was used to evaluate the accuracy of SEBAL model for estimating actual evapotranspiration. the regression analysis showed that the evapotranspiration estimated from SEBAL model is comparable to that one collected from the field. the statistical information of this analysis revealed that the correlation between the SEBAL and field values are ($R^2=0.86$) for the March and ($R^2=0.85$) for the September as shown in Fig. 7 and Fig. 8. SEBAL model highly sensitive to climate conditions, hence this is the reason why the correlations are different in the two studied seasons (March and September).
Conclusion
Remote sensing and GIS are effective tools for Evapotranspiration estimation. This study developed friendly tools for calculating actual Evapotranspiration based on SEBAL model and ArcGIS 10.2 software. This provides easy and cost-effective calculation for Evapotranspiration estimation from satellite images and climate data. In addition, this paper presented a comparison study between actual Evapotranspiration estimated by SEBAL model and that acquired from the field. The overall accuracy obtained of ($R^2 = 0.86$) for the first dataset on March and ($R^2 = 0.85$) for the second dataset on September were achieved. The result of this research indicates that the SEBAL model is effective for estimating actual Evapotranspiration in the studied area.

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