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Quantification of wheat crop evapotranspiration and mapping: A case study from Bhiwani District of Haryana, India

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ABSTRACT

In this study an attempt has been made to estimate the actual wheat crop evapotranspiration (ET_c) by Surface Energy Balance Algorithm (SEBAL) and standardized FAO-Penman-Monteith (FAO-PM) method. Improved knowledge of evapotranspiration (ET) helps in understanding the water balance of any region. The results obtained through measured lysimeter, SEBAL and PM method were evaluated through statistical performance measure tests. ET_c estimated from SEBAL was found to correlate significantly as R^2 (0.91) with the measured ET_c of lysimeter. ET_c estimated by SEBAL was also compared with PM ET_c with the help of crop coefficient and was found to correlate significantly as R^2 (0.85). The other statistical parameters (RMSE = 0.56, nRMSE = 0.09, MAE = 0.26, NRMSE = 0.20, R-RMSE = 0.27, NSE = 1, d = 0.87 ($\approx$1)) were also showing a good agreement between SEBAL ET_c and PM ET_c. The findings of work have suggested that SEBAL model shows a good potential to estimate spatial ET_c for the region. Additionally the validation of models results were performed with the analysis of correlation between models ET_c and district level wheat production and area under crop of five years. The results of this analysis outline that water availability and good amount of rainfall gives higher wheat yield and resulted into more ET_c.

1. Introduction

To understand the process of loss of water from soil and plant to the atmosphere through evapotranspiration (ET) is critical for water resources management. ET is a key and crucial component of hydrologic cycle and defined as loss of water through both plant (transpiration) and surface (evaporation). ET account for 60–90% on an average of rainfall water return back to the atmosphere. The scanty rainfall and rapid declining water table over last few decades is one of the critical problems in many parts of India. The demand of water for industries and agriculture sector in India is continuously growing to meet the demands of 1.2 billion people. The area under agriculture fields is continuously increasing hence more water is required to irrigate the crops. The real-time irrigation management and allocation of water resources needs real-time prediction of daily reference evapotranspiration (ET_o) that will help in understanding the Impact Based Decision Support Service (IBDSS).

ET models using remote sensing data can be categorised as Simplified Empirical Regression Method (Jackson et al., 1977) and Residual Method of Surface Energy Balance. Further, the Residual Method of Surface Energy Balance can be divided into Single Source Models and Dual Source Models (Li et al., 2009). The more details about these models are available in the comprehensive review article on current methodologies for regional evapotranspiration estimation from remotely sensed data by Li et al. (2009). Owing to this, different methods have been developed to retrieve the surface fluxes from remotely sensed data sets. These methods are categorised as Single Source Energy Balance and Two Source Energy Balance model. Single Source Energy Balance Model are as following: Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al., 1998a,b; Bastiaanssen 2000), Simplified Surface Energy Balance Index (S-SEBI) (Roerink et al., 2000), Surface Energy Balance System (SEBS) (Jia et al., 2003) and Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC). The Two-Source Energy Balance (TSEB) (French et al., 2003), and Norman et al. (1995) developed a Two-Source (soil + canopy) Model (TSM) and Anderson et al. (1997) examined and tested the Two-Source Time Integrated Model (TSTIM), subse-

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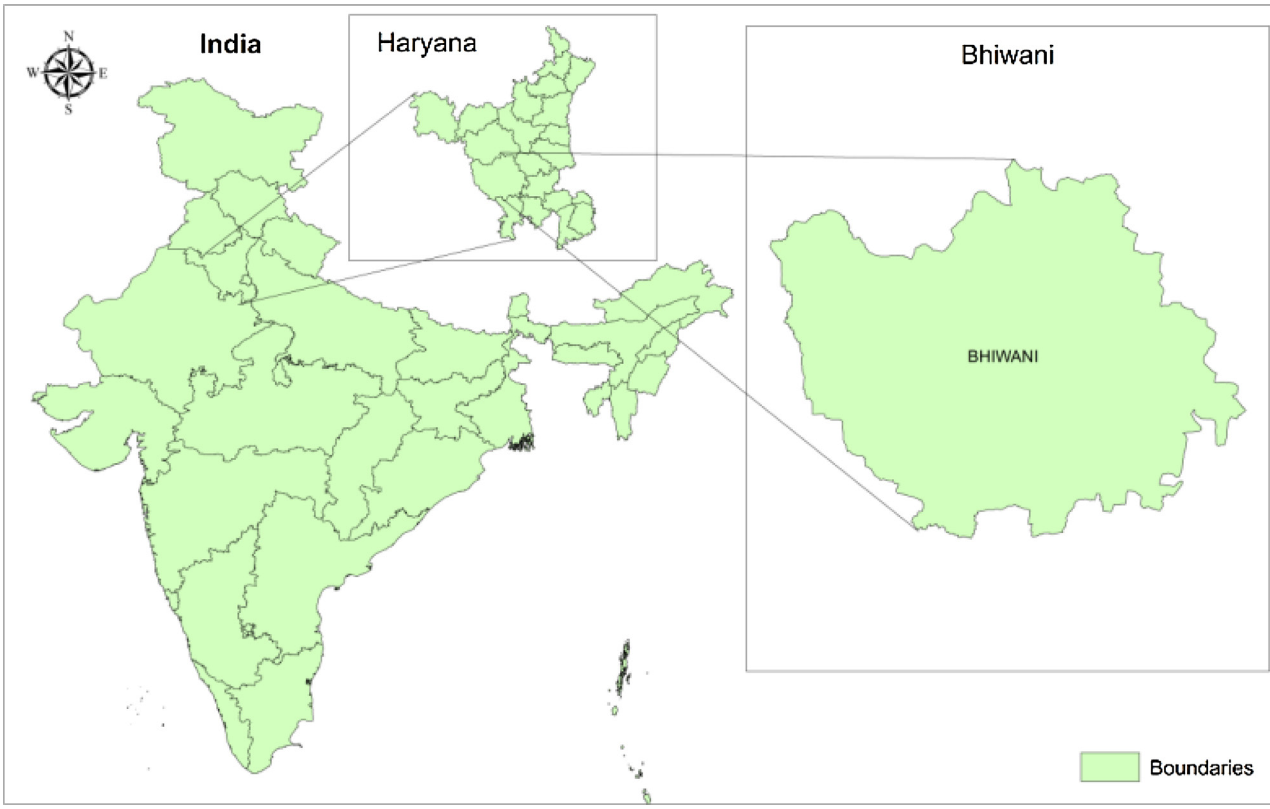

Fig. 1. Location map of the study area (Bhiwani district of Haryana).

quently was named as Atmosphere-Land Exchange Inverse (ALEXI) (Mecikalski et al., 1999).

Bastiaanssen et al. (1998a,b) have evaluated ET with minimum ground-based measurements using SEBAL and tested at both field and catchment scales under several climatic conditions in more than 30 countries worldwide. They found that seasonal scales accuracy was higher (95%) than daily scale (85%) at field scale. ET estimates for both irrigated and drylands fields using SEBAL (Gowda et al., 2008). SEBAL has been successfully applied for ET estimation, calculation of crop coefficients and evaluation of basin wide irrigation performance under various agro-climatic conditions in several countries including Spain, Sri Lanka, China, and the United States (Bastiaanssen et al., 2005; Singh et al., 2008).

Estimation of SEBAL ET from any region has added advantage as to get spatial distribution of biophysical descriptors namely surface albedo, surface temperature, Normalized Difference Vegetation Index (NDVI, Bala et al., 2015b; Rawat et al., 2012) and Soil Adjusted Vegetation Index (SAVI, Bala et al., 2015b) map and Leaf Area Index (LAI, Bala et al., 2015b) map etc. Zhao-Liang et al. (2009) have reviewed energy balance algorithms and found that if these models employed under clear sky conditions then these ET models can provide relatively more accurate spatial distribution of instantaneous ET. Actual ET maps can be used with confidence in water accounting and hydrological modelling if they are validated for different agro climatic zones (Karimi and Bastiaanssen, 2014).

Many studies have successfully used FAO-Penman-Monteith (FAO-56) method to calculate reference crop evapotranspiration (ET_o) (Cai et al., 2007; Abdelhadi et al., 2000; Hou et al., 2014; Li et al., 2016; Muniandy et al., 2016; Xu et al., 2017) and estimated crop water requirement (Allen et al., 1998). Jensen (1968) has introduced the concept of crop coefficient (K_c) and later many researchers have further improved (Doorenbos and Pruitt, 1975, 1977; Burman et al., 1980a,b; Allen et al., 1998). However, K_c approach has potential to precisely calculate actual crop evapotranspiration (ET_c). The K_c depends on many factors such as greenness, crop cover and LAI and varies differently in different ecological system with variations in environmental conditions.

Even though SEBAL model is strongly based on theoretical and physical relationship, minimum ground measurements, accurate atmospheric corrections are not needed and its automated internal calibration of empirical coefficients makes it accurate and operational (Allen et al., 2007). It also has few following disadvantages: applied over flat surfaces and uncertainty in the determination of anchor pixels. Owing to all these facts, SEBAL model is extensively being in practice to estimate ET from crop and vegetative ecosystems.

The main objective of the work was to estimate ET_c from wheat crop of Bhiwani district of Haryana (India) through the validated SEBAL model for the same agro-climatic zone (Bala et al., 2015a). Further, validation of spatial estimates of ET_c using FAO guidelines for K_c of wheat crop.

2. Materials and method

2.1. Geographical conditions and field data

The study area is Bhiwani district lies between latitudes 28°.19′ and 29°.05′ N and longitudes 75°.26′ and 76°.28′ E with an average elevation of 225 m above mean sea level (Fig. 1). The climate is mainly dry with very hot summer and cold winter and classified as tropical steppe, semi-arid and hot. The soil is loamy in the north and sandy in the southwest region. The water table in the region is declining at faster rate (Borana, 2012) and saline with few small pockets of fresh water in southwest parts. Very high seasonal differences in the temperature range (2 °C-winter to 45 °C-summer). The south west monsoon brings rain and contributed to 85% of annual rainfall, however, rest 15% rainfall is received during the non-monsoon period due to western disturbances and thunder