ESTIMATION OF REFERENCE EVAPOTRANSPIRATION BASED ON AVHRR DATA USING HARGREAVES EQUATION

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ABSTRACT: The use of satellite data to estimate reference evapotranspiration (ET_0) data has become an effective solution for large areas. The aim of this study is to investigate whether it is possible to reach reliable estimation of ET_0 only on the basis of the remote sensing-based surface temperature (T_s) data by Hargreaves equation (HG) under an arid environment of Iran. This study has assumed that the daytime surface temperature at the cold pixel obtained from the AVHRR/NOAA sensor can be used instead of air temperature in the HG equation for ET_0 estimation in irrigation network. For this purpose, 61 NOAA- AVHRR satellite images obtained between June and September in 2004 and 2005 and weather data measured at two weather stations located in two irrigation networks with sugar cane located in Khuzestan plain in the southwest of Iran were used to calibrate and test the HG equation. The FAO-56 Penman–Monteith model was used as a reference model for investigating the performance of the calibrated HG model. The results show that calibrated HG model provided close agreement with the reference values, with an average RMSE of 1.2 mm $d^{-1}$and a R^2 of 0.90.

1. INTRODUCTION

Referenvce evapotranspiration (ET_0) is very important parameter for farm irrigation scheduling and water resources management. ET_0 is defined as the evapotranspiration of extensive surface of green grass of uniform height (8 to 15 cm tall), actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt, 1977) and as a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23 (Allen et al., 1998). ET_0 can be measured using weighting lysimeters directly, which is the most accurate method. However, direct measurements are time-consuming and costly, so mathematical models or empirical relationships are used to determine ET_0. Many equations have been presented for determining ET_0 from meteorological data. The Penman-Monteith (PM) equation is the best known method (Allen et al. 1998) which recommended by the FAO as the standard method (hereafter referred to as FAO- PM). ET_0 by FAO-PM equation is calculated using climatic data such as air temperature, relative humidity, wind velocity and net radiation. These climatic data obtained from nearest weather stations. However, most weather stations are installed in dry land. Using weather data from these stations to estimate ET_0 cause a large error.

Most agricultural areas lack meteorological station or away from them, so in this situation, satellite data is useful. Satellite remote sensing ET models have enabled experts to estimate ET_0 for large cultivated areas. Papadavid et al. (2013) combined modeling and remote sensing data for estimating actual evapotranspiration near Mandria Village in Paphos District of Cyprus. Elhag et al. (2011) used the SEB model to estimate daily evapotranspiration in the Nile Delta. However, these models are complicated and they estimated actual vaporation rather ET_0.The estimate of ET_0 is an important parameter for irrigation management of farms. It is desirable to have a method that estimates ET_0 from a large irrigated farm surface. The combination of ET_0 models with remote sensing data provides valuable data. Maeda et al. (2011) evaluated three temperature- based ET_0 models by using land surface temperature data from the MODIS sensor that is replaced by air temperature data from ground weather stations. This evaluation has been carried out in an inter-tropical convergence zone. They showed that Hargreaves model is the most appropriate with an average RMSE of 0.47 mm day^{-1}, and a correlation coefficient of 0.67. In this paper, the accuracy of ET_0 values that estimated using Hargreaves equation with land surface temperature data from AVHRR images replaced by air temperature data.

2. MATERTIALS AND METHODS

2.1 Study area

The present study has been contacted in two irrigated units that cultivate sugar cane. These irrigated sites are the Shoabieh (SH) and Khazae (KH) and each of them covers an area of approximately 15,000 hectares (see Fig. 1 and Table 1). These areas are located in the Khuzestan province in the south-west of Iran, borders Iraq and the Persian Gulf. On the basis of the Koppen climate classification, the Khuzestan plain is categorized as having an arid climate. Maximum temperature reach 50 °C in summer and 12 °C in winter and the annual

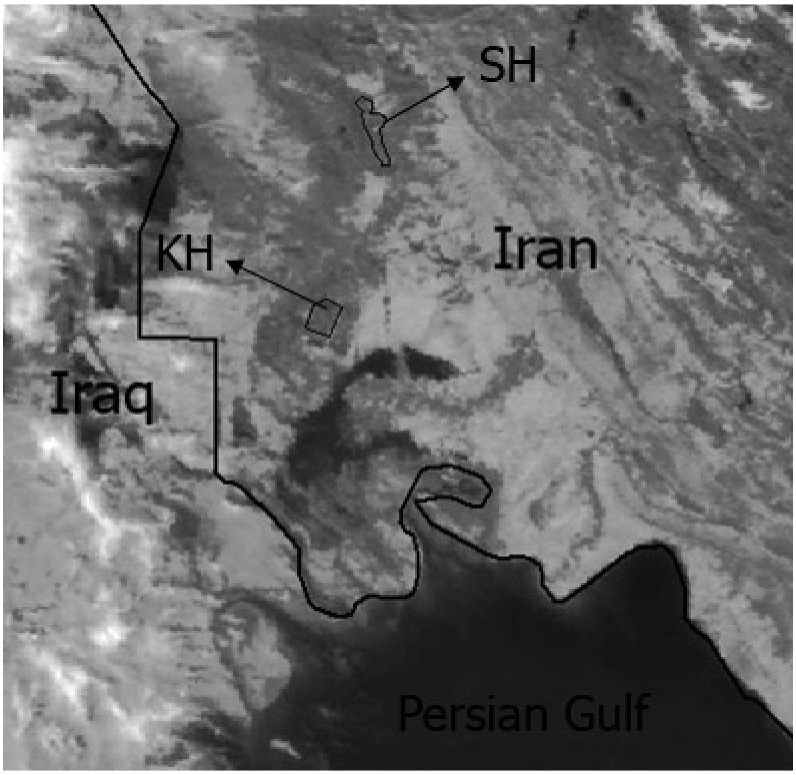

Figure 1- The location of irrigated sites in the Khuzestan plain

2.2 Satellite and Weather Data

A total of 61 daytime images without cloud cover of NOAA-AVHRR level 1b, covering the plain of Khuzestan in Iran were collected from the Satellite Active Archive (SAA) of NOAA. These images were scanned between noon and 3.00 pm (local time) between June and September in 2004 and 2005. The images were corrected radiometrically and geometrically, and the data in the digital counts were converted to reflectance (for channels 1 and 2) and to brightness temperatures (for the thermal channels 4 and 5) using the calibration information given in the documentation for each image. For each image, two polygons were defined around the sugarcane units. The cold pixel of each polygon was selected as a well-irrigated crop surface having full ground cover by vegetation. The daily air temperature in the Hargreaves ET_0 model was replaced with the daytime surface temperature of the cold pixel.
In this study, the equation presented by Ulivieri et al. (1994) was used for retrieving the land surface temperature, which is based on the following split window algorithm:

$$T_s = T_4 + 3.33\,(T_4 - T_5) + 48\,(1-\varepsilon) - 75\,\Delta\varepsilon \quad (1)$$

where, T_s is infrared surface temperature (^oC), T_4 and T_5 are brightness temperatures (^oC) in AVHRR channels 4 and 5, ε is the average emissivity in AVHRR channels 4 and 5, $\Delta\varepsilon$ is emissivity difference between 4 and 5 channels ($\varepsilon_4 - \varepsilon_5$). The emissivity in each channel has been calculated using the vegetation cover method of Valor and Caselles (1996):

$$\varepsilon_i = \varepsilon_v P_v + \varepsilon_s (1 - P_v) \quad (2)$$

where ε_i is channel emissivity values (channels 4 or 5), ε_v is the vegetation emissivity (0.985 in both channels 4 and 5), ε_s is the soil emissivity (0.949 for channel 4 and 0.967 for channel 5) and P_v is the fraction of vegetation cover, which was estimated from NDVI according to Carlson and Ripley (1997):

$$P_V = \left(\frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}\right)^2 \quad (3)$$

where $NDVI_V$ and $NDVI_S$ are the NDVI values of full vegetation cover (P_V=1) and bare soil (P_V=0), respectively, which can be obtained from the NDVI histogram. Values of NDVIv = 0.5 and NDVIs = 0.2 were proposed by Sobrino and Raissouni (2000) to apply the method in global conditions. In order to obtain consistent values of P_V, for those pixels with $NDVI < NDVI_S$ the P_V has been set to zero, whereas for those pixels with $NDVI > NDVI_V$ it has been set to 1.
During the same time period of collected satellite data, ground weather data were obtained from one weather station

installed in each irrigated sugarcane units. These weather data is necessary for the FAO-PM equation and consisted of daily observations of maximum and minimum temperature (Tmax and Tmin), relative humidity (RH), wind speed (U) and bright sunshine hours (n). Daily mean temperature (relative humidity) records by calculating the average of the daily maximum and minimum temperature (relative humidity) records. A linear variation between the daily minimum and maximum temperatures (relative humidity) were assumed. The locations and elevations of the stations are given in Table 1.

Table 1- Weather stations used in the study

Station	Code	Latitude (°N)	Longitude (°E)	Elevation (m)
Shoabieh	SH	31° 48'	48° 46'	29
Khazae	KH	31° 08'	48° 35'	7.2

2.3 FAO Penman–Monteith equation

In this study, the Hargreaves ET_0 equation was calibrated using the conventional FAO Penman–Monteith method as reference. Although in practice, the best way to test the performance of the empirical methods would be to compare their performances against the lysimeter-measured data; this type of data set is not available in the study area. The following equation was applied for the PM (Allen et al., 1998):

$$ET_0 = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T_a + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (4)$$

where the ET_0 is reference crop evapotanspiration (mm d^{-1}), R_n is the daily net radiation (MJ m^{-2} d^{-1}), G is the daily soil heat flux (MJ m^{-2} d^{-1}), T_a is the mean daily air temperature at a height of 2 m (°C), U_2 is the daily mean wind speed at a height of 2 m (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of the saturation vapor pressure versus the air temperature (kPa $^oC^{-1}$), and γ is the psychrometric constant (kPa $^oC^{-1}$).

2.4 Hargreaves equation

The Hargreaves equation was defined by the following equation (Hargreaves 1994):

$$\text{ET0 HG} = 0.0023R_a(T_a + 17.8)\,(T_x - T_n)^{0.5} \quad (5)$$

where the ET0 HG is the ET_0 calculated by the Hargreaves equation (mm day^{-1}), Ra is the water equivalent of the extraterrestrial radiation (mm day^{-1}) computed according to Allen et al. (1998), and Tx, Tn, and Ta are the daily maximum, minimum, and mean air temperatures (°C). In this study, mean air temperature data from ground stations were replaced by T_s. The $(T_x – T_n)^{0.5}$ component shows the cloudy effect of the air which is supposed to be a regional parameter in this study. Therefore, this component is assumed to have a simple linear regression (of the form Y = a + bX) of R_a (T_s+17.8) *versus* the ET_0 values was made. So, the equation 5 was modified as follows:

$$\text{ET0 CHG} = a + b\,R_a(T_s + 17.8) \quad (6)$$

where the ET0 CHG is the ET_0 calculated by the modified Hargreaves equation (mm day^{-1}) and a and b are constant parameter of the equation. In this study in order to calibrate the Hargreaves equation, the whole data set of the two stations (122 patterns, 2004 and 2005) was divided into two parts: the first part (58 patterns, 2004) was used for calibration and the second part (64 patterns, 2005) was used for validation**.**
ET_0 estimates from calibrated ET0 CHG equation were compared against the FAO-PM estimation with the validation data. For each location, the following parameters were calculated: coefficient of determination (R^2), mean bias error (MBE), root mean square error (RMSE).

3. RESULT AND DISCUSSION

To calibrate the Hargreaves equation with T_s as input data for estimating ET_0, a simple linear regression (of the form Y = a + bX) of R_a (T_s+17.8) *versus* the ET_0 values was made. The regression data is shown in Fig 2. The R^2 of the regression equation was 0.91, which means that approximately 91% of the variations in the ET_0 are linearly related to the R_a (T_s+17.8). The values of constants a and b are 0.0083 and -0.76, respectively.

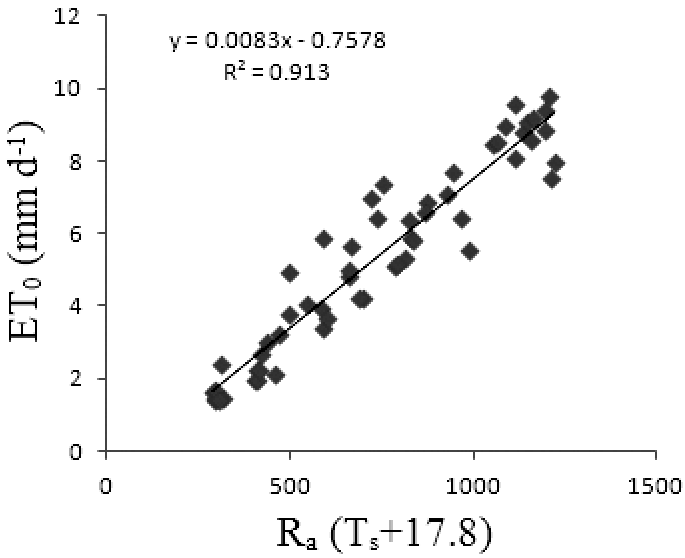

Figure 2- Relationship between R_a (T_s+17.8) and ET_0

To determine the usefulness of the calibrated Hargreaves equation in estimating ET_0, the dataset from SH and KH weather stations were used for the year 2005. Figure 3 shows a scatter plot of the ET0 values computed by equation 6 and FAO-PM method for the two irrigated area. It shows that, there is a very good correlation between the two methods. The slope of the straight line is nearly close to one (0.91 and 0.92 for SH and KH respectively). The high values of R2 (=0.95 and 0.88) with the calibrated Hargreaves model also confirms that this approach works well in estimating ET_0 for both irrigated sites. The root mean square (RMSE) of 1. 1 and 0.96 mm d−1 provided by the Calibrated Hargreaves equstion suggests that it can be used to estimate reference ET_0 for the sites.

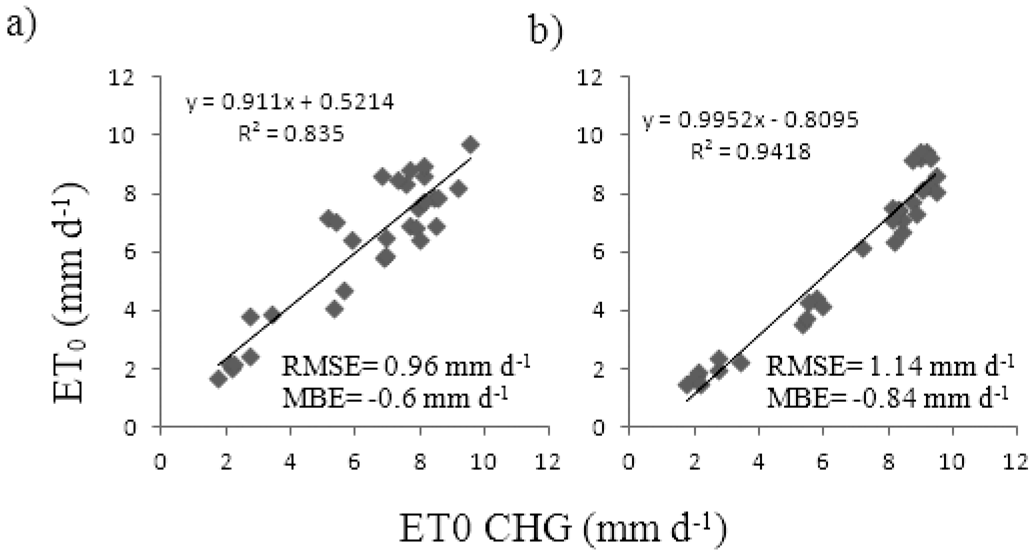

Figure 3- ET0 calculated from the reference method (FAO-PM) and the calibrated Hargreaves method for two irrigated area. a) Khazae, b) Shoabieh

4. CONCLUSIONS

The results of this study demonstrated that modelling of reference evapotranspiration is possible by using Hargreaves equation from land surface temperature data of cold pixels obtained from irrigated area. This result is practical for estimation of daily ET_0 in the areas where weather station data are not available.

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