A Comparative Study of Evapotranspiration Calculated from Remote Sensing, Meteorological and Lysimeter Data

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Abstract

Water resources are limited in many parts of the world. Due to fast growing world population the demand for domestic and industrial water use is increasing tremendously. This results in reduction of water for agricultural use, especially for major rice growing areas. But crop production has to be increased in spite of the limited water resources. Malaysia uses more than 75 % of its fresh water withdrawal for rice irrigation, but with only about 45 % efficiency due to losses from spillage, seepage, deep percolation and evapotranspiration. Hence water saving from rice cultivation is very important. An accurate measurement of evapotranspiration could lead to the development of improved water use efficiency. A study on evapotranspiration for rice was conducted in the Tanjung Karang Rice Irrigation Project Malaysia during the main season (August–November) of 2003. An automatic meteorological station was installed inside the field to collect data required for calculations of the evapotranspiration using the CROPWAT software. Non-weighing lysimeters (91 cm x 91 cm x 61 cm) with attached casella hook were installed to measure the crop evapotranspiration at five different locations within the 19000 ha irrigation scheme. NOAA satellite data was used as data input to correlate the remote sensing data with field evapotranspiration data. The observed ET from the lysimeters ranged from 3.2 to 5.8 mm/day, while ET by calculation ranged from 3.15 to 5.72 mm/day. The corresponding ET values from satellite data were 4.04 to 6.54 mm/day. Considering ET measured by lysimeter as the most accurate method, ET determined using satellite data overestimates those obtained by lysimeter by 10 % and CROPWAT underestimates by 14 %.Estimation of actual water use is an essential requirement for strategic water resource planning at national and regional levels.

Keywords: Rice Evapotranspiration, Lysimeters, CROPWAT, NOAA Data.

Introduction

Increasing attention is being paid to irrigation water management of paddy fields, both because of its importance in food production and its huge water use. Meeting the physiological and ecological water requirements of rice is a prerequisite for effective irrigation scheduling of paddy fields. Beside the crop water requirements, water losses, which are not beneficial in crop production, can add a huge volume to the total water usage in agriculture. Based on this argument, there could be greater possibility to save water from agriculture, which can be used for other purposes thereafter. There is considerable scope for improving water use efficiency by proper irrigation scheduling which is essentially governed by crop evapotranspiration (ETc). Accurate estimation of crop ET is an important factor in efficient water management. Traditional ET measurements using lysimeters is accurate but time consuming and laborious. There is a need for a more rapid assessment of ET resulting from global environmental changes. The objective of this work was to compute the evapotranspiration for the Tanjung Karang Irrigation Scheme using remote sensing and to validate the results with field measurements and meteorological computation.

Evapotranspiration by Remote Sensing

Remote sensing can be applied to the management of irrigated agricultural systems either at a local scale or nationally. It has the possibility of offering important water resource related information to policy makers, managers, consultants, researchers and to the general public. Remote sensing, with varying degrees of accuracy, has been able to provide information on land use, irrigated area, crop type, biomass development, crop yield, crop water requirements, crop evapotranspiration, salinity, water logging and river runoff. This information when presented in the context of management can be extremely valuable for planning and evaluation purposes. Remote sensing has several advantages over field measurements. First, measurements derived from remote sensing are objective; they are not based on opinion. Second, the information is collected in a systematic way which allows time series and comparison between schemes. Third, remote sensing covers a wide area such as entire river basins. Ground studies are often confined to a small pilot area because of the expense and logistical constraints. Fourth, information can be aggregated to give a bulk representation, or disaggregated to very fine scales to provide more detailed and explanatory information related to spatial uniformity. Fifth, information can be spatially represented through geographic information system, revealing information that is often not apparent when information is provided in tabular form (Bastiaanssen, 1998).

Evapotranspiration is generally computed not for its own sake but for some other purposes and each method can be assessed for its usefulness in this regard. Traditionally, actual evapotranspiration has been computed as a residual in water balance equations, from estimates of potential evapotranspiration using a soil moisture reduction function or from field measurements by meteorological equipment. Recent research (Bastiaanssen &

Molden, 2000), (Vidal & Perrier, 1989) used satellite data to estimate regional actual evapotranspiration.

Granger (2000) studied evapotranspiration assessment using NOAA satellite image and AVHHR data with 1.1 km ground resolution processed the data through radiometric calibration and geo-certified with ERDAS Imagine software. The satellite estimated evapotranspiration was calculated by multiplying potential evapotranspiration and the vegetation and moisture coefficient (VMC). The estimates compared to lysimeter measurements indicated successful estimates of regional evapotranspiration.

The application of surface energy balance algorithm for land (SEBAL) in Idaho indicates substantial promise as an efficient, accurate, and inexpensive procedure to predict the actual evapotranspiration fluxes from irrigated lands throughout a growing season (Droogers & Bastiaanssen, unpublished). Predicted evapotranspiration has been compared to ground measurements of evapotranspiration by lysimeters with good results, with monthly differences averaging +/- 16%, but with seasonal differences of only 4% due to reduction in random error (Allen et al, unpublished). The SEBAL method derives the evaporative fraction from satellite data. This is a measure of energy partitioning and a good indicator of crop stress. Actual evapotranspiration can be easily obtained from the product of the evaporative fraction and the net radiation. The SEBAL remote sensing technique is not restricted to irrigated areas, but can be applied to a broad range of vegetation types. Data requirements are low and restricted to satellite information although some additional ground observations can be used to improve the reliability.

The Study Area

The area chosen for this study is the Tanjung Karang Rice Irrigation Project (Fig.1). The site is located on a flat coastal plain in the Northwest Selangor Agricultural Development Project (PBLS) at latitude 3^0 35'and longitude 101^0 5' which covers an area of approximately 19,000 hectares extending over a length of 40 km along the coast with a width of 5 km on average. The main irrigation and drainage canals run parallel to the coast. The Bernam River, the water source for the project, meanders northwestward and forms the boundaries between the state of Selangor and Perak.

Evapotranspiration Estimation Method

The evapotranspiration estimation method described here is based on the calculation of reference evapotranspiration (ET_o), to be multiplied by the crop factor (Kc), resulting in crop evapotranspiration (ETcrop). ET_o is defined as "the rate of evapotranspiration from an extensive surface of 5-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". ETcrop is defined as "the rate of evapotranspiration from a disease free crop, growing in large fields, under non restricting soil water and fertility conditions and achieving full production potential under the given growing environment". In this study the reference evapotranspiration was calculated using FAO CROPWAT software version 7, (http://www.fao.org/ag/agl/aglw/cropwat.stm). The method is applied using 10-day running average. All data were collected from the selected study area of the Tanjung Karang Irrigation Scheme. Figure 2 shows a typical result of CROPWAT.

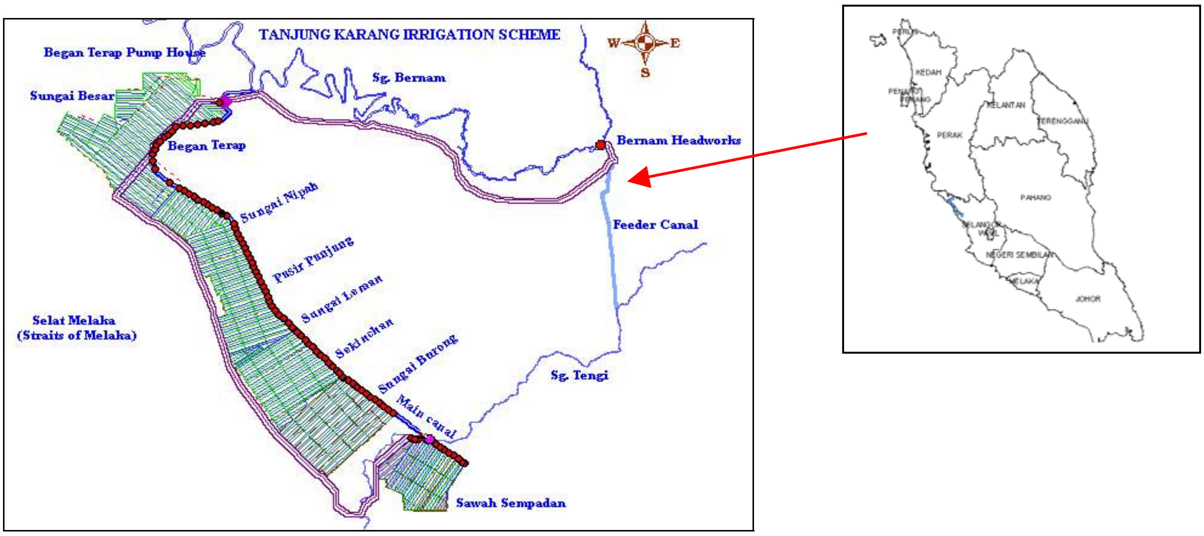
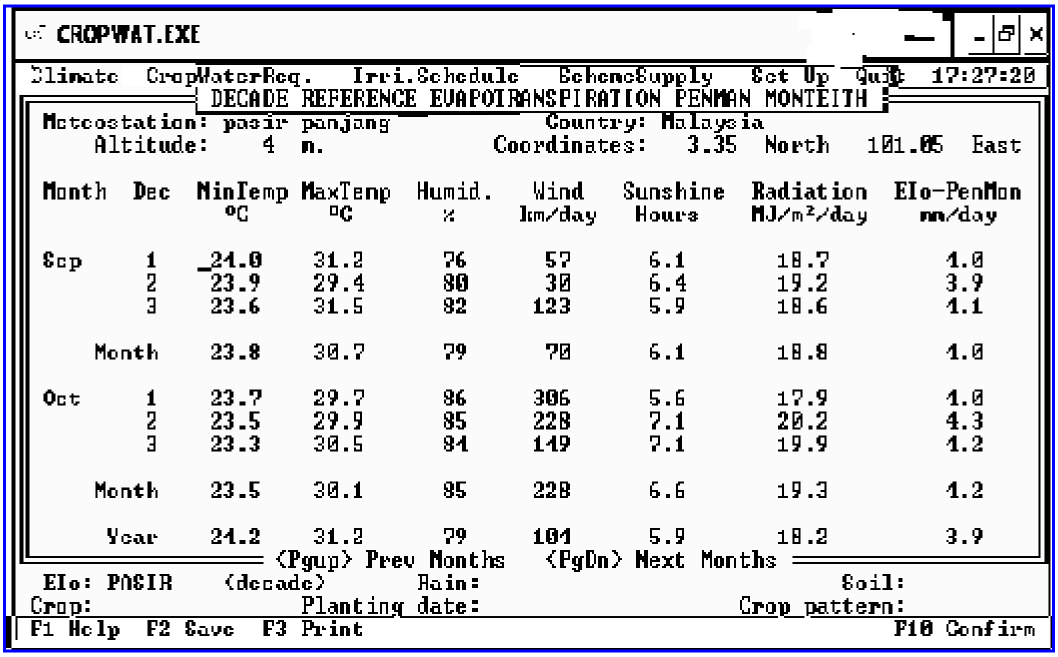


Fig. 1: Location of the Study Area



CROPWAT.EXE

Climate CropWaterReq. Irri.Schedule SchemeSupply Set Up Quit 17:27:20

DECADE REFERENCE EVAPOTRANSPIRATION PENMAN MONTEITH

Meteostation: pasir panjang Country: Malaysia
Altitude: 4 m. Coordinates: 3.35 North 101.05 East

Month	Dec	MinTemp °C	MaxTemp °C	Humid. %	Wind km/day	Sunshine Hours	Radiation MJ/m²/day	ETo-PenMon mm/day
Sep	1	24.0	31.2	76	57	6.1	18.7	4.0
	2	23.9	29.4	80	30	6.4	19.2	3.9
	3	23.6	31.5	82	123	5.9	18.6	4.1
	Month	23.8	30.7	79	70	6.1	18.8	4.0
Oct	1	23.7	29.7	86	306	5.6	17.9	4.0
	2	23.5	29.9	85	228	7.1	20.2	4.3
	3	23.3	30.5	84	149	7.1	19.9	4.2
	Month	23.5	30.1	85	228	6.6	19.3	4.2
	Year	24.2	31.2	79	104	5.9	18.2	3.9

<PgUp> Prev Months <PgDn> Next Months

ETo: PASIR (decade) Rain: Soil:
Crop: Planting date: Crop pattern:
F1 Help F2 Save F3 Print F10 Confirm

Fig.2: CROPWAT output for calculating ET_0

Remote Sensing Methods

Remote sensing method is attractive to estimate evapotranspiration as they cover large areas and can provide estimates at very high resolutions. Intensive field monitoring is not required, although some ground truth measurements can be helpful in interpreting the satellite images. The methods selected are varying in resolution and degree of physical realism.

Sebal Remote Sensing Technique

The Surface Energy Balance Algorithm for Land (SEBAL) developed by Bastiaanssen 1998 is a parameterization of the energy balance and surface fluxes based on spectral satellite measurements (Bastiaanssen, 1998). SEBAL requires visible, near-infrared and thermal infrared input data, which in this case were obtained from the free of charge data provided by NOAA AVHRR (National Oceanographic and Atmospheric Administration - Advanced Very High Resolution Radiometer). Instantaneous net radiation values were computed from incoming solar radiation measured at ground station, and the net radiation estimated from twenty six cloud-free NOAA images via surface albedo, surface emissivity and surface temperature. Surface albedo was computed from the top of the atmosphere broad-band albedo using an atmospheric correction procedure. Surface temperature was extracted from the images using an especial model developed for it. NDVI was calculated from the images using remote sensing software and the surface albedo was then calculated.

Lysimeter Method

Non-weighing lysimeters were fabricated and installed inside the paddy fields to measure the crop evapotranspiration at four randomly selected plots in block C of Sawah Sempadan-Irrigation compartment PBLS. Four other sets of lysimeters were installed in Sungai Burung, Sekinchan, Sungai Leman and Pasir Panjang compartments. The lysimeters, 91cm x 91cm x 61cm, were attached with a casella hook to monitor the daily water level. The lysimeters were inserted into the soil to a depth of 30 cm. Lysimeters were planted with the same rice variety in the scheme which was MR 219. Readings from the lysimeters and calculated ET from weather parameters were compared with the remote sensing derived ET estimates.

Data Collection and Analysis

Meteorological Data

The following meteorological data were obtained: location of the scheme (coordinates and elevation), Maximum and minimum temperature, Relative humidity, Wind speed, Sunshine duration or radiation per day, Total rainfall and effective rainfall data, and Pan evaporation.

Using meteorological and crop data, the crop water requirements were calculated using the CROPWAT software. The Penman-Montieth equation used in the software is being adopted by FAO as standard evapotranspiration equation to be used all over the world. The crop evapotranspiration, ET_{crop} can be expressed as

$$ET_{crop} = K_C \, ET_o \quad \text{.........} \quad (1)$$

where K_C is the crop coefficient and ET_o is the reference crop evapotranspiration. K_C values used were 1.3, 1.09 and 0.9 for the initial stage, the mid season stage and the end of the late season stage, respectively. These values were suggested by FAO (paper 56).

Satellite Data

Satellite data was ordered from the Malaysian Center for Remote Sensing (MACRES) for the rice cultivation season. Images were registered, subset to the selected study area and analyzed. The evapotranspiration was calculated using the SEBAL model. The day net radiation is the electromagnetic balance of all incoming and outgoing fluxes reaching and leaving a flat surface for the daylight hours (Bastiaanssen 1995) obtained using the following equation

$$R_{n-day} = (1-\rho_0)\times(K^{\downarrow}) - 110\times\tau_{sw} \quad \text{W/m}^2 \ldots\ldots\ldots\ldots. (2)$$

where $K^{\downarrow}$ is the incoming short -wave solar radiation (W/m^2), ρ_0 the surface albedo (-), τ_{sw} is the day single way transmissivity t of the atmosphere (default = 0.7, or from meteorological data if available).

The calculation of evapotranspiration is including the transformation of day net radiation from W/m^2 to mm/day using the following equation

$$ET = R_n 86400\times10^3\left[2.501-(0.002361T)\times10^6\right]^{-1} \quad \text{mm/day}\ldots. (3)$$

Using GIS, the data can be manipulated by digitizing the spatial data, entering the non spatial data and associated spatial attributes data, and linking between the spatial and non spatial data

Results and Discussion

Satellite Derived Et

Surface reflectance, red and near infrared band, was used to calculate the Normalized Difference Vegetation Index values (NDVI). It is defined as the difference between the visible (red) and near infrared (nir) bands, over their sum.

NDVI = nir-red / nir + red

The NDVI is representative of plant assimilation condition and of its photosynthetic apparatus capacity and biomass concentration (Groten 1993, Loveland et al 1991). The NDVI values range from -1 to +1 (pixel values 0-255). Calculated NDVI is used to estimate the emissivity values. Figure 3 represents the variations of NDVI between the different compartments obtained from the images. The values in December are low because it was the time of harvesting in the study area.

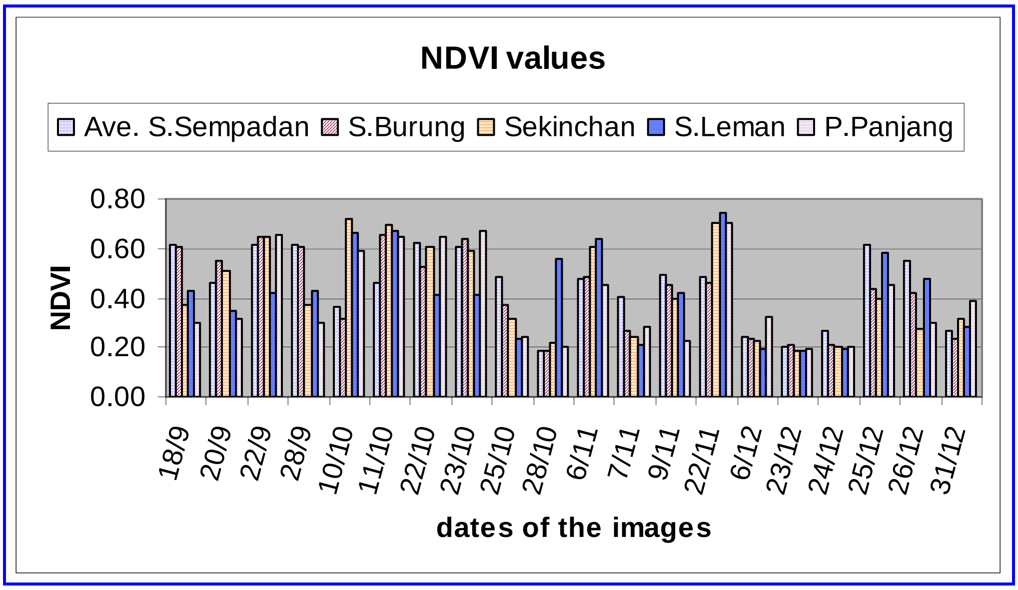


Fig: 3 NDVI values from satellite data

Figure 4 (a-e) shows the ET results obtained from satellite data calculations with the support of solar radiation data from the meteorological station. The images used were cloud free images and they were selected from a set of images taken from MACRES. The range of ET values from the images ranged between 4.04 mm/day to 6.54 mm/day.

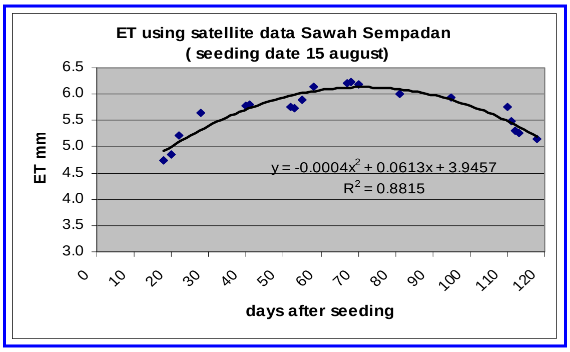


Fig 4a

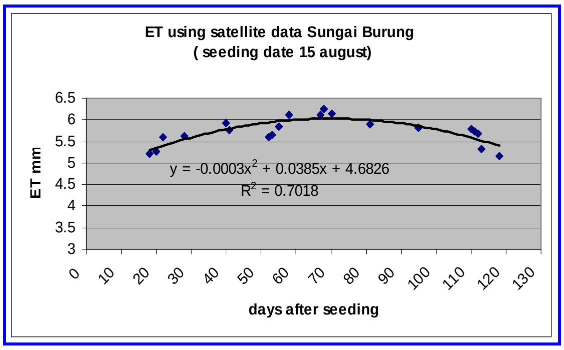


Fig 4b

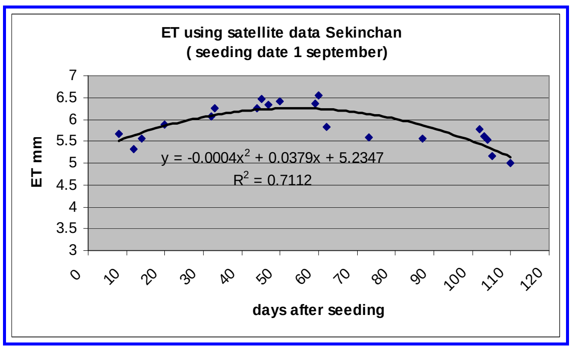


Fig 4c

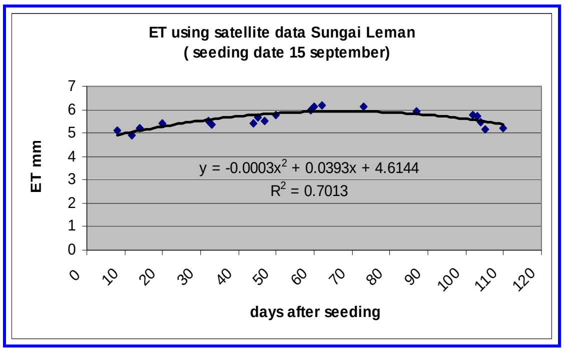


Fig 4d

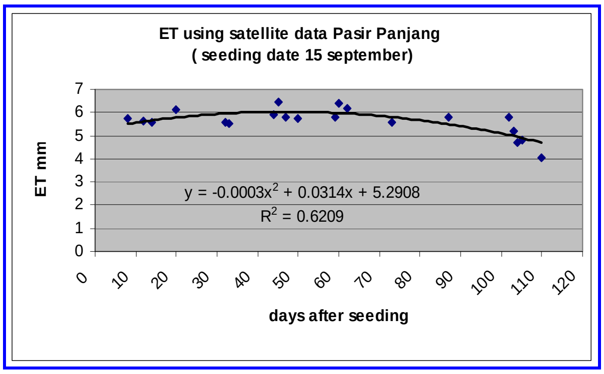


Fig 4e

Fig 4. ET rate obtained by satellite data at 5 locations within the irrigation scheme

Twenty cloud-free images were used in the study. The results obtained from all methods were compared. Evapotranspiration values from the NOAA data are generally 10% higher than the lysimeter data, but the ETcrop obtained from CROPWAT are generally 14% lower than those measured by lysimeter Figure 5(a-e).

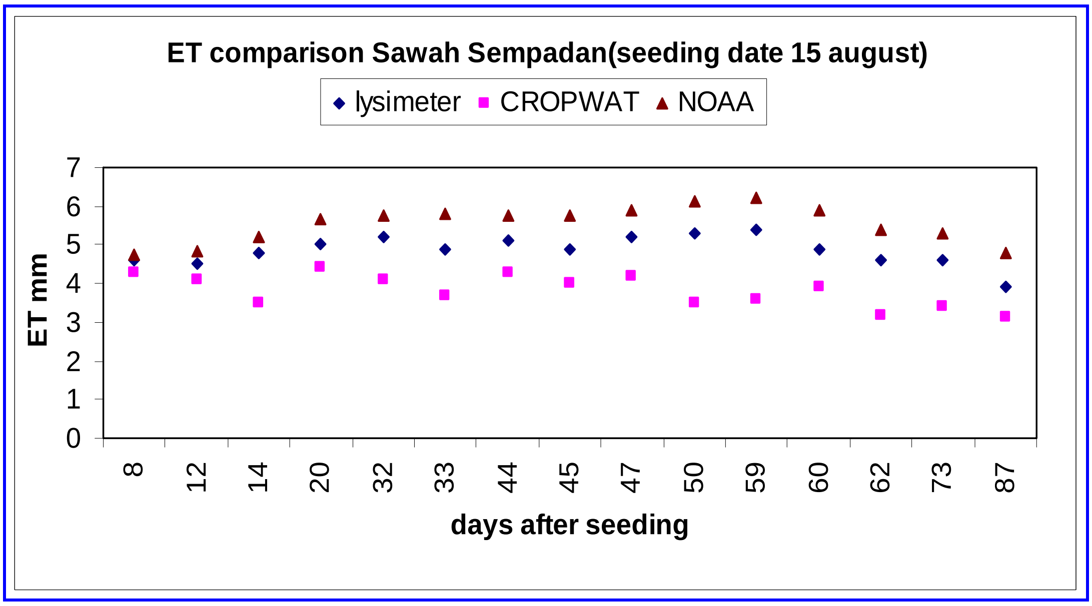
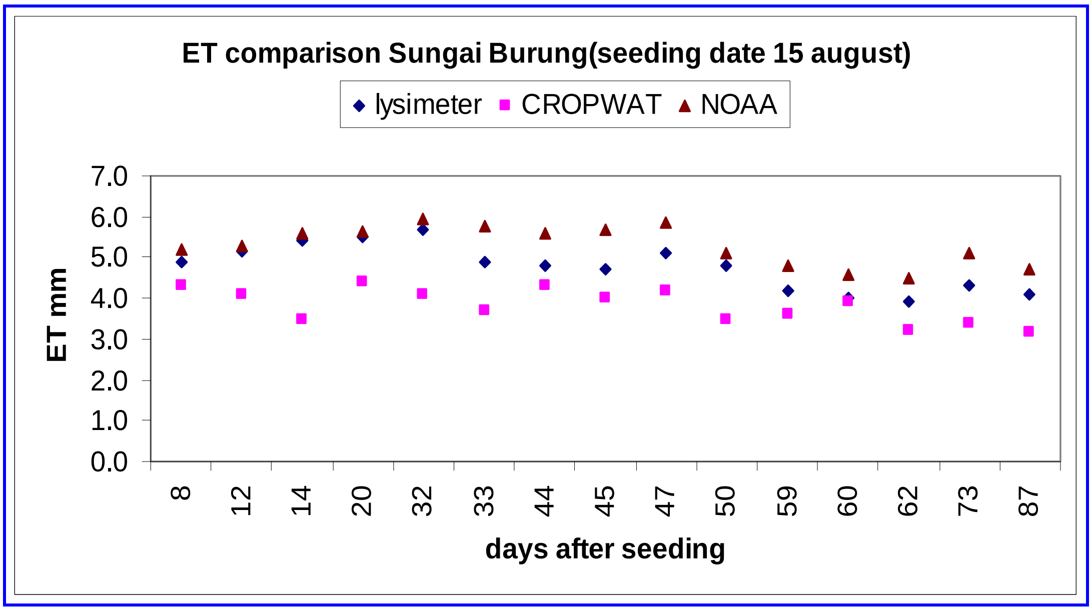
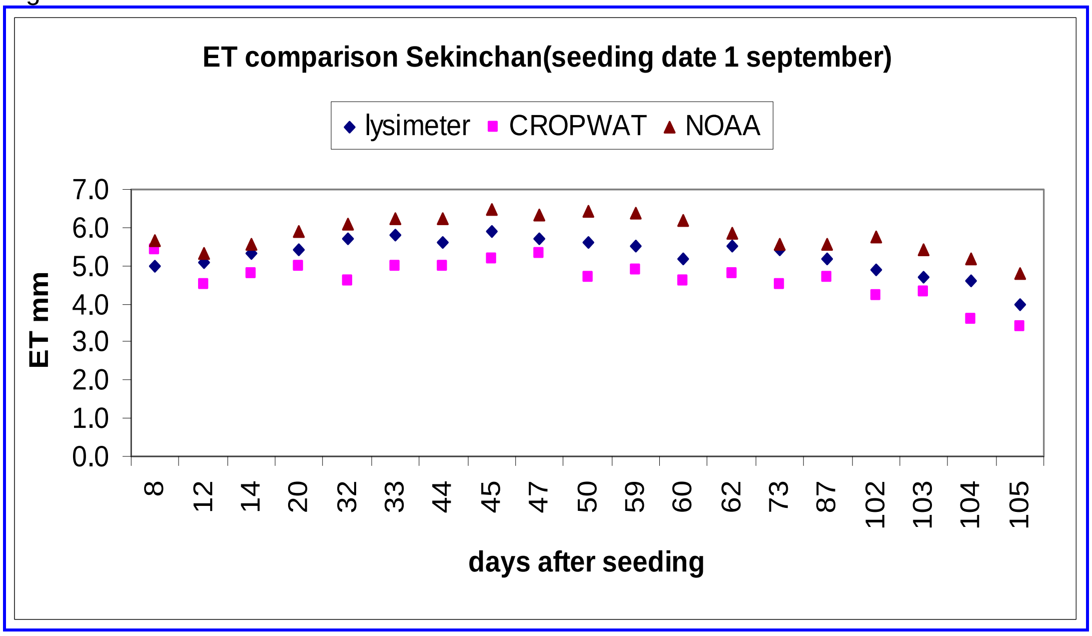


Fig 5a



ET comparison Sungai Burung(seeding date 15 august)
lysimeter
CROPWAT
NOAA
ET mm
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
8
12
14
20
32
33
44
45
47
50
59
60
62
73
87
days after seeding

Fig 5b



ET comparison Sekinchan(seeding date 1 september)
lysimeter
CROPWAT
NOAA
ET mm
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
8
12
14
20
32
33
44
45
47
50
59
60
62
73
87
102
103
104
105
days after seeding

Fig 5c

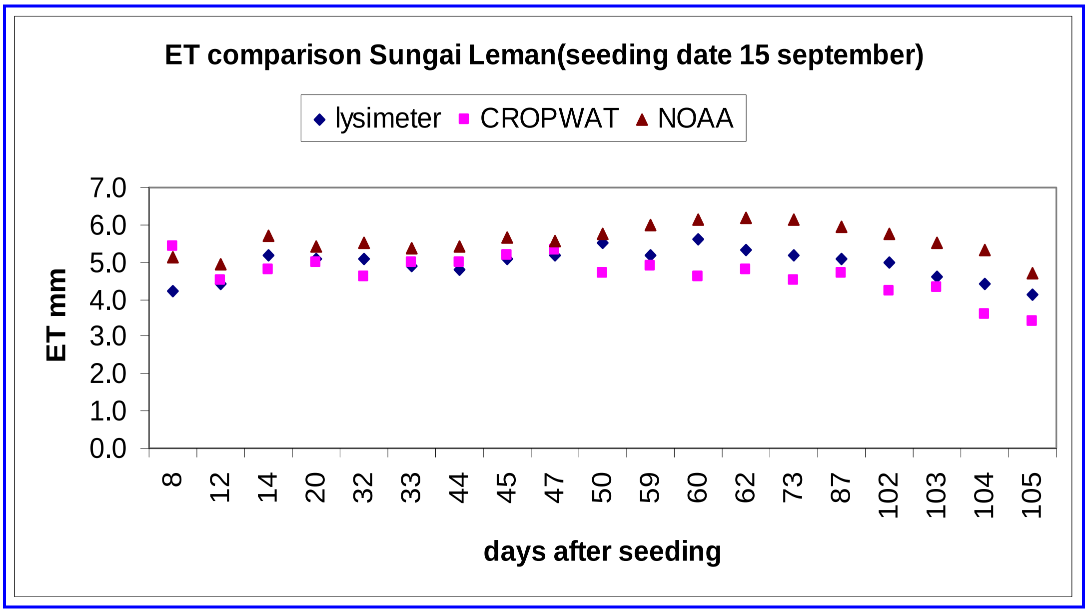


Fig 5d

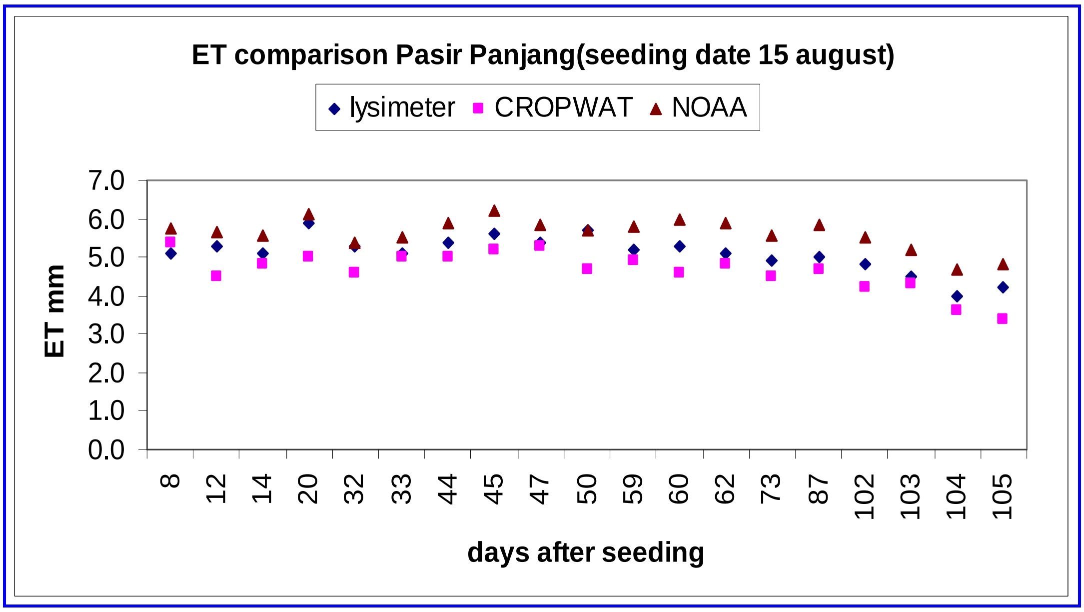


Fig 5e

Fig 5. ET comparison at 5 locations within the irrigation scheme

The application of remote sensing needs highly skilled workers and they will require some time to get the necessary skill. Consequently, it will be easy to apply the technique. The use of NOAA data with 1 km resolution is not the ideal for small areas because of its low spatial resolution, but the availability and cost of other data is the limiting factor. NOAA data is available daily even though a cloud free image may not be obtained easily in the humid tropics such as Malaysia.

Conclusions

Estimates of evapotranspiration over the Tanjung Karang irrigation scheme were obtained using lysimeters, calculation from weather parameters and satellite-derived data. Penman-Monteith equation through the use of CROPWAT software was applied to calculate ET. Considering ET obtained by lysimeters as the most accurate, the ET from satellite data overestimates ETcrop, while CROPWAT underestimates ETcrop. The comparison results show that the ETcrop derived from NOAA data are generally 10% higher than the lysimeter data but by the CROPWAT are generally 14% lower than those measured by lysimeters. The availability of advanced very high resolution radiometer AVHRR data from NOAA on daily basis is a cheaper alternative for evapotranspiration estimation. Satellite images can provide data and information about the paddy fields at any time, hence reduces the cost of taking field data and also reduce the error of missing data. Estimation of evapotranspiration using NOAA data will give good reflection of global changes. However, based on this study a factor of 0.9 needs to be multiplied to the satellite derived ET results.

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