

Estimation of Spatial and Temporal Reference Evapotranspiration in the Chao Phraya River Basin

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ABSTRACT

In the hydrological cycle and water use, evapotranspiration is one of the most important components because it represents a loss of usable water from the hydrologic supply. The purposes of this research are to calculate spatial and temporal reference evapotranspiration using FAO Penman-Monteith and Kriging methods and to determine the relationship between mean monthly temperature and monthly reference evapotranspiration. To achieve the first purpose, daily reference evapotranspiration from 1971 to 2002 was computed for each weather station using the FAO Penman-Monteith method. The average of monthly reference evapotranspiration in each weather station was figured. Thereafter, monthly reference evapotranspiration, that is point reference evapotranspiration, was interpolated using the Kriging interpolation. The result of this calculation is spatial reference evapotranspiration or reference evapotranspiration map from January to December (temporal). After spatial and temporal reference evapotranspiration was calculated, the relationship between mean monthly temperature and mean monthly reference evapotranspiration was figured. The result shows that linear regression and polynomial analysis can be used to explain this relationship.

Key words: spatial and temporal reference evapotranspiration, Kriging interpolation

INTRODUCTION

In the hydrological cycle and water use, evapotranspiration is one of the most important components because it represents a loss of usable water from the hydrologic supply (e.g. agriculture, natural resources, and municipalities). Evapotranspiration occurs from evaporation and transpiration. Evaporation is the process of liquid water converted to water vapor and removed from the evaporating surface or vapor removal. Transpiration is included by the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere (Hongjie *et al.*,

2002; Hafeez *et al.*, 2003; Kalluri *et al.*, 2003).

Actual evapotranspiration for an interested crop can be calculated from the crop coefficient multiplied by reference evapotranspiration. Crop coefficients can be evaluated from land use maps. Land use maps show the types of crops growing in the study area. The value of the crop coefficient depends on the type and age or growth stage of the crop. At present, reference evapotranspiration can be estimated by using weather data. The weather data are the elements of the FAO Penman-Monteith method which is now recommended as the sole standard method for the definition and computation

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of the reference evapotranspiration (Allen *et al.*, 1998). The Penman-Monteith method is suitable to calculate reference evapotranspiration because it uses many data and factors which has impact to the reference evapotranspiration calculation. According to the above reason, reference evapotranspiration in this research was obtained by the FAO Penman-Monteith method.

In the Chao Phraya River Basin, 33 weather stations of Thailand Meteorological Department are used and point reference evapotranspiration is presented by the FAO Penman-Monteith method. Reference evapotranspiration between weather stations is not computed. To determine this reference evapotranspiration, the concept of Kriging interpolation is used for the calculation of spatial reference evapotranspiration. Kriging is an estimation method for interpolation at unknown data. Furthermore, reference evapotranspiration obtained from the FAO Penman-Monteith method is involved with weather factor, the relationship between temperature and reference

evapotranspiration was concerned. Thus, the purposes of this research are to calculate spatial and temporal reference evapotranspiration using FAO Penman-Monteith and Kriging methods, and to determine the relationship between mean monthly temperature and monthly reference evapotranspiration.

MATERIALS AND METHODS

To determine spatial and temporal reference evapotranspiration, daily reference evapotranspiration from 1971 to 2002 was computed for each weather station using the FAO Penman-Monteith method. There are 33 weather stations used for this calculation as shown in Table 1. These weather stations are distributed in both north and central regions of Thailand. The average of monthly reference evapotranspiration in each weather station was figured so there are 12 months reference evapotranspiration (January to December) for 33 weather stations. According to this, point reference evapotranspiration from

Table 1 The 33 weather stations of Thailand Meteorological Department.

Station no.	Weather station	Station no.	Weather station
1	Nakhon Sawan	17	Lampang
2	Suphan Buri	18	Lamphun
3	Lop Buri	19	Phrae
4	Bua Chum	20	Nan
5	Pilot Station	21	Tha Wangpha
6	Kanchanaburi	22	Thung Chang
7	Thong Phaphum	23	Uttaradit
8	Krung Thep Maha Nakhon	24	Sukhothai
9	Bangkok Port	25	Tak
10	Don Muang Airport	26	Mae Sot
11	Loei	27	Bhumibol Dam
12	Mae Hong Son	28	Umphang
13	Mae Sariang	29	Phitsanulok
14	Chiang Rai	30	Phetchabun
15	Phayao	31	Lom Sak
16	Chiang Mai	32	Wichian Buri
		33	Kamphaeng Phet

January to December was result. Thereafter, point reference evapotranspiration for each month was interpolated using Kriging interpolation. The result is spatial and temporal reference evapotranspiration. The equations of above method are presented. Furthermore the computation of spatial and temporal reference evapotranspiration, the relationship between mean monthly temperature and monthly reference evapotranspiration was concerned. Mean daily temperature from 1971 to 2002 at the same weather station was used.

Chao Phraya River Basin

In Thailand, the Chao Phraya River Basin is the largest and most important geographical unit in terms of land and water resources development. It is located in the north and central regions of the country. The area of the Chao Phraya River Basin is 157,925 km². It includes eight sub-basins that are Ping, Wang, Yom, Nan, Sakae Krang, Pasak, Tha Chin, and Chao Phraya sub-basins. The average yearly rainfall is about 1,200 mm in the northern region and 1,350 mm in the central valley, where the peak is in September and the dry months are November through April. The rainy season starts from the middle of April and ends in late October (Attthaporn, 1999).

The Chao Phraya River Basin is used for agriculture and covered with forest. The major forest areas are in the northern sub-basins, those are Ping, Wang, Yom, and Nan. The Chao Phraya sub-basin also has some forest area. Agricultural areas are concentrated in the southern sub-basins and ranges from 78% in the Chao Phraya, 63% in Pasak and 55% in Tha Chin compared to 20 to 45% in the four northern sub-basins (Ping, Wang, Yom and Nan). Furthermore, there are varieties of water use in Chao Phraya River Basin such as agriculture, municipal, and industrial. They tend towards higher water demands (Sathianpantarit *et al.*, 2002).

Reference evapotranspiration

Evapotranspiration is a variable of primary interest to many end-users of hydrologic data. Evapotranspiration is highly variable both spatially and temporally. The variability in evapotranspiration occurs from the wide spatial variability of precipitation, hydraulic characteristics of soils, and vegetation types and densities. Evapotranspiration has an impact on plant water stress and generation of connective precipitation patterns. Evapotranspiration is required to close both the water and energy budgets.

Evapotranspiration is the summation of all water leaving the soil and plant surfaces for the air above them and is measured as the equivalent depth of water lost over time, (mm/d), (m/s) or any other such rate measure.

Evapotranspiration occurs from evaporation and transpiration. Evapotranspiration is normally computed from the Penman-Monteith equation using weather data. This equation is affected by principal weather parameters such as radiation, air temperature, humidity and wind speed. These parameters can be measured by weather station data and computed by the equation of FAO irrigation and Drainage Paper No. 56 (Allen *et al.*, 1998).

To compute reference evapotranspiration with the FAO Penman-Monteith method, daily weather data for a 32-year period (1971-2002) will be used. Weather data in Thailand are recorded from 1971; using 32 years are nearly the maximum period of data collection available. The accuracy of these results, which uses this data to compute reference evapotranspiration, is better than for a shorter time period, and the results should provide some confidence. The results can be a fairly accurate representation of reference evapotranspiration in the Chao Phraya River Basin.

Reference crop evapotranspiration (ET_o) can be calculated on a daily basis using the FAO Penman-Monteith equation (Allen, 2000):

$$ET_o = \frac{0.408D(R_n - G) + g \frac{900}{T_M + 273.2} u_2 (e_s - e_a)}{D + g(1 + 0.34u_2)} \quad (1)$$

where ET_o is reference crop evapotranspiration (mm d^{-1}), T is air temperature ($^{\circ}\text{C}$), R_n is net radiation ($\text{MJ m}^{-2}\text{d}^{-1}$), G is soil heat flux ($\text{MJ m}^{-2}\text{d}^{-1}$), e_s is saturation vapor pressure at air temperature (kPa), e_a is vapor pressure of air (kPa), u_2 is wind speed at 2 m (m s^{-1}), g is psychrometer constant ($\text{kPa } ^{\circ}\text{C}^{-1}$), and D is slope of saturation vapor pressure curve at air temperature ($\text{kPa } ^{\circ}\text{C}^{-1}$).

For this equation, evapotranspiration is estimated for a hypothetical short grass with a height of 0.12 m, a surface resistance of 70 s m^{-1} , and albedo of 0.23 (Allen *et al.*, 1998; Allen, 2000).

Meteorological factors to determine evapotranspiration consist of solar radiation, air temperature, air humidity, and wind speed. All of these factors are applied to the FAO Penman-Monteith equation and the following is the process so as to compute elements in this equation.

The psychrometric constant (g) is given by:

$$g = \frac{c_p P}{e} \quad (2)$$

where g is the psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$), c_p is specific heat at constant pressure, $1.013 \times 10^{-3} \text{ MJ kg}^{-1} \text{ } ^{\circ}\text{C}^{-1}$, and e is the ratio of the molecular weight of water vapor/dry air = 0.622.

In this FAO Penman-Monteith equation, mean daily air temperature (T_{mean}) in $^{\circ}\text{C}$ is employed to compute the slope of the saturation vapor pressure curve (D) in $\text{kPa } ^{\circ}\text{C}^{-1}$ as described below:

$$T_{\text{mean}} = \frac{T_{\text{max}} + T_{\text{min}}}{2} \quad (3)$$

$$D = \frac{4098 \left[0.6108 \exp \left\{ \frac{17.27 T_{\text{mean}}}{T_{\text{mean}} + 237.3} \right\} \right]}{(T_{\text{mean}} + 237.3)^2} \quad (4)$$

To obtain the mean saturation vapor

pressure (e_s) in kPa, the following are the calculation procedures.

$$e(T) = 0.6108 \exp \left\{ \frac{17.27 T}{T + 237.3} \right\} \quad (5)$$

where $e(T)$ is saturation vapor pressure at the air temperature T (kPa), T is the air temperature ($^{\circ}\text{C}$), and $\exp[.]$ is the natural logarithm that is raised by the power $[.]$.

Then

$$e_s = \frac{e(T_{\text{max}}) + e(T_{\text{min}})}{2} \quad (6)$$

The actual vapor pressure (e_a) in kPa can be obtained from relative humidity data as follows:

$$e_a = \frac{e(T_{\text{min}}) \frac{RH_{\text{max}}}{100} + e(T_{\text{max}}) \frac{RH_{\text{min}}}{100}}{2} \quad (7)$$

where $e(T_{\text{min}})$ is saturation vapour pressure at daily minimum temperature (kPa), $e(T_{\text{max}})$ is saturation vapour pressure at daily maximum temperature (kPa), RH_{max} is maximum relative humidity (%), and RH_{min} minimum relative humidity (%).

The difference between the incoming net shortwave radiation and the outgoing net long-wave radiation is the net radiation (R_n) as shown by the following equation:

$$R_n = R_{ns} - R_{nl} \quad (8)$$

The soil heat flux (G) can be described by a complex model, but soil heat flux is small compared to R_n . Thus, the soil heat flux can be computed from the following equation which is based on the idea that the soil temperature follows air temperature:

$$G = c_s \frac{T_i - T_{i-1}}{Dt} Dz \quad (9)$$

where G is soil heat flux ($\text{MJ m}^{-2} \text{d}^{-1}$), c_s is soil heat capacity ($\text{MJ m}^{-3} \text{ } ^{\circ}\text{C}^{-1}$), T_i is air temperature at time i ($^{\circ}\text{C}$), T_{i-1} is air temperature at time $i-1$ ($^{\circ}\text{C}$), Dt is length of time interval (day), and Dz is effective soil depth (m).

FAO recommends that as the magnitude of the day or ten-day soil heat flux beneath the

grass reference surface is relatively small, it may be ignored and thus:

$$G_{day} = 0$$

Kriging method

Kriging is a regression technique used in geostatistics and it is commonly known as Gaussian process regression in the statistical community. Kriging is the estimation method assumed that a weight average of one or more sample points is the best estimate. Kriging is the method of analysis by which the optimal values of the weights are computed (Clark, 1979; Oliver and Webster, 1990). The following are equations for the interpolation of spatial monthly reference evapotranspiration.

$$ET_m(x, y, t_m) = \sum_{i=1}^n W_i ET(x_i, y_i, t_m) \quad (10)$$

where ET_m is estimated monthly reference evapotranspiration, $ET(x_i, y_i, t_m)$ is monthly reference evapotranspiration and W_i is the Kriging weight.

$$\sum_{i=1}^n W_i C((x_i, y_i, t_i), (x_j, y_j, t_j)) + m = C((x_j, y_j, t_j), (x_o, y_o, t_o)) \quad (11)$$

where $C((x_i, y_i, t_i), (x_j, y_j, t_j))$ are spatial covariances at different observational locations, and $C((x_j, y_j, t_j), (x_o, y_o, t_o))$ are covariances between the observation and an estimated field point. m is Lagrange multiplier in ordinary Kriging.

$$\sum_{i=1}^n W_i = 1 \quad (12)$$

Calibration

Monthly reference evapotranspiration from the FAO Penman-Monteith method was checked the accuracy by pan evaporation, which is recorded data from Thailand Meteorological Department, using correlation coefficient. The pan

evaporation is the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pan provides a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Pan evaporation and reference evapotranspiration depends on weather condition. For example, if temperature is high and relative humidity is low, the high value of pan evaporation is included and reference evapotranspiration should also be a high value. Then, the correlation coefficient between pan evaporation and reference evapotranspiration should be nearby 1.00. The result of calibration presents that the correlation coefficients between monthly pan evaporation and monthly reference evapotranspiration for 33 weather stations are from 0.85 to 0.96.

RESULTS AND DISCUSSION

The result of monthly reference evapotranspiration calculation is presented for each weather station. There are 33 weather stations shown monthly reference evapotranspiration in Figure 1 and Figure 2.

Both Figure 1 and Figure 2 showed that maximum reference evapotranspiration from January to December were 135.46, 159.27, 181.23, 194.20, 167.18, 149.40, 144.53, 138.11, 128.52, 124.28, 132.76 and 135.31 mm, respectively. Minimum reference evapotranspiration from January to December were 82.41, 104.42, 124.22, 146.22, 137.04, 121.60, 110.01, 107.11, 108.99, 102.48, 85.08 and 72.28 mm, respectively and mean reference evapotranspiration from January to December were 101.86, 127.15, 148.12, 165.12, 149.82, 131.95, 123.57, 118.61, 116.58, 112.59, 103.52 and 95.52 mm, respectively. The patterns of reference evapotranspiration from January to December for each weather station were the same except station no. 2, 3, 4, 5, 8, 9 and 10 in September to December. The tendency of

reference evapotranspiration at stations no. 2, 3, 4, 5, 8, 9 and 10 was gradually increased from September to December but the other were gradually decreased. There was a different tendency at these stations because the tendency of air temperature at station no. 2, 3, 4, 5, 8, 9 and 10 was gradually increased from September to December but the other were gradually decreased.

The above results were point reference evapotranspiration that means monthly reference evapotranspiration was only presented at point of weather station. Figure 3 to Figure 14 showed

spatial reference evapotranspiration from January to December that resulted from Kriging interpolation.

Regression analysis has been employed to formulate the relationship between mean monthly temperatures and mean monthly reference evapotranspiration. Table 2 presented the relationship between mean monthly temperature in °C, represented by 'X', and monthly reference evapotranspiration in mm represented by 'Y'. This Table showed that both linear regression analysis and polynomial (2nd order) are suitable to

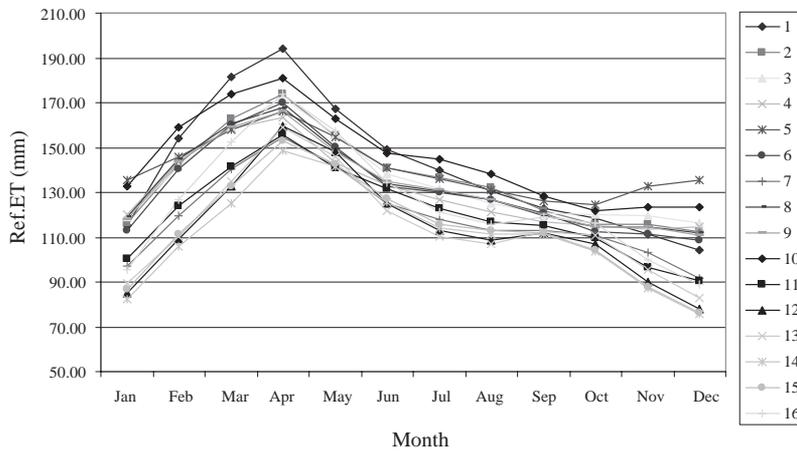


Figure 1 Monthly reference evapotranspiration for Station No. 1-16.

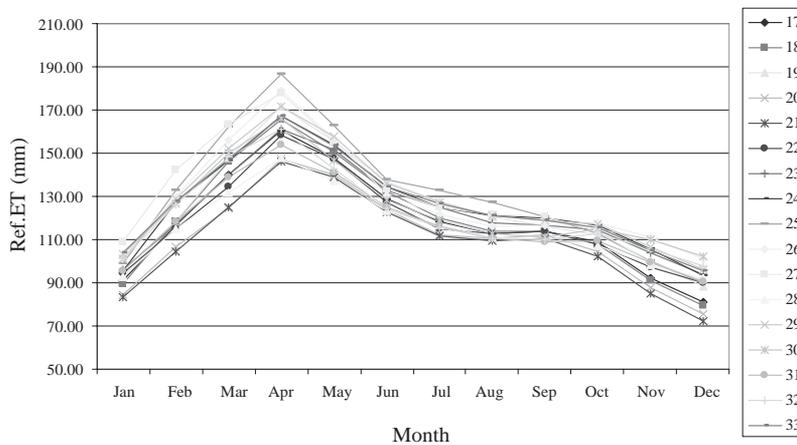


Figure 2 Monthly reference evapotranspiration for Station No. 17-33.

determine the relationship between mean monthly temperature and monthly reference evapotranspiration. However, 3rd and 4th orders of polynomial are considered that there is stronger relation. For example, in January, R² for 2nd, 3rd and 4th orders of polynomial were 0.8144, 0.8168 and 0.8204,

respectively. Since R² of linear regression and 2nd orders of polynomial were close to higher order, the equations of linear regression and 2nd orders of polynomial were selected and presented in Table 2.

Table 2 The relationship between mean monthly temperature in °C (X) and monthly reference evapotranspiration in mm (Y).

Month	Equation	R ²
January	Y=6.1545X-44.996	0.7807
February	Y=6.3768X-38.063	0.7376
March	Y=7.6674X-69.76	0.6633
April	Y=7.3252X-56.331	0.5345
May	Y=0.9778X ² -49.586X+761.57	0.5552
June	Y=1.7308X ² -92.657X+1363.9	0.5349
July	Y=3.1146X ² -166.18X+2330.2	0.7016
August	Y=2.6963X ² -141.67X+1970.9	0.7278
September	Y=0.7363X ² -34.223X+500.63	0.6026
October	Y=4.821X-19.367	0.5384
November	Y=7.4075X-85.484	0.7113
December	Y=7.3122X-76.164	0.7416
Yearly	Y=8.5241X-107.76	0.7375

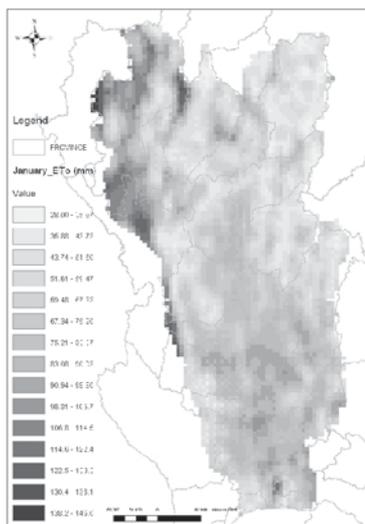


Figure 3 Spatial Ref. ET for January.

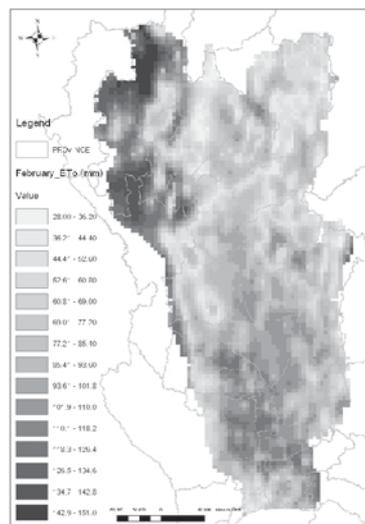


Figure 4 Spatial Ref. ET for February.

CONCLUSION

The FAO Penman-Monteith method is suitable to calculate monthly reference evapotranspiration in Chao Phraya River Basin, Thailand because this equation is affected by principal weather parameters and these weather parameters were collected by Thailand Meteorological Department from 1971 to present.

Also, monthly reference evapotranspiration from this method are reliable because there is strong correlation coefficient between monthly pan evaporation and monthly reference evapotranspiration (0.85 to 0.96).

Spatial and temporal reference evapotranspiration from this research can be applied to manage water. To use this spatial reference evapotranspiration or reference

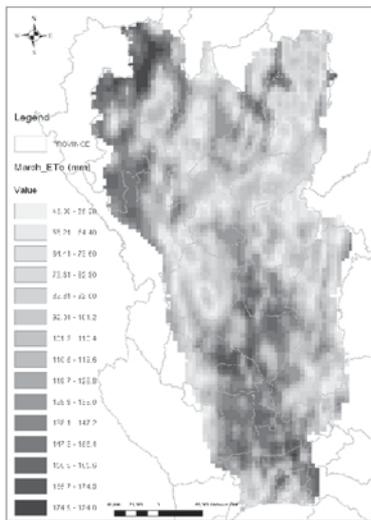


Figure 5 Spatial Ref. ET for March.

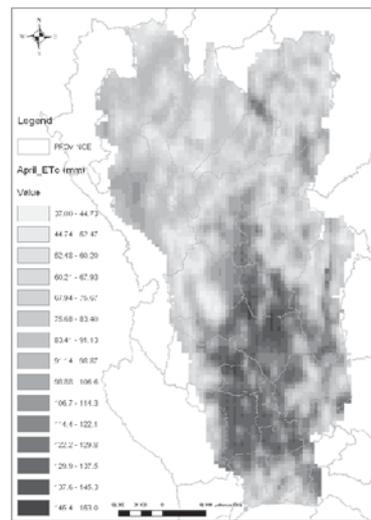


Figure 6 Spatial Ref. ET for April.

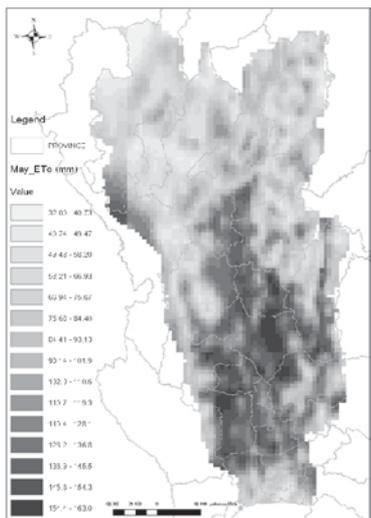


Figure 7 Spatial Ref. ET for May.

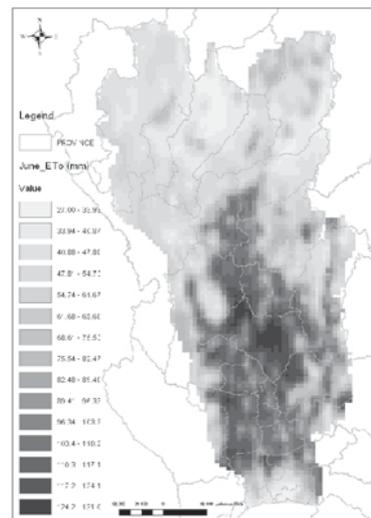


Figure 8 Spatial Ref. ET for June.

evapotranspiration map for each month (temporal), users have to know coordinate and crop type of their area because coordinate and crop type are used to determinate monthly reference evapotranspiration and crop coefficient. Thereafter, actual evapotranspiration, which is actual water demand, will be calculated and used to design released water to agricultural area or irrigated area.

Linear regression and polynomial

analysis can be used to explain the relationship between mean monthly temperature and mean monthly reference evapotranspiration. The polynomial analysis is stronger relationship than linear regression.

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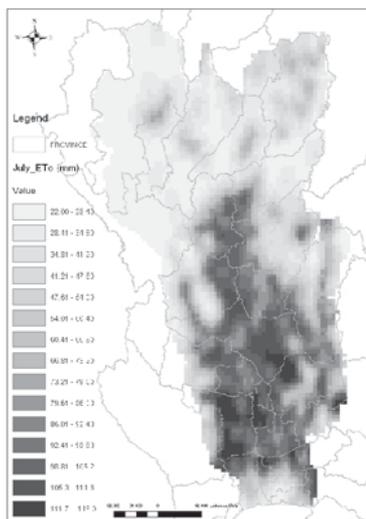


Figure 9 Spatial Ref. ET for July.

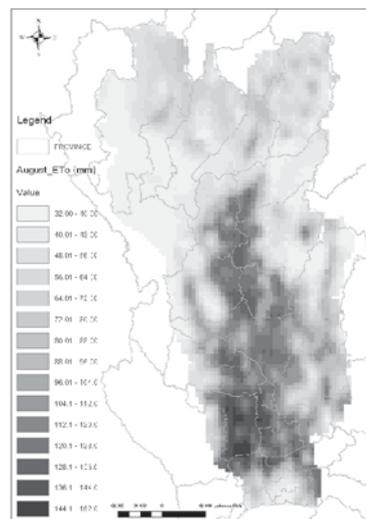


Figure 10 Spatial Ref. ET for August.

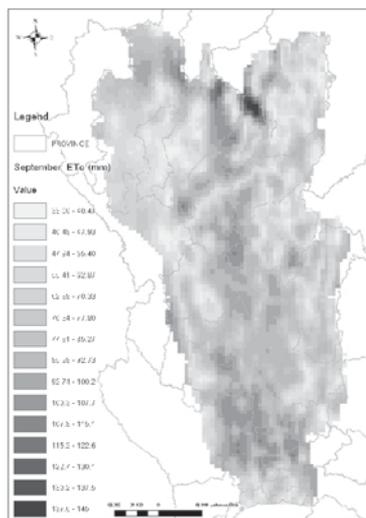


Figure 11 Spatial Ref. ET for September.

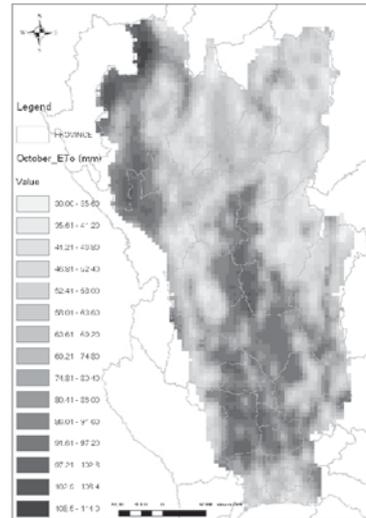


Figure 12 Spatial Ref. ET for October.

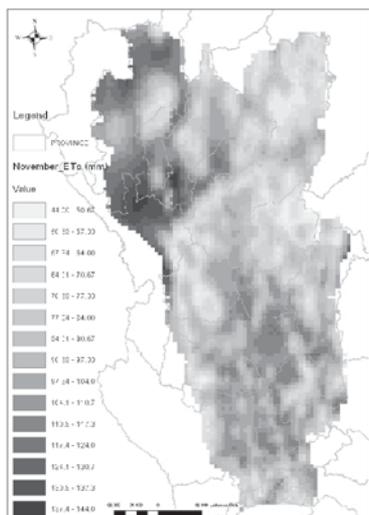


Figure 13 Spatial Ref. ET for November.

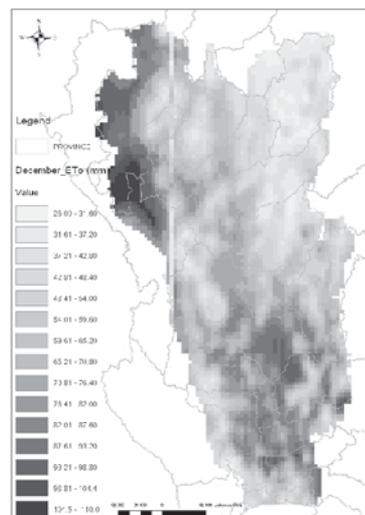


Figure 14 Spatial Ref. ET for December.

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