Kasetsart J. (Nat. Sci.) 43 : 605 - 611 (2009)

Air Temperature and Actual Evapotranspiration Correlation Using Landsat 5 TM Satellite Imagery

Preeyaphorn Kosa

ABSTRACT

Actual evapotranspiration is a significant component of the water cycle and it is a function of weather data. Moreover, it is difficult to measure. Air temperature is normally measured in a number of weather stations. Since temperature relates to many other weather variables, temperature can be used to infer the characteristics of other weather data. For example, high temperature is associated with low humidity but high evaporation can occur under conditions of high temperature. Thus, the purpose of this study was to determine the relationship between air temperature and actual evapotranspiration. To achieve this objective, spatial temperature and spatial actual evapotranspiration were calculated using the concept of surface energy balance in conjunction with Landsat 5 TM satellite imagery. Thereafter, actual evapotranspiration for each temperature was averaged. Finally, the relationship between air temperature and actual evapotranspiration was determined using a polynomial equation. The results showed that the mean air temperature and the daily mean actual evapotranspiration were 296.4 °K (23.4 °C) and 4.1 mm, respectively. The temperature in Kelvin, could be explained by the equation $y = -0.028x^2 + 17.069x - 2593.2$, where y is the actual evapotranspiration (mm.) and x is the temperature. The equation can be applied to estimate the actual evapotranspiration when the temperature is known. Thereafter, daily actual evapotranspiration is defined when the reference evapotranspiration calculated from weather data in the same area is also known.

Key words: spatial actual evapotranspiration, spatial temperature, SEBAL, Landsat 5 TM

INTRODUCTION

Actual evapotranspiration for a crop can be calculated from the crop coefficient multiplied by the reference evapotranspiration. Crop coefficients can be evaluated from land use maps and the cropping calendar. Land use maps show the types of crops in the study area while the cropping calendar presents the growth stage of crops. Thus, it can be said that the value of the crop coefficient depends on the type and growth stage of the crop. Reference evapotranspiration can be estimated using meteorological parameters such as temperature, humidity, wind speed and net radiation. These parameters are the elements of the FAO Penman-Monteith method that is now recommended as the sole standard method for the definition and reference of evapotranspiration. However, before the FAO Penman-Monteith method became the accepted standard, many methods were used for the estimation of reference evapotranspiration. These included the formulae

School of Civil Engineering, Institute of Engineering, Suranaree University of Technology, Nakhonratchasima 30000, Thailand.
* Corresponding author, e-mail: kosa@sut.ac.th

Received date : 16/12/08 Accepted date : 30/03/09

of Penman (1948), Monteith (1965), Priestly-Taylor (1972) and Hargreaves (1985). The FAO Penman-Monteith method is suitable to calculate reference evapotranspiration, because it uses many factors, which impact the reference evapotranspiration calculation (Allen *et al.*,1998; Kosa, 2007).

Temperature is normally measured in a number of weather stations. Since temperature relates to many weather data, temperature can be used to infer the characteristics of other weather data. For example, high temperature is associated with low humidity but high evaporation can occur under conditions of high temperature.

The characteristics of temperature and actual evapotranspiration can be described by variable spatial resolution. At present, remote sensing technology is used to determine the temperature and actual evapotranspiration. Remote sensing observations bolster spatial resolution. However, remote sensing technological developments in evaluating actual evapotranspiration and temperature over large areas have not been applied in Thailand. Thus, the purposes of this study were to determine spatial temperature, spatial actual evapotranspiration and the relationship between temperature and actual evapotranspiration using the concept of surface energy balance in conjunction with Landsat 5 TM satellite imagery.

MATERIALS AND METHODS

There were three main parts to this research: spatial temperature calculation, spatial actual evapotranspiration estimation and determination of the relationship between temperature and actual evapotranspiration. Landsat 5 TM satellite imagery path 127/row 48 constituted the main input data. The spatial resolution of Landsat 5 TM satellite imagery is 30 m and the swathe width covered by the image is 185 km. This image covered the Sri Songkhram sub-river basin located in the lower part of the Mekhong river basin in the northeast of Thailand. The period selected for this study was from November 2006 to January 2007 because it is in the dry season and there is clear sky. Moreover, there was cultivation during this time so there was both evaporation and transpiration involved in evapotranspiration.

Spatial temperature was first computed using Landsat 5 TM satellite imagery. Spatial actual evapotranspiration was then calculated using the surface energy balance algorithm for land (SEBAL). In the SEBAL method, Landsat 5 TM satellite images were also used to estimate spatial daily actual evapotranspiration. After the maximum and minimum values of actual evapotranspiration in each temperature were excluded, the selected actual evapotranspiration for each temperature was averaged. Finally, the relationship between temperature and actual evapotranspiration was determined using a polynomial equation.

Temperature computation

Normally, Landsat 5 TM satellite imagery data is based on digital number (DNs), so it was necessary to convert the DNs to radiances for all bands in the Landsat 5 imagery (Equation 1):

$$L_{\lambda} = \frac{(LMAX_{\lambda} - LMIN_{\lambda})}{(QCALMAX - QCALMIN)} \times (QCAL - QCALMIN) + LMIN_{\lambda} \tag{1}$$

where $LMAX_{\lambda}$ and $LMIN_{\lambda}$ are differ for each bands, QCAL or DN, $LMAX_{\lambda}$ and $LMIN_{\lambda}$ are input data. These elements are values in the header file information.

Thereafter, effective satellite temperature (T_{bb}) was calculated by Equation 2:

$$T_{bb} = \frac{1282.71}{\ln\left(\frac{666.09}{L_6} + 1\right)} \tag{2}$$

For the calculation of the thermal band, the radiance image was used, because the thermal band provides a dummy of the reflectance image. Surface temperature (T_s) was then computed by Equation 3:

$$T_s = \frac{T_{bb}}{\varepsilon_0^{0.25}} \quad (3)$$

where ε_0 is surface emissivity calculated using normalized difference vegetation index (NDVI), the reflectance value in the red band (ρ_3) and the reflectance value in the near-infrared band (ρ_4) as shown in Equations 4 and 5:

$$\varepsilon_0 = 1.009 + 0.047 \times \ln(\text{NDVI}) \quad (4)$$

$$\text{NDVI} = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3} \quad (5)$$

Actual evapotranspiration calculated by SEBAL

The SEBAL algorithm is a tool to compute actual evapotranspiration for flat areas with the greatest accuracy and confidence. Satellite images and weather data are used in the SEBAL model to calculate actual evapotranspiration using a surface energy balance model. SEBAL evaluates an instantaneous actual evapotranspiration flux at the time the image was captured because the satellite image provides information for the overpass time only. The actual evapotranspiration flux can be calculated for each pixel of the image as a residual of the surface energy budget equation (Bastiaanssen, 1998a; Bastiaanssen, 1998b) (Equation 6):

$$LE = (R_n - G) - H \quad (6)$$

where LE is the latent energy per unit time per unit area of evaporation (W/m^2), R_n is the net radiation flux at the soil surface (W/m^2), G is the soil heat flux (W/m^2), and H is the sensible heat flux to the air (W/m^2).

After LE was computed, the evaporative fraction ($\wedge$) was obtained using Equation 7. The evaporative fraction at each pixel of a satellite image can be estimated using the 24-hour evapotranspiration for the day of the image. The evaporative fraction is assumed to remain constant over the full 24-hour period.

$$\wedge = \frac{LE}{R_n - G} = \frac{LE}{LE + H} \quad (7)$$

To estimate 24-hour actual evapotranspiration, Equation 8 was used:

$$ET_{24} = \frac{86400 \wedge (R_{n24} - G_{24})}{\lambda} \quad (8)$$

where R_{n24} is daily net radiation, G_{24} is daily soil heat flux, 86 400 is the number of seconds in a 24-hour period, and λ is the latent heat of vaporization (J/kg). The 24-hour actual evapotranspiration, ET_{24}, can be expressed in mm/day.

Since energy, on average, is stored in the soil during the daytime and released into the air at night, G_{24} is very small for the combined vegetative and soil surface, so it can be assumed as zero at the soil surface (Morse *et al.*, 2000; Hafeez and Chemin, 2005). Equation 9 can be then rewritten as:

$$ET_{24} = \frac{86400 \wedge R_{n24}}{\lambda} \quad (9)$$

Validation

The temperature computed using the Landsat 5 TM satellite images was validated by a comparison with the recorded temperature. However, to validate actual evapotranspiration calculated by SEBAL, the recorded pan evaporation was used. Pan evaporation is the amount of water evaporated during a period (mm/day) with an unlimited supply of water (potential evaporation). It is a function of surface and air temperatures, insolation and wind, all of which affect water-vapor concentrations immediately above the evaporating surface. On the other hand, actual evapotranspiration is a function of temperature, wind, humidity and net radiation. The decreasing trend detected in the pan evaporation and actual evapotranspiration can be attributed to the significant decreasing trends in the net radiation and in the wind speed. It can be attributed also to the significant increasing trend in the air temperature. (Humphreys *et al*., 1994; Grismer *et al*., 2002; Marco, 2002).

RESULTS AND DISCUSSION

The three main parts of the results involved spatial temperature, spatial actual evapotranspiration and the relationship between temperature and actual evapotranspiration.

Temperature

The spatial distributions of temperature calculated using Landsat 5 TM satellite images are presented in Figures 1 to 3. The mean temperatures from Figures 1, 2 and 3 were 297.34 °K (24.19°C), 295.74°K (22.59°C) and 296.25°K (23.10°C), respectively.

Actual evapotranspiration

The spatial distributions of actual evapotranspiration calculated using Landsat 5 TM satellite images and SEBAL are presented in Figures 4 to 6. The mean actual evapotranspiration from Figures 1, 2 and 3 were 3.67, 4.50 and 4.26 mm., respectively.

Relationship between temperature and actual evapotranspiration

After temperature and actual evapotranspiration were calculated as shown in Figures 1 to 6, the temperature and actual evapotranspiration were plotted (Figures 7 and 8). These figures present the relationship between the temperature and actual evapotranspiration explained by the equations: $y = -0.028x^2 + 17.069x - 2593.2$ ($R^2 = 0.987$); and $y = -0.028x^2 + 1.7608x - 22.932$ ($R^2 = 0.987$), where y is the actual evapotranspiration (mm) and x is the temperature in units of °K and °C, respectively.

CONCLUSION

From the above results, it can be concluded that the mean temperature and the mean actual evapotranspiration in the Sri Songkhram sub-river basin were 296.44°K (23.44°C) and 4.14 mm, respectively. The relationship between the temperature (°K and °C) and actual evapotranspiration (mm) was in the form of a polynomial equation. For the temperature in degrees Kelvin, the equation was $y = -0.028x^2 +$

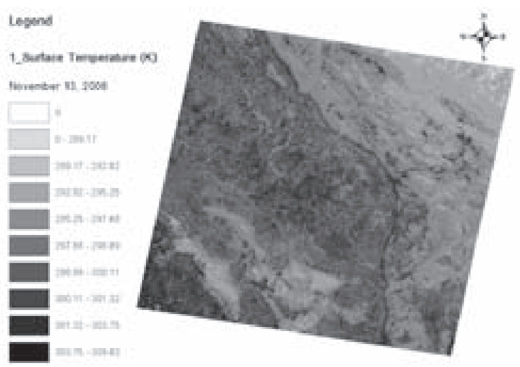

Figure 1 The surface temperature on November 13, 2006.

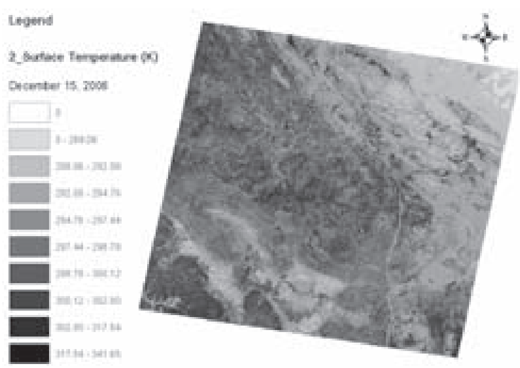

Figure 2 The surface temperature on December 15, 2006.

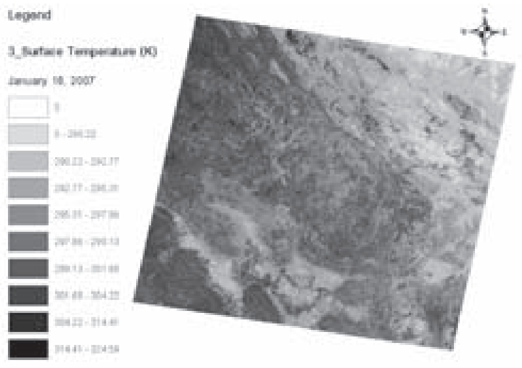

Figure 3 The surface temperature on January 16, 2007

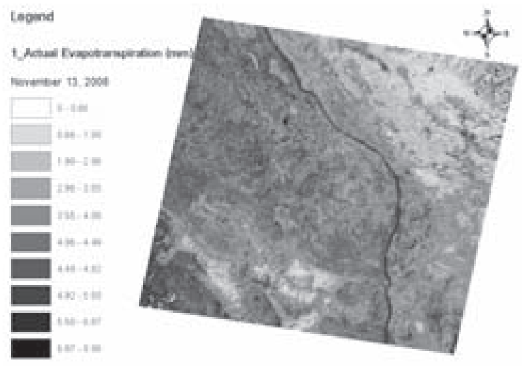

Figure 4 The actual evapotranspiration on November 13 2006.

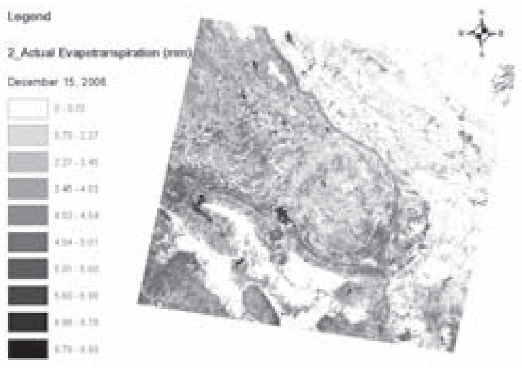

Figure 5 The actual evapotranspiration on December 15, 2006.

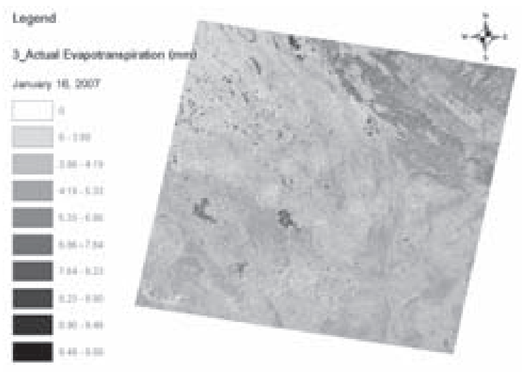

Figure 6 The actual evapotranspiration on January 16, 2007.

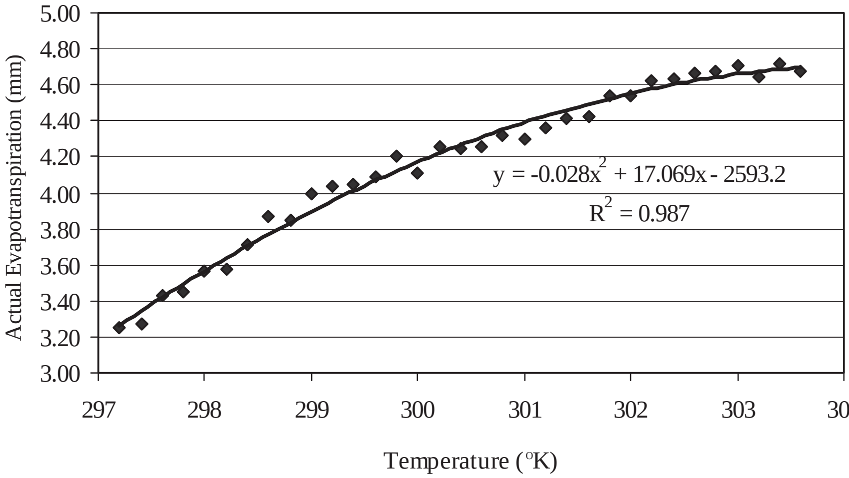

Figure 7 The relationship between the temperature (°K) and actual evapotranspiration (mm).

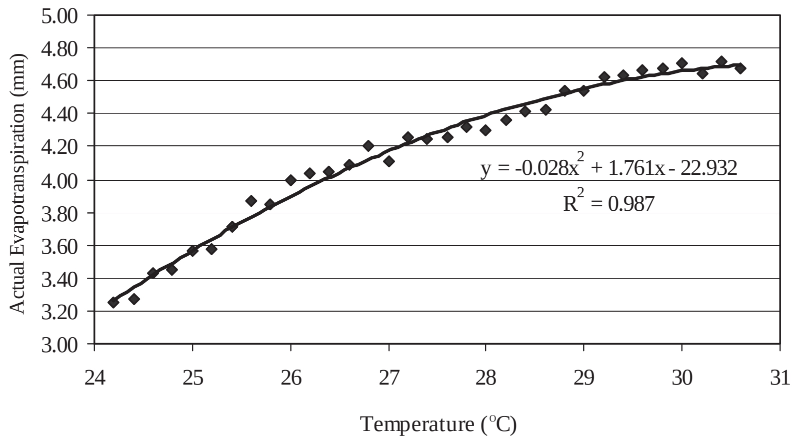

Figure 8 The relationship between the temperature (°C) and actual evapotranspiration (mm).

17.069x - 2593.2 and for the temperature in degrees Celsius, the equation was $y = -0.028x^2 + 1.7608x - 22.932$.

These results are useful for irrigation project and water management. For spatial actual evapotranspiration, they can be used to present daily actual evapotranspiration. Daily actual evapotranspiration is a leading parameter in the planning of water management in an area. The spatial temperature results present the temperature for each area. The relationship between actual evapotranspiration and temperature can be used to estimate actual evapotranspiration when temperature is known. Thereafter, daily actual evapotranspiration can be defined when the reference evapotranspiration calculated from weather data in the same area is also known.

ACKNOWLEDGEMENTS

This research was supported by the Faculty of Science and Engineering, Kasetsart University Chalermphrakiat Sakonnakhon province. The Landsat satellite images were supplied by the Geo-Informatics and Space Technology Department Agency (Public Organization) or GISTDA. The author would sincerely like to acknowledge the efforts of many people who contributed to the research. Without them, the work would never have been undertaken.

LITERATURE CITED

Allen, R. G., L. S. Pereira, D. Raes and M. Smith. 1998. **Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements.** FAO irrigation and drainage paper No 56. FAO, Rome, 300 p.

Bastiaanssen, W. G. M., M. Meneti, R. A. Feddes and A. A. M. Holtslag. 1998a. A remote sensing surface energy balance algorithm for land (SEBAL) 1. Formulation. **J. of Hydrology** 212: 198-212.

Bastiaanssen, W. G. M., M. Meneti, R. A. Feddes and A. A. M. Holtslag. 1998b. A remote sensing surface energy balance algorithm for land (SEBAL) 1. Validation. **J. of Hydrology** 212: 213-229.

Grismer, M. E., M. Orang, R. Snyder, and R. Matyac 2002. Pan Evaporation to Reference Evapotranspiration Conversion Methods. **J. of Irrigation and Drainage Engineering** 128 (3): 180-184.

Hafeez, M. M. and Y. Chemin. 2005. Evapotranspiration Estimation using TERRA/ ASTER sensor: A case study in District 1 of UPRIIS, Central Luzon, Philippines. **Canadian J. of Remote Sensing (CJRS).** 11.

Hargreaves, G.H. and Z.A. Samani. 1985. Reference crop evapotranspiration from temperature. **Applied Engineering in Agriculture** 1: 96-99.

Humphreys, E., W. S. Meyer, S. A. Prathapar and D. J. Smith. 1994. Estimation of evapotranspiration from rice in southern New South Wales: a review. **Australian J. of Experimental Agriculture** 34 (7): 1013-1020.

Kosa P. 2007. **Evaluation of spatial and temporal evapotranspiration using satellite imagery in the Chao Phraya River Basin.** Ph.D. Thesis . Kasetsart University. Thailand.

Marco, A. F. C. 2002. Reference Evapo-transpiration Based on Class A Pan Evaporation. **Scientia Agricola J.** 59 (3): 417-420.

Monteith, J.L. 1965. Evaporation and the environment In The state and movement of water in living organisms. **19th Symposia of the Society for Experimental Biology**. Cambridge Univ. Press, London, U.K.

Morse, A., M. Tasumi, R. G. Allen and J. W. Kramber. 2000. **Application of the SEBAL Methodology for Estimating Consumptive Use of Water and Streamflow Depletion in the BEAR River Basin of IDAHO Through Remote Sensing.** Final Report submitted to The Raytheon System Company Earth Observation System Data and Information System Project.

Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. **Proceedings of the Royal Society of London**, A193: 120-146.

Priestley, C. H. B. and R. J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Mon. **Weather Rev.** 100: 81-92.