ESTIMATION OF EVAPOTRANSPIRATION FROM A LARGE IRRIGATION SCHEME USING REMOTE SENSING METHOD A CASE OF CENTRAL PLAIN OF THAILAND

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ABSTRACT

This research investigated the remote-sensing methods in estimating crop evapotranspiration (ET) from a large-irrigation scheme in the Central Plain of Thailand, during the dry season of 2001-2002. Evaporation flux was estimated by the surface-energy-balance approach, and validated with the results from the FAO Penman-Monteith method and the evaporation pan method. Surface albedo, vegetation index (NDVI) and surface temperature were used as basic inputs in calculating the energy-balance parameters, including net radiation, soil heat flux and sensible heat flux. These parameters were subsequently used in estimating the evaporative fraction (EF) by two comparative methods: SEBAL and S-SEBI. Finally the 24-h actual ET was derived. The results showed that the maximum ET increases during the dry season which is in good agreement with the reference crop ET derived from the FAO Penman-Montieth method. Also, the actual ET from the irrigated area presented similar tendency. However, in the non-irrigated area, the actual ET was found to be lesser due to the difference in the evaporative fraction between these areas. The evaporative fraction can be used to describe the soil moisture of the investigated area. In conclusion, the surface-energy-balance algorithms yielded reliable results in estimating ET from satellite image. However, further researches are still needed in order to improve the accuracy of the estimation and to minimize limitations of the algorithms.

1. INTRODUCTION

Agriculture is the largest water-use activity and plays a crucial role in agriculture-based country, like Thailand. An accurate estimation of consumptive use of water by crops, also known as evapotranspiration helps planning the effective water management. However, this task requires a lot of data especially in a large region, such as in a river basin or in a large irrigation system. It is difficult and costly to obtain all the necessary data. The use of satellite images could solve the problem of data acquisition. But the application of this approach seems very limited, particularly in the field of water management. The limitations are due to high cost of satellite image and the lack of personnel skilled in both remote sensing and water management.

This research aims at investigating the applicability of the low-cost satellite images, downloadable via the Internet, in determining evapotranspiration in the large irrigation scheme.

2. MATERIALS AND METHOD

Study Area

The Central Plain of Thailand lies approximately between latitude 13-17°N and longitude 98-102°E. It is crossed by four main streams from the west to the east respectively: the Mae Klong, the Tha Chin, the Chao Phraya and the Bang Pakong. The Central Plain can be divided into a few sub-areas. On the western side, the lower part of the Mae Klong River Basin is irrigated with water diverted from the Mae Klong River. The rest of the delta can be subdivided into upper and lower parts. The upper part is irrigated by gravity from a network of raised canals, and the lower delta comprises the West Bank and the East Bank of the Chao Phraya River

The irrigated area is approximately of 12 millions rai (~2 millions ha). The dominant crop in the delta is rice. The other significant portions of the delta occupied by other crops or urbanized area. In the western part, the Mae Klong area encompasses large area of sugar cane and orchards. Salt pans and aquacultures are found in the littoral zone, while the Bangkok Metropolitan occupies a large part of the lower delta (Molle *et al.*, 2001).

Data

The meteorological data, provided by the Thailand Meteorological Department (TMD), were selected from 8 agro-meteorological stations in the study area. These data were used in estimating reference crop evapotranspiration by the FAO Penman-Monteith method (Allen, 1998) and Class-A evaporation pan (Doorenbos and Pruitt, 1977).

The 30-arc-second (~1-km) DEM was provided by the NOAA's National Geophysical Data Center (NGDC) at URL: http://www.ngdc.noaa.gov/seg/topo/globe.shtml. The images of NOAA/AVHRR were obtained from online data processing system, PaNDA (Package for Noaa Data Analysis) at URL: http://webpanda.iis.u-tokyo.ac.jp/WebPaNDA/. For processing the evapotranspiration estimation, the projection of images was transformed to the UTM, WGS 1984, zone 47, with pixel size of 1x1 km^2.

Methodology

The estimation of evapotranspiration with remote sensing techniques relies on two algorithms: the Surface Energy Balance Algorithm for Land, SEBAL (Bastiaanssen *et al.*, 1998), and the Simplified Surface Energy Balance Index, S-SEBI (Roerink *et al.*, 2000). Both algorithms require measured spectral radiances under cloud-free conditions in the visible, near-infrared and thermal infrared range to determine surface parameters, i.e. surface albedo, vegetation index (NDVI), and surface temperature. With these inputs, the parameters of the energy balance at the surface can be determined from the following relation:

$$R_n = G_o + H + \lambda \cdot E \qquad [W/m^2] \qquad (1)$$

where R_n is the net radiation [W/m^2], G_0 is the soil heat flux [W/m^2], H is the sensible heat flux [W/m^2], and λE is the latent heat flux [W/m^2]. The net radiation term is calculated from all incoming and outgoing shortwave and long wave radiation. The soil heat flux is derived with an empirical relationship of the vegetation and surface characteristics (Roerink *et al.*, 2000).

The SEBAL method derives the sensible heat flux H on iteration basis from the following equation:

$$H = \frac{\rho_{air} Cp_{air} dT}{r_{ah}} \quad [W/m^2] \quad (2)$$

where ρ_{air} is the air density $[kg/m^3]$, Cp_{air} is the air specific heat at constant pressure $[J/kg/K]$, r_{ah} is the aerodynamic resistance to heat transport $[s/m]$, and dT is the vertical difference in air temperature between two layers. More details can be found in the work of Bastiaanssen *et al.* (1998). For the SEBAL method, the instantaneous latent heat flux can be determined as the residual of the energy balance equation ($\lambda E = R_n - G_o - H$).

In order to estimate the 24-h actual evapotranspiration, ET_{a24}, the evaporative fraction, Λ is defined as following:

$$\Lambda = \frac{\lambda E}{R_n - G_o} = \frac{R_n - G_o - H}{R_n - G_o} \quad [-] \quad (3)$$

The nominator represents the actual evaporation and the denominator the potential evaporation. The evaporative fraction is equal to 1, when the evaporation flux attains to the potential. While the fraction is equal to 0, no evaporation occurs. The constant evaporative fraction is assumed for the whole day. Finally, the ET_{a24} is derived as follows:

$$ET_{a24} = \Lambda R_{n24} \quad [W/m^2] \quad (4)$$

where R_{n24} is the 24-h net radiation $[W/m^2]$ and Λ is the evaporative fraction.

For the S-SEBI algorithm, the sensible and latent heat flux are not calculated as separate parameters, but as evaporative fraction, Λ (Roerink *et al.*, 2000). The evaporative fraction is derived from the feature-space plot between surface albedo, r_0 (x-axis) and surface temperature for reference elevation, T_0 (y-axis). From the feature-space plot, lower and upper limits can be observed as linear lines. The slightly increasing lower line, $T_{\lambda E}$ is assumed as the condition of maximum latent heat flux (maximum evaporation); the steep decreasing upper line, T_H as the condition of maximum sensible heat flux (no evaporation). The evaporative fraction is given by the following equation:

$$\Lambda = \frac{T_H - T_0}{T_H - T_{\lambda E}} \quad [-] \quad (3)$$

where T_0 is the surface temperature; T_H is the maximum surface temperature given by $T_H = a_H + b_H \cdot r_0$; and $T_{\lambda E}$ is the minimum surface temperature given by $T_{\lambda E} = a_{\lambda E} + b_{\lambda E} \cdot r_0$.

3. RESULTS AND DISCUSSIONS

The results of evapotranspiration (ET) estimation were summarized in Table 1. The daily actual ET in Figure 1 was derived from the SEBAL method and in Figure 2 from the S-SEBI method. Figure 3 showed the comparison of three evapotranspiration rates derived from different methods including: maximum or crop ET (ETc) from daily net radiation, reference crop evapotranspiration (ETo) from FAO Penman-Monteith method (Allen, 1998), and ETo from Class-A evaporation pan (Doorenbos and Pruitt, 1977). The upper limits in Figure 1 and Figure 2 represent the maximum ET. The condition when the evaporative fraction is equal to one was assumed for the estimation. The average values of maximum ET tend to increase from the wet period in November to the dry period in April, which is in a good agreement with those of ETo in Figure 3. The average values of actual ET in the irrigated area present a similar tendency, whereas those in the non-irrigated area are less varied.

The evaporative fractions (EF) calculated by both methods were compared in Figure 4. It was found that the EFs in the irrigated area were relatively constant for both methods of estimation, while those in the non-irrigated area were lower and decreasing. The soil-moisture condition in the irrigated area was consistently maintained by irrigation water throughout the investigated period, in contrast to the non-irrigated area, water in the soil dried up gradually. Finally, Figure 5 and Figure 6 showed the maps of EF and daily actual ET respectively. They are the results of the SEBAL method derived from NOAA/AVHRR image in February 28, 2002. They permit us to investigate different dry-season cropping activities and spatial distribution of soil moisture.

The methods of SEBAL and S-SEBI are based on the surface energy balance approach. Both methods need to label the “wet” and “dry” reference areas, where maximum ET and zero ET were respectively assumed. Although the SEBAL method requires a few reference pixels, it employs sophisticated algorithm to estimate the sensible heat flux (H) and then the EF. The S-SEBI method seems less complicated, yet in deriving the EF, a large number of reference pixels are needed in order to rationally draw the upper and lower envelopes. Both methods still encounter some difficulty of their application in irrigated area, where few “dry” reference pixels exist. Regarding the accuracy of estimation, both methods provided moderately coherent results in comparing with the standard methods. However, the extensive field measurements, if feasible, seem necessary in order to help in validation of the results.

4. CONCLUSIONS

This research investigated the remote-sensing methods in estimating crop evapotranspiration from a large-irrigation scheme in the Central Plain of Thailand, during the dry season of 2001-2002. Evaporation flux was estimated by the surface-energy-balance approach, and validated with the results from the FAO Penman-Monteith method and the evaporation pan method. The surface-energy-balance algorithms using NOAA/AVHRR images yielded reliable estimation of ET. The SEBAL method has an advantage over the S-SEBI method due to its sophisticated algorithm in determining the sensible heat flux, while the S-SEBI method is superior in term of its simplicity.

5. ACKNOWLEDGEMENTS

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DATE	Actual ET: SEBAL		Actual ET: S-SEBI		Maximum ET	ETo	ETo
	Irrigation	Non-irrigation	Irrigation	Non-irrigation	EF = 0	Evap. Pan	Penman-Monteith
29 Nov 01	2.87	2.65	3.18	3.09	4.39	3.45	3.71
27 Dec 01	3.12	2.51	3.03	2.59	4.23	3.70	3.94
30 Jan 02	3.62	2.67	3.36	2.54	4.80	3.84	4.42
28 Feb 02	4.39	3.07	3.62	2.61	5.66	3.93	4.87
27 Mar 02	4.78	3.02	3.75	2.45	5.76	5.21	6.12
22 Apr 02	4.94	2.90	4.48	3.07	6.32	5.84	7.14

Table 1 : Evapotranspiration estimated by different methods

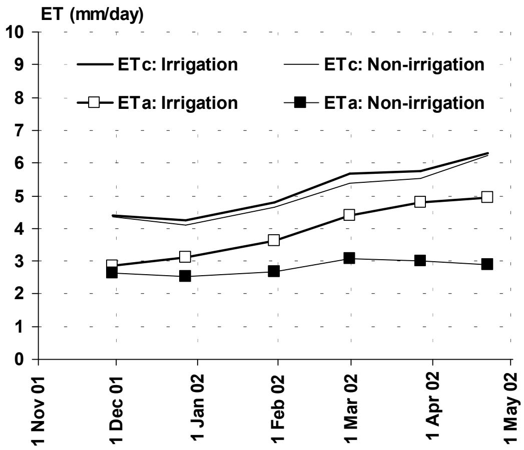

Figure 1 : Evapotranspiration estimated by SEBAL method

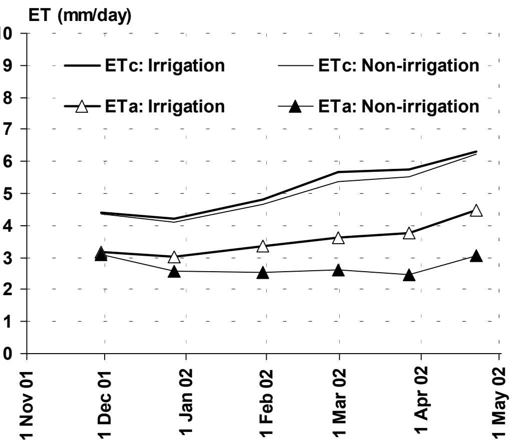

Figure 2 : Evapotranspiration estimated by S-SEBI method

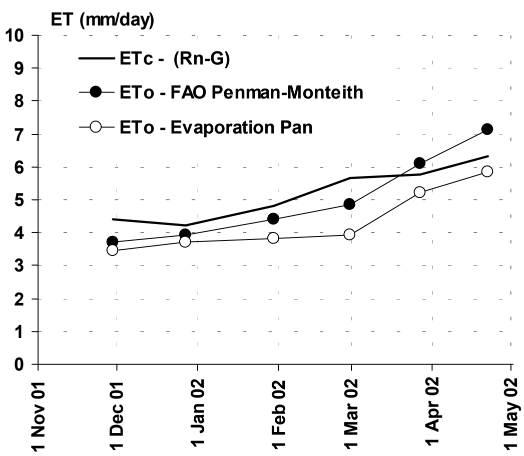

Figure 3 : Comparison of maximum evapotranspiration with ETo

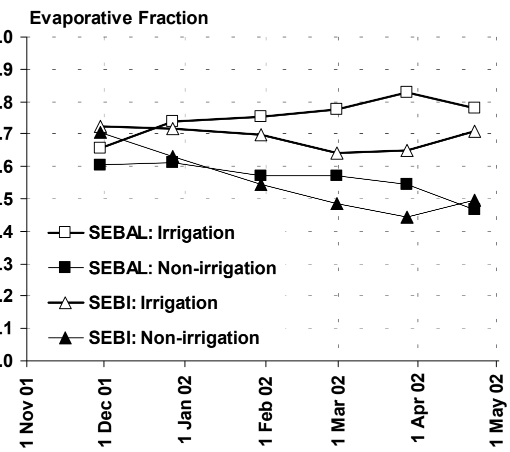

Figure 4 : Comparison of evaporative fraction

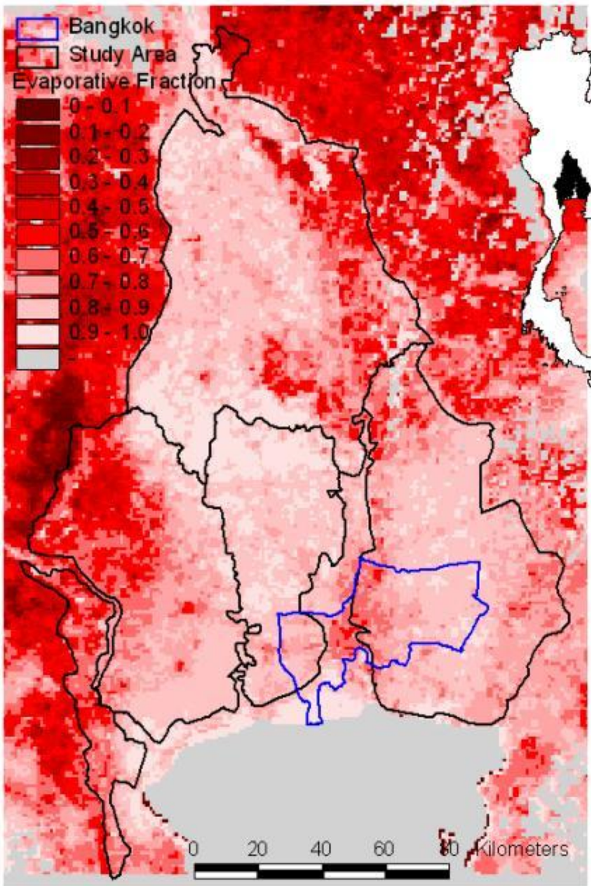

Figure 5 : Example of evaprative fraction in Febuary 28, 2002 estimated by SEBAL method

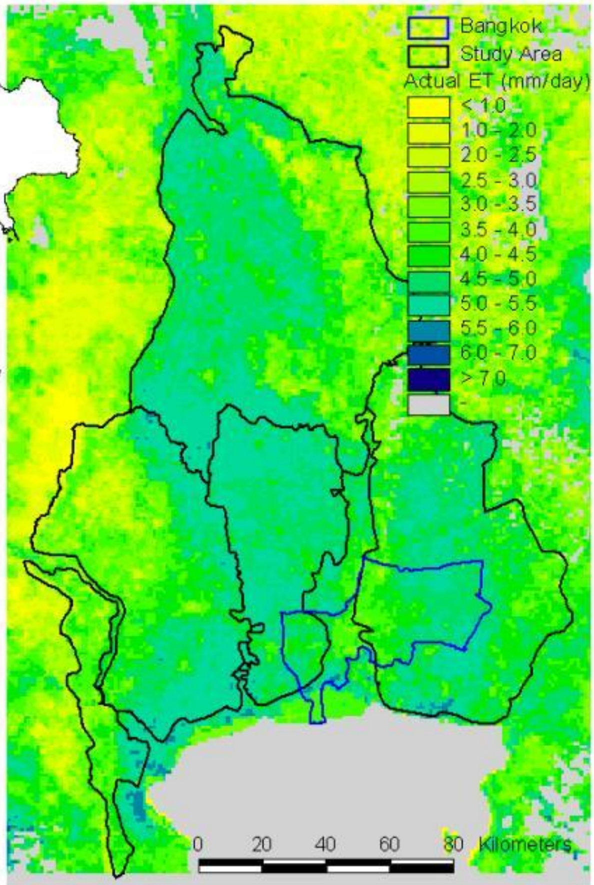

Figure 6 : Example of daily evapotranspiration in Febuary 28, 2002 estimated by SEBAL method

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