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Estimation of Rice Evapotranspiration Using Reflective Images of Landsat Satellite in Sefidrood Irrigation and Drainage Network

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Abstract: More accurate estimation of crop evapotranspiration (ET_c) in a regional scale has always been one of the most important challenges. Temporal and spatial monitoring of ET_c using satellite images can help to enhance accuracy of estimations. In this study, the $(ET_c)_{rice}$ maps were produced by using statistical/experimental methods based on crop coefficient (K_c) maps derived from vegetation index (VI). K_c was estimated using four methods, including linear relationship between K_c and VI (K_c-VI), calibrated model of K_c-VI, linear relationship between K_{cb} (the basal crop coefficient) and VI (K_{cb}-VI), and calibrated model of K_{cb}-VI. The results showed that calibrated model of K_c-VI had a better performance compared to the other methods, with normalized root mean square errors (NRMSE), mean absolute error and root mean square error being 5.7%, 0.05 mm/d and 0.06 mm/d, respectively. $(ET_c)_{rice}$ maps were produced by using calibrated model of K_c-VI and reference evapotranspiration (ET_0) from FAO Penman-Monteith method. The NRMSE was 21.3% for using FAO Penman-Monteith method. Therefore, calibrated K_c-VI model in combining with ET_0 based on the Landsat 7 ETM+ images could be provided a good estimation of $(ET_c)_{rice}$ in regional scale, and can be applied to estimate water requirement due to the free and facilitate access.

Key words: vegetation index; lysimeter; satellite data; evapotranspiration; crop coefficient; Landsat image

Evapotranspiration (ET) is one of the main hydrological cycle components (Anda et al, 2015; Güçlü et al, 2017), which has extreme importance for agricultural water resources management (Blanka et al, 2017). The assessment of ET on large irrigated lands, from irrigation district to entire basin or region, provides support for water management at different decision levels (Gonzalez-Dugo et al, 2013). Water productivity analysis, irrigation scheduling and planning, and water resources allocation can be realized only if timely and accurate information about water consumption by crops is available (Kite and Droogers, 2000). ET, including water evaporation from soil surface and transpiration from vegetation cover, is an important process of the hydrological cycle and a major element of water resources management (Gao et al, 2008). The direct methods of ET estimation (Bowen ratio, Eddie covariance and lysimeter) are very costly and time-consuming for continuous application at appropriate intervals in the region. Also, these point measurements are not applicable to larger basins due to the fluctuation of weather conditions and the dynamic nature of water-heat transfer process (Gao et al, 2008). Remote sensing technology can be an appropriate option in determining the required parameters because of spatial data collecting in a regional scale and updated information. It has the capability to estimate the spatial distribution of ET in an area without knowing the history in relation to soil condition and farm management (Bastiaanssen et al, 2005). High spatial ($< 10^3$ m) and temporal (≥ 1 d) data from the land surface are provided by satellites and have been used for a wide range of purposes, one of which is to estimate ET over large irrigated districts (Garatuza-Payan and Watts, 2005; Rossi et al, 2010).

Numerous studies have been conducted to estimate crop evapotranspiration (ET_c) based on remote sensing. Many of these studies use the energy balance method in which estimating the surface temperature and radiation data is needed

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(Tasumi et al, 2005; Gowda et al, 2008). Another method called the VI-ET_0 method is based on estimating the reference evapotranspiration (ET_0) and crop coefficient (K_c). K_c is the ratio of ET_c and ET_0 (Allen et al, 1998) and is related to vegetation indices (VIS, conversion of the measured surface's reflections in specific bands of electromagnetic spectrum which are normally red and infrared obtained by remote sensing) (Heilman et al, 1982; Bausch and Neale, 1987; Neale et al, 1989; Hunsaker et al, 2003, 2005a, b; Gonzalea-Dugo and Mateos, 2008; Campos et al, 2010; Glenn et al, 2011).

VI-ET_0 method requires fewer data based on basic principles. Mateos et al (2013) considered the reductions in ET_c and crop growth in relation with stomatal closure. The method was introduced by Heilman et al (1982) and then it was evaluated by other researchers (Bausch and Neale, 1989; Choudhury et al, 1994; Bausch, 1995). Also, some studies showed that remote sensing VIS can be used to estimate the basal crop coefficient (K_{cb}) for the agricultural crops (Belmonte et al, 2005; Kambel et al, 2013; Odi-Lara et al, 2016).

Rice, as the main agricultural crop in Guilan Province, north of Iran, is cultivated on 2.30×10^5 hm^2. Irrigation water requirement of 1.89×10^5 hm^2 is supplied by Sefidrood River. The reservoir capacity of Sefidrood dam has been reduced due to building multiple dams in the upstream catchment and being filled with sediments. Moreover, the climate changes in form of reduction in rainfall and increase of temperature in recent years also result in the scarcity (Hadinia et al, 2017). To achieve the food security based on the sustainable agriculture, producing more food with less water consumption is necessary. Thus, ET estimation of paddy fields as an important parameter of the regional water balance can be certainly a key factor for water allocation in Guilan Province. The accuracy of estimated ET from remote sensing data should be increased based on the field measured data. This study was conducted to calibrate and validate the estimated $(ET_c)_{rice}$ from remote sensing data based on the measured ET from lysimeter in Eastern F_1 command area in Foomanat irrigation district, Guilan Province of Iran.

MATERIALS AND METHODS

Study area

The study area was located at the Eastern F_1 command area in Fouman plain in Guilan, Iran (Supplemental Fig. 1). Cultivated area of paddy fields in the Eastern F_1 command area was 3 504 hm^2 that located between 49º38′ to 49º47′ E and 37º16′ to 37º26′ N.

Data collection and pre-processing

Two types of data including field and satellite data are used. Field measurements were conducted during two consecutive years of 2012 and 2013. Ten rice fields were selected. A closed bottom cylindrical mini-lysimeter with a diameter of 56 cm and depth of 60 cm was installed in each field to measure the $(ET_c)_{rice}$. Farming operations such as transplanting date and density (6 plants at 20 cm × 20 cm spacing in each mini-lysimeter) in mini-lysimeters were the same as the surrounding. The $(ET_c)_{rice}$ were measured in periods of 2 to 3 d. To adjust water level in the mini-lysimeters to be the same as the surrounding, a reference mark within 5 cm above soil surface was determined. In each measurement, water level in each mini-lysimeter reached to the reference level, and the volume of reduced water was considered as $(ET_c)_{rice}$ during the period. In the event of rain, $(ET_c)_{rice}$ was calculated as the sum of rain and the added water (when water was added to reach the reference mark), or as the amount of rain minus the removed water (when water was removed to reach the reference mark).

Five Landsat images for 2012 were obtained by Landsat 7 Enhanced Thermal Mapper Plus (ETM+) with intervals of 16 d from 14 May to 2 August, except 1 July because of high cloud cover. In 2013, because of high cloud cover in the region, only two images were used on 17 May and 18 June. Two corrections were done for all images. The first step was the correction of machine error as affected by failure of scan-line corrector (SLC) of the Landsat 7 ETM+ sensor, and the second step was atmospheric correction on the studied images. Therefore, All Landsat images were corrected using IDW method (Taherparvar et al, 2017), and the darkest pixel atmospheric correction was used for recovering the VI (Song et al, 2001; Hadjimitsis et al, 2010; Agapiou et al, 2011).

Estimation methods of crop coefficients

Linear relationship of K_c-VI

The easiest method to estimate the K_c is its modeling as a function of VI from remote sensing data, which represents a linear relationship between normalized difference vegetation index (NDVI) and K_c ($K_c = 1.25 \times NDVI + 0.2$) (Belmonte et al, 2005), where *NDVI* is calculated with comparing electromagnetic energy reflected by the vegetation in visible spectral ranges (red) to near infrared (NIR).

Linear relationship of K_{cb}-VI

Another method to achieve K_c is dual K_c method in which K_c is divided to a basal crop coefficient (K_{cb}) and a soil evaporation coefficient (K_e) (Pirmoradian and Sedaghatdoust, 2014). K_{cb} map was derived by using a linear relationship between NDVI and K_{cb} ($K_{cb} = 1.5628 \times NDVI - 0.1$) (Belmonte et al, 2005).

Rice evapotranspiration [$(ET_c)_{rice}$]

In this study, rice evapotranspiration was derived based on ET_c concept ($ET_c = K_c \times ET_0$) (Doorenboos and Pruitt, 1977). ET_0 values were calculated using FAO Penman-Monteith method by Ref-ET software based on the meteorological station's data (Allen et al, 1998).

Validation criteria

The validation of K_c and $(ET_c)_{rice}$ estimation models were conducted using statistical criteria including root mean square