Engineering, 2013, 5, 459-468
http://dx.doi.org/10.4236/eng.2013.55055 Published Online May 2013 (http://www.scirp.org/journal/eng)

Evaluating Reference Crop Evapotranspiration (ET_o) in the Centre of Guanzhong Basin

—Case of Xingping & Wugong, Shaanxi, China

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Received January 29, 2013; revised March 8, 2013; accepted March 15, 2013

ABSTRACT

In this paper, the Penman-Monteith method was applied to evaluate the reference crop evapotranspiration. A reliable estimation of the reference evapotranspiration (ET_o) is of critical importance and required accurate estimates to close the water balance. The aim of this paper is estimating the reference evapotranspiration (ET_o) as preliminary to use for groundwater modeling in the area. Based on FAO-Penman-Monteith method, ET_o calculator software was applied. Meteorological data within this study were obtained from two gauges stations (Xing ping and Wu gong) and available literatures. The results indicated that the values of ET_o for a period (1981-2009)—29 years—in two stations approximately the same. Specifically, is ranged between 0.4 - 6.9 mm /day, 0.4 - 6.7 mm/day and the average value is 2.6 mm/ day, 2.6 mm/day in Xing ping and Wu gong respectively. In addition, the maximum values were occurred in summer season (May, June and July). The result also found that the correlation coefficient ≈ 1. Moreover, "ET_o" was increasing by recent years. The reference crop evapotranspiration for some crops were calculated.

Keywords: Reference evapotranspiration; Part of Baoyang Irrigation Area; Meteorological Data; FAO Penman-Monteith Equation

1. Introduction

Estimates of reference crop evapotranspiration (ET_o) are widely used in irrigation engineering to define crop water requirements. These estimates are used in the planning process for irrigation schemes to be developed as well as to manage water distribution in existing schemes. From the several existing ET_o equations, the FAO-56 application of the Penman-Monteith equation [1] is currently widely used and can be considered as a sort of standard [2]. The FAO-56 Penman-Monteith equation is referred to hereafter as PM. The PM has two advantages over many other methods. First, it is a predominately physically based approach, indicating that the method can be used globally without any need for additional parameter estimations. Secondly, the method is well documented, implemented in a wide range of software, and has been tested using a variety of lysimeters [3].

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1.1. Evaporation and Transpiration

Evaporation is the process by which water precipitated on the earth's surface is returned to the atmosphere by vaporization, while the transpiration is a process similar to evaporation. It is a part of the water cycle, and it is the loss of water vapor from parts of plants (similar to sweating), especially in leaves but also in stems, flowers and roots. Quantitatively expressed, evaporation and transpiration are the depths of water vaporized from a unit surface in unit time, (e.g. mm/day, and m/year). The rate of evaporation depends on several factors [4].

1.2. Reference Evapotranspiration (ET_o)

The reference evapotranspiration (ET_o) was defined as the rate of evapotranspiration from a hypothetic crop with an assumed crop height (12 cm) and a fixed canopy resistance (70) [$s \cdot m^{-1}$], and albedo (0.23). This would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water [3,5]. Evapotranspiration is the combination of soil evaporation and crop transpiration. Weather parameters, crop characteristics, management and environmental aspects affect evapotranspiration. The evapotranspiration rate from a reference surface is called the reference evapotranspiration and is denoted as-ET_o-**Figure 1**.

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET_o. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. ET_o values measured or calculated at different locations or in different seasons are comparable as they refer to the evapotranspiration from the same reference surface. The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors [1].

A good estimation of evapotranspiration is vital for proper water management. Evapotranspiration can be obtained by many estimation methods such as (Penman, Penman-Monteith, Pan Evaporation, Kimberly-Penman, Priestley-Taylor, Hargreaves, Samani-Hargreaves, and Blaney-Criddle). Some of these methods need many weather parameters as inputs while others need fewer. Numerous methods have been developed for evapotranspiration estimation out of which some techniques have been developed partly in response to the availability of data. An Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration ET_o. In this paper, The Penman-Monteith method was applied.

2. Study Area

The study area is located in Shaanxi Province, a part of loess plateau, and an important part of loess platform. The centre of Guanzhong Basin, North of Weihe River, and Weibei loess mesa is a unique landform of Loess Plateau in Northern China, which is also relatively short in water resources. Geological map of the study was presenting **Figure 2**. It is one of the biggest irrigation districts in Shaanxi and an important agricultural production area in China.

Xingping (latitude 34˚18'S, longitude 108˚28'E, altitude 408.0 m) and Wugong (latitude 34˚18'S, longitude 108˚04'E, altitude 505.0 m), which are located in the middle of central of Guanzhong Basin is the part of Baoyang irrigation area, occupied total areas 507.4 Km^2, 397.8 Km^2, and 292.81 Km^2, 287.8 Km^2 of cultivation area respectively. Climatically, this area belongs to continental monsoon climate, which is featured with four clear seasons with rains in spring and autumn, hot in summer and cold in winter.

During the study period 1981-2009, we found that the mean annual rainfall is 554.47 mm. Air temperature varies between; −2.1˚C (Min) and 28.6˚C (Max), mean relative humidity ranges from 48% (Min) to 90% (Max). The mean actual vapour pressure is 0.955 Kpa (Min) and 0.983 Kpa (Max), wind speed-above soil surface is 0.3 m/sec (Min) and 2.2 m/sec (Max) and the relative sunshine duration is 0.1 and 0.76 in Xingping district. Likewise, in Wugong county—the mean annual rainfall is 583.72 mm, air temperature varies between: −2.9˚C (Min) and 28.1˚C (Max), mean relative humidity is 45% (Min) and 89% (Max), mean actual vapour pressure is from 0.951 Kpa (Min) and 0.978 Kpa (Max), wind speed-above soil surface is 0.5 m/sec and 2.5 m/sec and the relative sunshine duration is 0.0 and 0.71.

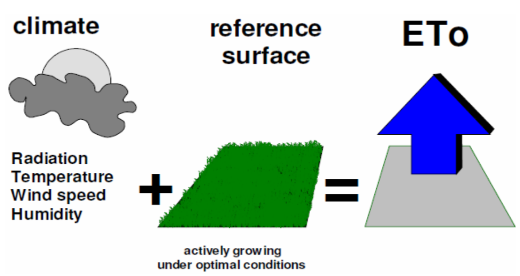


Figure 1. Reference evapotranspiration (ET_o) by FAO.

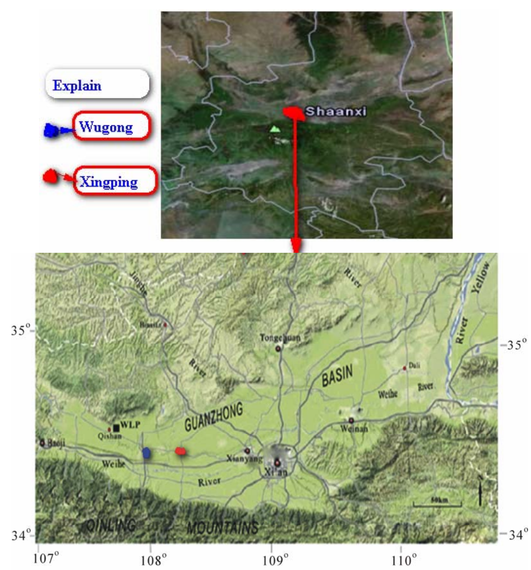


Figure 2. Illustrated the graphs of max, average, min, SD and skew of ET_o (mm/day) of Xingping County from Table 3.

3. Materials and Method

Crop evapotranspiration (ET_c) is a key factor to determine proper irrigation schedule and to improve water use efficiency in irrigated agriculture. ET_c can be estimated by a reference crop evapotranspiration (ET_o) and crop coefficient [6-9]. The reference evapotranspiration "ET_o" can be estimated by many methods [10-12]. Methods range from the complex energy balance equations [13] to simpler equations that require limited meteorological data [14]. According to [5], the Penman-Monteith method gives more consistently accurate "ET_o" than other methods. In addition, [15] after applying it in the Muda Irrigation Scheme in northwest Malaysia recommended this method. Therefore, in this study the reference evapotranspiration was estimated using Penman-Monteith equation. The calculation procedures allow for estimation of ET_o using FAO Penman-Monteith method under all circumstances, even in the case of missing climatic data.

For the study, the Food and Agriculture Organization (FAO) Penman-Monteith methodology was used to determine the reference evapotranspiration (ET_o) for the two stations (Xingping and Wugong) as it allows for the potential to alter ET_c estimates for different crop types in the center of a large arid and sub-humid area **Figure 1**. Moreover, where, irrigation makes possible an intensive agricultural production. To carry out the reference evapotranspiration "ET_o" in the area, the meteorological data of two stations have been selected within the region. With record monthly data, ranging from 1981 to 2009 years in length **Table 1**, this period was chosen preliminary to develop groundwater of the area as the part of study plan of Numerical simulation of groundwater. Thus, the study aims to establish the underlying best model result of reference evapotranspiration to lead that to estimate crop water requirements, which in turn leads for study water balance of the area. No interruptions and missing data find through the period.

3.1. FAO-56 PM Method

The FAO Penman-Monteith method for calculating the reference crop evapotranspiration is the adopted standard for this calculation [1]. In this paper, the result of "ET_o" was compared between two stations of record throughout of 29 years. Evapotranspiration and rainfall are the two major components of the water balance and required accurate estimates to close the water balance of the area and the important components in the water cycle, which represents the water consumption by the plants and evaporation from the water and the non-vegetated surfaces. Reliable estimates of the total evapotranspiration from the wetland are useful information both for understanding the hydrological process and for water management to protect natural environment.

Table 1. Shows the type, period and length of data.

Type of data in Stations, Xingping & Wugong		
Type of data	Period	Length of data
Monthly mean relative humidity %	1981-2009	29 years
Monthly mean wind speed (m/s)	1981-2009	29 years
Monthly mean air temperature (˚C)	1981-2009	29 years
Monthly mean air pressure (Kpa)	1981-2009	29 years
Sunlight (hours)	1981-2009	29 years

3.2. Calculation Method

The reference evapotranspiration (ET_o) from meteorological data is assessed in the ET_o calculator Software by means of the FAO Penman-Monteith equation. This method has been selected by FAO as the reference because it closely approximates grass "ET_o" at the location evaluated is physically based, and explicitly incorporates both physiological and aerodynamic parameters. The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the Area Study Centre for Europe (ASCE) and European studies. The FAO Penman-Monteith equation [1] is given by:

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

where $ET_o =$ reference evapotranspiration $\left[\text{mm}\cdot\text{day}^{-1}\right]$, $R_n =$ net radiation at the crop surface $\left[\text{MJ}\cdot\text{m}^{-2}\cdot\text{day}^{-1}\right]$,
$G =$ soil heat flux density $\left[\text{MJ}\cdot\text{m}^{-2}\cdot\text{day}^{-1}\right]$,
$T =$ average temperature $\left[^\circ\text{C}\right]$,
$u_2 =$ wind speed at 2 m height $\left[\text{m}\cdot\text{s}^{-1}\right]$,
$e_s =$ saturation vapour pressure $\left[\text{kPa}\right]$,
$e_a =$ actual vapour pressure $\left[\text{kPa}\right]$,
$\left(e_s - e_a\right) =$ saturation vapour pressure deficit $\left[\text{kPa}\right]$,
$\Delta =$ slope vapour pressure curve $\left[\text{kPa}\cdot^\circ\text{C}^{-1}\right]$,
$\gamma =$ psychrometric constant $\left[\text{kPa}\cdot^\circ\text{C}^{-1}\right]$.

The value 0.408 converts the net radiation Rn expressed in $\text{MJ/m}^2\cdot\text{day}$ to equivalent evaporation expressed in mm/day. Because soil heat flux is small compared to R_n, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, the estimation of G is ignored in the ET_o calculator and assumed to be zero. This corresponds with the assumptions reported in the FAO Irrigation and Drainage Paper No. 56 for daily and 10-daily periods [13]. State that the soil heat fluxes beneath the grass reference surface is relatively small for that time period.

Psychrometric constant (γ): The psychrometric constant in the Penman and Penman-Monteith (PM) equations is calculated as following [16]:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.664742 \times 10^{-3} \times P \qquad (2)$$

where $\gamma =$ psychrometric constant $\left[\text{kPa} \cdot {}^\circ\text{C}^{-1}\right]$, $P =$ mean atmospheric pressure $[\text{kPa}]$, $\lambda =$ latent heat of vaporization, 2.45 $\left[\text{MJ} \cdot \text{kg}^{-1}\right]$, $c_p =$ specific heat at constant pressure, 1.013 × 10^{-3} $\left[\text{MJ} \cdot \text{kg}^{-1} \cdot {}^\circ\text{C}^{-1}\right]$, $\varepsilon =$ ratio molecular weight of water vapour/dry air = 0.622.

The value of the latent heat varies as a function of temperature. As λ varies only slightly over normal temperature ranges, a single value of 2.45 $\left[\text{MJ} \cdot \text{kg}^{-1}\right]$ is considered in the program. This corresponds with the calculation procedure for the FAO Penman-Monteith equation. The fixed value for λ is the latent heat for an air temperature of about 20˚C.

The Saturation vapour pressure as a function of air temperature $(e^\circ(T))$ is calculated from Equation (3) [1,17].

$$e^o(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right] \qquad (3)$$

Slope of saturation vapour pressure curve (Δ): To calculate the reference evapotranspiration, the slope of the relationship between saturation vapour pressure and temperature, Δ, is required [1]. Give the slope of the curve at a given temperature.

$$\Delta = \frac{4098 e^o(T)}{(T + 237.3)^2} \qquad (4)$$

where $\Delta =$ slope of saturation vapour pressure curve at air temperature T $\left[\text{kPa} \cdot {}^\circ\text{C}^{-1}\right]$, $T =$ average air temperature $[{}^\circ\text{C}]$.

For RH_{mean}, analysis with several climatic data sets proved that more accurate estimates of e_a could be obtained with [5]:

$$e_a = e^o(T_{\text{mean}}) \frac{RH_{\text{mean}}}{100} \qquad (5)$$

Net radiation (R_n): Net radiation (R_n) was calculated based on the FAO expert panel methodology [2] which has been considered a standard in other studies [17,18]. (R_n) is calculated by subtracting the net incoming short-wave radiation (R_{ns}) from the net outgoing longwave radiation (R_{nl}) as summarized in Equation (6).

$$R_n = R_{ns} - R_{nl} \qquad (6)$$

Solar radiation (R_s): If the solar radiation, R_s, is not measured, it can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \qquad (7)$$

where $R_s =$ solar or shortwave radiation $\left[\text{MJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}\right]$, $n =$ actual duration of sunshine [hour], $N =$ maximum possible duration of sunshine or daylight hours [hour], n/N-relative sunshine duration [-], $R_a =$ extraterrestrial radiation $\left[\text{MJ} \cdot \text{m}^{-2} \cdot \text{day}^{-1}\right]$, $a_s =$ regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days $(n = 0)$, $a_s + b_s =$ fraction of extraterrestrial radiation reaching the earth on clear days $(n = N)$. The default values for a_s and b_s are 0.25 and 0.50. If the user has site specific information, calibrated values for a_s and b_s can be specified in the Data and ET_o menu (Calculation method and coefficients).

4. Results and Discussion

As you, know this study just as primary for entering to develop groundwater of the area as the part of study plan of Numerical simulation of groundwater in this area, so we only have these results such as following:

By relating the measured of meteorological information from the study area to estimate reference crop evapotranspiration, the mean monthly rate of reference evapotranspiration was calculated employing the Penman-Monteith equation according to FAO-56 [19].

The reference evapotranspiration was calculated based on the data taken from the Xing ping and Wugong stations, taking into account the mean monthly values of the parameters involved in the above equations, for the period 1981-2009 (*i.e.*, 29 years).

Table 2 shows that the annual (Maximum, Minimum, Mean, Skew, SD and Variations) of reference evapotranspiration of two stations—Xingping & Wugong—valued by FAO Method(s) and developed the ET_O software for the study area. The results indicated that the annually-values approximately closed throughout the period for two stations. The maximum values occurred in 1995 and 1997.

4.1. Monthly Average (ET_o) for the Study Area

Tables 3, **4** and **Figures 3**, **4** illustrated the monthly values (*i.e.* Maximum, Mean, Minimum, SD and Skew) of reference evapotranspiration in Xingping County and Wugong County respectively. The results found that the values of (ET_o) in Xingping and Wugong; ranged between 0.4 - 6.9 mm/day, 0.4 - 6.7 mm/day, and the average values are 2.6 mm/ day, 2.6 mm/day respectively. The amount of reference evapotranspiration approximately the same values at both stations. The monthly values of the reference evapotranspiration in (May, June, July and August) occurred as the maximum values that

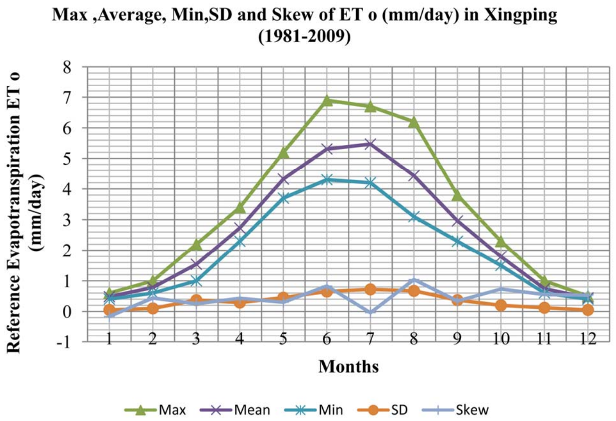


Figure 3. Illustrated the graphs of max, average, min, SD and skew of ETo (mm/day) of Xingping County from Table 3.

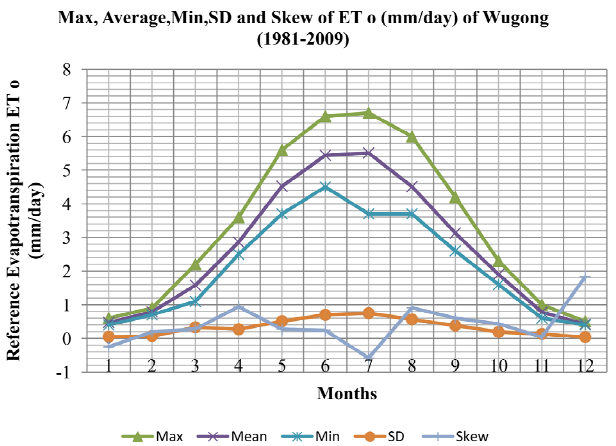


Figure 4. Illustrated the graphs of max, average, min, SD and skew of ETo (mm/day) of Wugong County from Table 4.

are refer to the maximum mean temperature for those months **Figures 3** and **4**.

We did the simple calibration used simple as the regression analyses between two stations **Figure 5**. The relation of reference evapotranspiration ET_o between two stations (Xingping & Wugong) are very closing from the result the correlation coefficient $\left(r_{xy} = 0.99 \approx 1\right)$ *i.e.* $R^2 = 0.9918$, and $Y = 0.9927x + 0.0659$.

4.2. Daily, Monthly and Annul Mean Values of ET_o

The daily values for every month through the time period (*i.e.* 1981-2009) were presented in **Tables 5** and **6**, as the model (software) results. Obviously, the maximum values of ET_o were occurred in may, June, July and August due to the highly temperature of those months. **Figure 6** presents the mean annual reference evapotranspiration values estimated by The FAO Penman-Monteith method for the study area. The three straight lines refer to the average values of the ET_o the upper line explain the mean value of Wugong and the lower explain the values of Xingping, while the middle is the average values from both. From the trend line, the values of both stations, even the mean were indicating that the "ET_o" was increasing by recent years if exclude the first two years and the middle years of the length (1994 to 1997).

4.3. The Estimation of Crop Evapotranspiration ET_c

This simple model can be used for the study area to reasonably estimate reference crop evapotranspiration in our study. Evapotranspiration rates vary between plant species and also vary for different times of the year and different stages of plant growth. To account of these variations the reference evapotranspiration $\left(ET_o\right)$ is multiplied by a crop factor $\left(k_c\right)$ to give a particular crop evapotranspiration $\left(ET_c\right)$ as shown in Equation (4.1)

$$ET_c = k_c \times ET_o \tag{4.1}$$

where: k_c is the single crop coefficient, which averages crop transpiration and soil evaporation.

The crop factors $\left(k_c\right)$ have been determined by field experiments, and have been compiled and are provided for most crops by the FAO. As these are generalized, crop factors developed specifically for the study area were developed in 1991 by Xiaoling Su from Northwest Agricultural and Forestry University. Crop factors used in the study were compared to those available from the FAO, The length of growing season and crop factor were comparable and as shown in **Figure 7**.

The average monthly reference crop evapotranspiration $\left(ET_c\right)$ for winter wheat, maize, rice/cotton and rapeseed crops in Xingping and Wugong for the irrigation period were presented in **Table 7**. Since this area is hot in summer and cold in winter and the different stage of crops, as the results, that the value of the reference crop evapotranspiration are increasing from January to May, and the maximum values are occurred between Jun to August, then start to decrease from September to December.

5. Conclusion

The calculation procedures in this paper allow for estimation of ET_O as a preliminary for entering to develop groundwater of the area as the part of study plan of Numerical simulation of groundwater in this basin (Baoyang irrigation area) using FAO Penman-Monteith method under all circumstances. The paper compares the reference evapotranspiration of two Counties based on the data from the (North West A&F University). It can be concluded that the mean values of $\left(ET_o\right)$ throughout the period (1981-2009) in Xingping and Wugong, ranging

Table 2. Presents the annual parameters for two stations.

Year	Xingping County						Wugong County					
	Max	Min	Mean	Skew	SD	Vary	Max	Min	Mean	Skew	SD	Vary
1981	6.0	0.4	2.7	0.48	2.1	4.2	6.5	0.4	2.9	0.49	2.3	5.2
1982	5.7	0.4	2.6	0.43	2.0	3.8	6.3	0.4	2.8	0.42	2.2	4.8
1983	4.6	0.4	2.4	0.13	1.6	2.5	4.5	0.4	2.4	0.14	1.6	2.5
1984	4.5	0.4	2.3	0.22	1.6	2.7	4.7	0.4	2.3	0.18	1.6	2.4
1985	5.3	0.4	2.4	0.46	1.8	3.3	5.7	0.4	2.5	0.46	1.9	3.7
1986	4.7	0.5	2.4	0.28	1.7	2.7	5.4	0.4	2.6	0.26	1.9	3.6
1987	5.0	0.5	2.5	0.09	1.7	2.9	5.6	0.5	2.7	0.15	1.9	3.7
1988	5.3	0.4	2.3	0.49	1.8	3.2	5.7	0.4	2.5	0.46	1.8	3.3
1989	4.9	0.4	2.3	0.34	1.7	2.9	5.5	0.4	2.6	0.32	1.9	3.7
1990	5.3	0.4	2.4	0.39	1.7	3.0	5.6	0.4	2.6	0.36	1.9	3.7
1991	6.0	0.4	2.5	0.6	2.0	4.1	5.9	0.4	2.6	0.47	1.9	3.8
1992	6.4	0.4	2.5	0.62	2.1	4.2	5.9	0.4	2.5	0.45	1.9	3.8
1993	5.5	0.4	2.5	0.45	1.9	3.7	5.1	0.4	2.4	0.31	1.7	3.0
1994	6.7	0.4	2.9	0.5	2.4	5.5	6.6	0.4	3.0	0.39	2.3	5.2
1995	6.9	0.4	3.0	0.55	2.4	5.9	6.7	0.4	3.0	0.5	2.4	5.6
1996	6.3	0.4	2.6	0.6	2.2	4.7	5.8	0.4	2.6	0.42	2.0	4.2
1997	6.9	0.4	3.0	0.51	2.5	6.1	6.6	0.4	3.0	0.4	2.4	5.7
1998	5.6	0.5	2.7	0.22	1.8	3.4	5.8	0.5	2.7	0.27	1.8	3.4
1999	5.2	0.5	2.6	0.25	1.8	3.4	5.0	0.5	2.6	0.19	1.8	3.3
2000	6.3	0.5	2.7	0.49	2.0	3.9	5.8	0.4	2.6	0.28	1.9	3.6
2001	6.3	0.4	2.7	0.53	2.0	4.0	6.4	0.4	2.9	0.45	2.1	4.5
2002	6.1	0.4	2.7	0.49	2.0	4.0	6.4	0.4	2.9	0.42	2.1	4.4
2003	5.3	0.5	2.4	0.56	1.8	3.1	6.1	0.4	2.7	0.41	2.1	4.4
2004	5.6	0.5	2.7	0.35	1.9	3.7	6.4	0.4	3.0	0.34	2.3	5.2
2005	5.3	0.4	2.5	0.33	1.8	3.3	5.9	0.4	2.7	0.42	2.0	3.9
2006	5.6	0.5	2.7	0.34	1.9	3.7	5.6	0.4	2.7	0.32	1.9	3.7
2007	5.2	0.5	2.6	0.23	1.8	3.2	4.9	0.4	2.4	0.24	1.6	2.7
2008	5.5	0.4	2.6	0.31	1.9	3.6	4.9	0.4	2.5	0.26	1.7	3.0
2009	5.9	0.4	2.7	0.46	2.0	4.0	5.6	0.4	2.5	0.43	1.8	3.4

Table 3. Xingping (China)—monthly values: January 1981-December 2009, average ET_o (mm/day).

ETo (mm/d)	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Max	0.60	1.00	2.20	3.40	5.20	6.90	6.70	6.20	3.80	2.30	1.00	0.50
Mean	0.48	0.78	1.54	2.73	4.32	5.31	5.47	4.43	2.96	1.79	0.74	0.44
Min	0.40	0.60	1.00	2.30	3.70	4.30	4.20	3.10	2.30	1.50	0.60	0.40
SD	0.05	0.10	0.37	0.29	0.45	0.65	0.72	0.67	0.37	0.20	0.12	0.05
Skew	−0.16	0.44	0.25	0.43	0.30	0.83	−0.04	1.04	0.34	0.73	0.55	0.53

Table 4. Wugong (China)—monthly values: January 1981-December 2009, average ET_o (mm/day).

ETo (mm/d)	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Max	0.60	0.90	2.20	3.60	5.60	6.60	6.70	6.00	4.20	2.30	1.00	0.50
Mean	0.47	0.79	1.58	2.86	4.52	5.44	5.51	4.51	3.13	1.90	0.78	0.42
Min	0.40	0.70	1.10	2.50	3.70	4.50	3.70	3.70	2.60	1.60	0.60	0.40
SD	0.05	0.07	0.33	0.27	0.51	0.70	0.75	0.56	0.38	0.19	0.13	0.04
Skew	-0.25	0.19	0.28	0.94	0.27	0.24	-0.58	0.91	0.60	0.43	0.04	1.83

Table 5. Xingping (China)—monthly results: average ET_o (mm/day) January 1981-December 2009.

Years	Months											
	Jan	Feb	Mar	April	May	Jun	July	Augu	Sept	Oct	Nov	Dec
1981	0.4	0.8	2.0	2.7	4.9	6.0	5.7	4.1	2.8	1.7	0.7	0.4
1982	0.5	0.7	1.4	2.8	4.7	5.7	5.3	4.2	2.5	2.1	0.7	0.4
1983	0.5	0.8	1.4	2.9	3.9	4.6	4.2	4.1	2.9	1.7	0.8	0.4
1984	0.4	0.7	1.5	2.6	4.0	4.5	4.2	4.5	2.6	1.7	0.7	0.4
1985	0.5	0.7	1.1	2.8	3.8	4.7	5.3	4.5	2.3	1.6	0.7	0.4
1986	0.5	0.8	1.3	2.3	3.8	4.5	4.7	4.3	3.1	1.7	0.7	0.5
1987	0.5	0.9	1.2	2.7	3.7	4.3	5.0	4.4	3.8	2.3	0.7	0.5
1988	0.5	0.7	1.0	2.6	4.0	5.3	4.5	4.3	2.3	1.5	0.8	0.4
1989	0.4	0.7	1.2	2.5	3.9	4.8	4.9	4.0	2.7	1.8	0.6	0.5
1990	0.4	0.6	1.3	2.3	3.9	4.7	5.3	3.8	3.0	1.9	0.8	0.4
1991	0.5	0.7	1.1	2.4	3.9	5.6	6.0	4.2	3.0	1.8	0.6	0.4
1992	0.5	0.8	1.0	2.8	4.1	4.8	6.4	4.8	2.7	1.5	0.6	0.4
1993	0.4	0.7	1.2	2.5	3.7	5.5	5.5	4.2	3.3	1.8	0.6	0.4
1994	0.5	0.6	1.3	2.7	5.0	5.4	6.7	6.1	3.3	1.8	0.8	0.4
1995	0.5	0.8	1.5	2.6	4.8	6.9	6.6	5.5	3.4	2.0	0.7	0.4
1996	0.4	0.7	1.1	2.3	4.1	5.6	6.3	5.2	2.8	1.9	0.6	0.4
1997	0.5	0.7	1.6	2.7	4.9	6.9	6.4	6.2	3.4	2.0	0.7	0.4
1998	0.5	0.8	1.4	3.1	4.1	5.6	4.9	4.3	3.6	2.0	1.0	0.5
1999	0.6	1.0	1.6	2.8	4.3	4.8	5.2	5.0	3.4	1.7	0.8	0.5
2000	0.5	0.9	2.0	3.0	4.6	5.0	6.3	4.1	2.9	1.6	0.6	0.5
2001	0.5	0.9	2.1	2.4	4.4	5.1	6.3	4.7	2.9	1.7	0.8	0.4
2002	0.6	0.9	1.9	2.7	4.0	6.1	5.8	4.4	3.4	1.9	0.8	0.4
2003	0.5	0.8	1.6	2.5	4.5	5.3	5.0	3.1	2.7	1.6	0.7	0.5
2004	0.5	1.0	1.9	3.4	4.9	5.6	5.5	3.9	2.9	1.6	0.8	0.5
2005	0.5	0.7	1.9	3.2	4.4	5.3	5.2	3.6	2.8	1.6	0.9	0.4
2006	0.5	0.7	2.1	3.0	4.8	5.4	5.6	4.4	2.6	1.9	1.0	0.5
2007	0.5	0.9	1.8	3.1	5.2	5.1	4.4	4.2	3.1	1.7	0.9	0.5
2008	0.4	0.8	2.2	2.7	4.7	5.0	5.5	4.6	2.8	1.6	0.9	0.5
2009	0.5	0.8	2.0	3.2	4.4	5.9	5.9	3.7	2.8	2.1	0.6	0.4

Table 6. Wugong (China)—monthly results: average ET_o (mm/day) January 1981-December 2009.

Years	Months											
	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1981	0.4	0.7	2	2.8	4.8	6.5	6.4	4.8	3.2	1.8	0.7	0.4
1982	0.5	0.7	1.5	3	5.2	6.3	5.9	4.6	2.9	2.3	0.7	0.4
1983	0.5	0.8	1.4	2.9	3.9	4.5	4.3	4.1	2.9	1.6	0.9	0.4
1984	0.5	0.7	1.6	2.6	3.8	4.7	3.7	4.3	2.8	1.9	0.8	0.4
1985	0.5	0.7	1.1	2.9	3.7	5.2	5.7	4.6	2.8	1.8	0.7	0.4
1986	0.5	0.8	1.4	2.5	4.5	4.7	5.4	4.8	3.4	1.9	0.6	0.4
1987	0.5	0.8	1.2	2.9	4.2	4.5	5.6	4.8	4.2	2.2	0.7	0.5
1988	0.5	0.7	1.1	2.8	4.3	5.7	4.4	4.2	2.6	1.8	0.9	0.4
1989	0.4	0.7	1.3	2.7	4.5	5.5	5.3	4.2	3.2	2	0.8	0.4
1990	0.5	0.7	1.5	2.6	4.5	5.1	5.6	4.5	3.1	1.8	0.9	0.4
1991	0.5	0.8	1.3	2.6	3.9	5.3	5.9	4.4	3.2	1.9	0.7	0.4
1992	0.4	0.9	1.1	3	4.3	4.8	5.9	4.5	2.7	1.6	0.7	0.4
1993	0.5	0.8	1.4	2.5	3.7	5.1	5	3.9	3.2	2	0.6	0.4
1994	0.5	0.8	1.5	2.9	5.5	5.2	6.6	5.8	3.5	2	0.9	0.4
1995	0.5	0.8	1.6	2.7	5	6.6	6.7	5.3	3.5	1.9	0.8	0.4
1996	0.4	0.7	1.1	2.5	4.3	5.4	5.8	4.9	3.1	1.9	0.7	0.4
1997	0.4	0.8	1.6	2.7	5	6.6	6.1	6	3.5	2.2	0.6	0.4
1998	0.5	0.8	1.4	3.2	4	5.8	4.8	4.2	3.6	2	1	0.5
1999	0.5	0.9	1.6	2.9	4.5	4.8	4.9	5	3.3	1.8	0.8	0.5
2000	0.4	0.8	2	3	4.7	4.7	5.8	4.1	3.1	1.7	0.6	0.4
2001	0.5	0.8	2.2	2.6	4.8	5.8	6.4	4.8	3.1	2	0.9	0.4
2002	0.6	0.9	2.1	3	4.2	6.4	6.1	4.8	3.5	2.3	0.9	0.4
2003	0.5	0.8	1.6	2.8	5	6.1	5.7	4	3.4	2	0.6	0.4
2004	0.5	0.9	1.9	3.6	5.6	6.4	6.4	4.6	3.5	1.9	0.8	0.4
2005	0.4	0.7	1.7	3.4	4.5	5.9	5.6	3.8	2.8	1.8	0.9	0.4
2006	0.4	0.8	2.1	3.3	5.1	5.6	5.3	4.1	2.6	1.8	1	0.5
2007	0.5	0.9	1.6	2.9	4.9	4.6	4.2	3.7	2.8	1.7	0.9	0.4
2008	0.4	0.8	2	2.6	4.5	4.5	4.9	4.4	2.6	1.6	0.8	0.5
2009	0.5	0.8	1.8	2.9	4.1	5.6	5.3	3.7	2.7	2	0.6	0.4

Table 7. Presents the total ET_c in mm for winter wheat, maize, rice/cotton and rapeseed crops in Xingping and Wugong.

Months	(ET_c mm) in Xingping station				(ET_c mm) in Wugong station				Total (ET_c mm)
	Winter wheat	Maize	Rice/Cotton	Rapeseed	Winter wheat	Maize	Rice/Cotton	Rapeseed	
Jan.	14.31	-	-	18.57	14.02	-	-	18.18	65.08
Feb.	18.89	-	-	21.29	22.79	-	-	25.68	88.65
Mar.	46.31	-	-	59.91	37.74	-	-	48.83	192.79
Apr.	113.35	-	51.19	91.15	118.75	-	53.63	95.5	523.57
May	116.11	-	75.93	108.48	121.48	-	79.45	113.5	614.95
Jun.	90	81.4	76.15	111.51	92.21	83.4	78.01	114.24	726.92
Jul.	-	178.22	185.51	-	-	179.52	186.87	-	730.12
Aug.	-	196.93	187.73	-	-	200.49	191.12	-	776.27
Sep.	-	113.66	118.02	115.53	-	120.19	124.79	122.16	714.35
Oct.	57.99	-	90.23	66.92	61.55	-	95.77	71.03	443.49
Nov.	34.83	-	-	28.46	36.71	-	-	30	130
Dec.	24.13	-	-	21.89	23.03	-	-	20.9	89.95

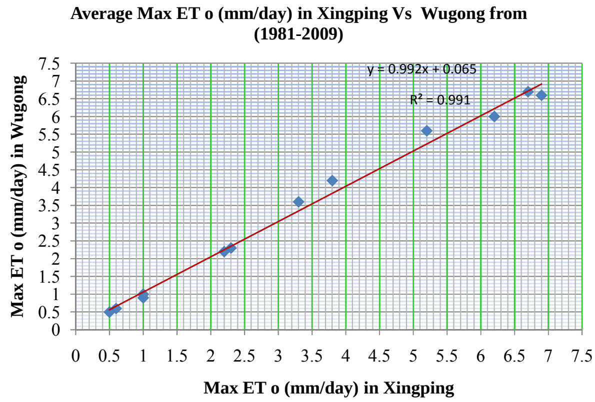


Figure 5. The relationship of Maximum ET_o from Xing ping and Wu gong. X-axis illustrated the ET_o in Xing ping, while Y-axis illustrated ET_o of Wugong station.

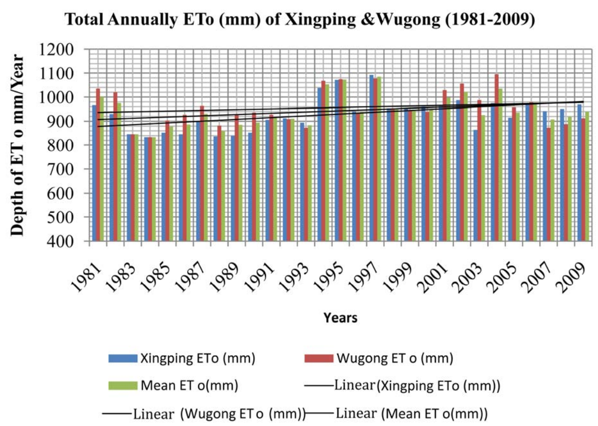
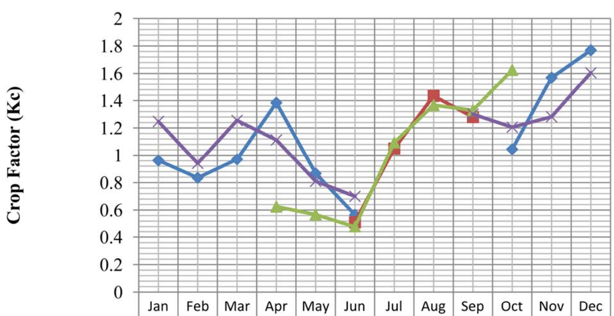


Figure 6. The mean annual reference evapotranspiration.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
winter wheat	0.96	0.83	0.97	1.38	0.86	0.56				1.04	1.56	1.76
maize						0.51	1.05	1.43	1.28			
rice,cotton				0.62	0.56	0.47	1.09	1.36	1.32	1.62		
rapeseed	1.24	0.94	1.25	1.11	0.81	0.70			1.30	1.20	1.28	1.60

Figure 7. Crop factors for different seasons and crops.

between 0.4 - 6.9 mm·day^{-1}, 0.4 - 6.7 mm·day^{-1} and the average value is 2.6 mm·day^{-1}, 2.6 mm·day^{-1} respectively. The maximum values are occurred in summer season (May, June and July). The annually values of ET_o occurred in 1995 and 1997 as the higher one, that are refer to the maximum mean temperature for those months (*i.e.* the temperature is most sensitive parameters in this study). The correlation coefficient is very high $\left(r_{xy} = 0.99 \approx 1\right)$. The daily values for every month through the time period (*i.e.* 1981-2009) were presented in **Tables 5** and **6**. The results of both stations were indicating that the "ET_o" was increasing by recent years. The average monthly reference crop evapotranspiration $\left(ET_c\right)$ for winter wheat, maize, rice/cotton and rapeseed crops in Xingping and Wugong for the irrigation period were presented in **Table 7**.

6. Acknowledgements

For data sources, we thank the Shaanxi office of meteorological information through Northwest A&F University. We also wish to express our appreciation to Agronomy journal reviewers for their valuable comments and suggestions concerning this manuscript.

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