Original Research Article

A Comparative Study of Evapotranspiration Calculated from Remote Sensing and Meteorological Data for Gaya District

Abstract

A study on evapotranspiration for wheat was conducted in the two-year Rabi season crop from November, 2017 to April, 2018 and from November, 2018 to April 2019 at Gaya District, Bihar. Spatio-temporal information on actual evapotranspiration (ET_a) helps users to better understand evaporative depletion and to establish links between land use, water allocation, and water use. The Surface Energy Balance Algorithm for Land (SEBAL) was adopted for the Gaya District, employing the essential adaptations for local soil and meteorological conditions. AOI images were used to retrieve the needed of spectral data. The results have been compared to the in-situ measurements of CROPWAT Model, Makkink Model (MM) and remote sensing SEBAL model. Due to its crucial function in predicting the crop water requirement in irrigated agriculture, accurate and reliable estimation of reference crop evapotranspiration (ET_o) is necessary. The purpose of this study was to estimate evapotranspiration (ET_c) in a semi-arid environment utilizing regionally distributed crop coefficient (K_c) and open access earth observation datasets. SEBAL and Makkink models were used to predict the actual evapotranspiration (ET_c) based on regionally distributed crop coefficient (K_c). Through statistical tests for model comparison, it was discovered that the Makkink model performed satisfactorily when compared to the typical Penman-Monteith model estimate (R^2=0.88). Analysis also demonstrates distributed actual evapotranspiration from the Penman-Monteith model and actual evapotranspiration based on the Makkink model with R^2 = 0.76, respectively. The result implies that the Penman-Monteith model-based ET_o and Makkink model estimations of ET_o are very similar. ET_c estimated by SEBAL was also compared with PM ET_c with the help of crop coefficient. Additionally, the validation of model's were performed with the analysis of correlation between models ET_c and district level wheat production and area under crop of two 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.

Keywords: *Evapotranspiration, SEBAL, CROPWAT, Penman-Monteith and Makkink Model.*

Introduction

The process of water loss from soil and plant to the atmosphere through evapotranspiration (ET) can be estimated for water resources management. ET is a main component of hydrologic cycle and defined as loss of water through both plant (transpiration) and surface (evaporation). 60–90% of rainfall water goes back into the atmosphere due to evapotranspiration. The problem of low rainfall and rapidly depleting groundwater is being seen in many parts of India for few decades. The demand of water for industries and agriculture sector in India is continuously increasing to meet the needs of growing population. 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 (ETo). ET models using remote sensing data can be categorized as Simplified Empirical Regression Method (Jackson et al., 2010). Owing to this, different methods have been developed to retrieve the surface fluxes from remotely sensed data sets. These methods are categorized as Single Source Energy Balance and Two Source Energy Balance model. Single Source Energy Balance Model areas following: Surface Energy Balance Algorithm for Land (SEBAL) (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) (Frenchet al., 2003), and Norman et al. (2011) developed a Two-Source(soil + canopy) Model (TSM) and Anderson et al. (2008) examined and tested the Two-Source Time Integrated Model (TSTIM), subsequently was named as Atmosphere-Land Exchange Inverse (ALEXI)(Mecikalski et al., 2005).Bastiaanssen et al. (2010a,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 (Gowdaet 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). 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 ETc from wheat crop of Gaya district of Bihar (India). Further, validation of spatial estimates of ETc using FAO guidelines and Makkink Model for Kc of wheat crop.

Evapotranspiration by Remote Sensing

Both locally and nationally, irrigated agricultural systems can be managed using remote sensing. It may provide crucial information about water resources to decision-makers, managers, consultants, academics, and the general public. It has been possible to obtain data on land usage, irrigated area, crop type, biomass development, crop yield, crop water requirements, crop evapotranspiration, salinity, water logging, and river runoff via remote sensing, with varied degrees of precision. When provided in a managerial setting, this information can be very beneficial for planning and evaluation. Compared to field measurements, remote sensing has several benefits. Remote sensing measures are based on fact rather than opinion, data is gathered methodically, enabling time series and comparisons between systems broad range of coverage, including entire river basins due to cost and logistical issues, ground studies are sometimes limited to a small pilot region. The data is presented in tabular format. Satellite data were recently employed in studies (Bastiaanssen & Molden, 2000) to estimate regional real evapotranspiration. Granger (2000) used AVHHR data with a 1.1 km ground resolution and NOAA satellite images to study evapotranspiration assessment. The data were geo-certified using ERDAS Imagine software and radio-metrically calibrated. Multiplying potential evapotranspiration by the vegetation and moisture coefficient yielded the satellite-estimated evapotranspiration (VMC).

Study Area

Averaging 111 m above mean sea level, the study area in the Gaya district is located between latitudes 24° 46' 48.0360" N and 84° 58' 54.5772" E (Fig. 1). The climate is primarily dry, characterized as tropical steppe, semi-arid, and hot, with extremely hot summers and frigid winters. The region contains Black soils (42%), Sandy Loam soils (14%), and Sandy soils (22%). Area water table is saline with only a few tiny pockets of fresh water in the southwest. Extremely wide seasonal temperature variations (2 ^{o}C in winter to 45 ^{o}C in summer). Gaya district receives 961.83 mm of typical rainfall annually, of which 847.4 mm fall during the monsoon and 114.43 mm during the dry season. Water is limited resources in many parts of the Gaya district. Agriculture is main occupation of Gaya district and the main crops of Gaya district are paddy, wheat, potato, lentils, sorghum, millet, cowpea, ground nut. Groundwater, which is 38.5 % of the available water sources.

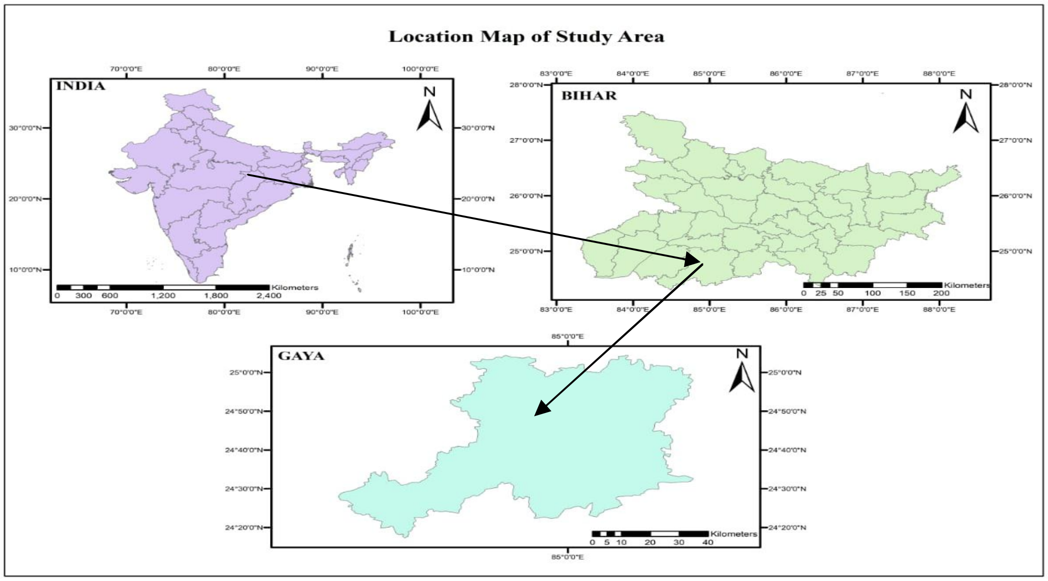

Fig:1 Study Area

Evapotranspiration Estimation Method

The evapotranspiration estimation method described here is based on the calculation of reference evapotranspiration (ET_o), to be multiplied by the crop factor (K_c), resulting in crop evapotranspiration (ET_{crop}). ETo is defined as "the rate of evapotranspiration from an extensive surface of 5-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". ET_{crop} is defined as "the rate of evapotranspiration from a disease-free crop, growing in large fields, under non restricting soil water and fertility conditions and achieving full production potential under the given growing environment". In this study the reference evapotranspiration was calculated using FAO CROPWAT, (http://www.fao.org/ag/agl/aglw/cropwat.stm). The method is applied using 10-day running average. The Makkink model (Ma; Makkink, 1957; radiation-based), the Hargreaves model (Ha; Hargreaves and Samani, 1985), the Hargreaves and Samani model (Hs; Hargreaves and Samani, 1982), and the Jensen-Haise model are several reduced-set techniques that are widely used to estimate ETo (Je; Jensen and Haise, 1963). For estimating actual evapotranspiration, several other models, including Priestley-Taylor (Priestley and Taylor, 1972), Blaney-Criddle (Blaney and Criddle, 1950), Turc-radiation (Turc, 1961), Thornthwaite (Thornthwaite, 1948).

Remote Sensing Methods

When they may produce estimates at extremely high resolutions and cover wide areas, remote sensing techniques are appealing for estimating evapotranspiration. Although some ground truth measures can be useful in interpreting the satellite images, intensive field monitoring is not necessary. The methods selected are varying in resolution and degree of physical realism. Remote sensing using the SEBAL

(Surface Energy Balance Algorithm for Land) developed by Bastiaanssen 1998 is a parameterization of the energy balance and surface fluxes based on spectral satellite measurements (Bastiaanssen, 1998). SEBAL requires visible, near-infrared, and thermal infrared input data, Instantaneous net radiation values were estimated using ground-based solar radiation measurements as well as surface albedo, surface emissivity, and surface temperature estimates (M. Jabloun, et.al., 2008). Using a unique model created for it, surface temperature was retrieved from the photos. Remote sensing software was used to extract the NDVI from the photos, and the surface albedo was then determined.

Data Collection and Analysis

Meteorological data obtained from the NASSA site with the help of coordinates and elevation, Maximum and minimum temperature, Relative humidity, Wind speed, Sunshine duration or radiation per day, Total rainfall and effective rainfall data, and Pan evaporation. Using meteorological and crop data, the crop water requirements were calculated using the CROPWAT software.

The Penman-Monteith equation used in the software is being adopted by FAO as standard evapotranspiration equation to be used all over the world. The crop evapotranspiration, ETcrop can be expressed as

$$ET_{crop} = KC\ ET_o \qquad (1)$$

Where, KC is the crop coefficient and ET_o is the reference crop evapotranspiration. KC values used were 0.28, 1.7 and 0.84 for the initial stage, the mid-season stage, and the end of the late season stage, respectively. These values were suggested by FAO (paper 56).

The Makkink (1957) had developed a radiation-based empirical approach and estimated evapotranspiration in millimeters per day (mm day $^{-1}$) by the following expression

$$ET_o = 0.62 \times \frac{\Delta}{\Delta+\gamma} \times \frac{Rs}{58.5} - 0.012 \qquad (2)$$

where, Rs is solar radiation (at the surface) in equivalent mm day $^{-1}$

Δ is the slope of saturation vapor pressure curve (mbar °C $^{-1}$) and

γ (mbar ^{o}C $^{-1}$) is the psychometric constant.

Results and Discussion

Performance and selection of optimal ETo model

In order to assess Mankkink Model (Ma) ET_o models, the daily ET_o was calculated using the PM method. When compared to one another, the ET_o pattern shows a similar trend. According to statistical analysis, the Mankkink Model is the most effective approach. The calculated ET_o value from the Ma was statistically compared to the PM reference ET_o, and the results show that the calculated ET_o value from the Makkink is highly like the PM reference ET_o, with an R2 value of 0.82, respectively. The estimated ET_o by the Ma technique is comparable to the reference ET_o based on R^2 value (PM based on FAO-56). Comparative results showed that the perfect selection of simple and complex model in a region is based on availability of meteorological data and calibration by PM (FAO-56) method for precise regional practical purposes as suggested by Lingling et al. (2014).

Table:1 Stage wise ET_c value of Makkink Model.

Makkink Model							
		2017-18	**2018-19**			**2017-18**	**2018-19**
Sr.No.	**Stage**	**ETc(mm/day)**			**Stage**	**ETc(mm/day)**	
1	Init	0.5	1.1	8	Mid	1.6	1.8
2	Init	1.2	1.5	9	Mid	1.9	1.9
3	Init	1.4	1.5	10	Mid	2.2	2.2
4	Dev	1.5	1.4	11	Mid	2.4	2.3
5	Dev	1.5	1.4	12	Late	2.6	2.5
6	Dev	1.4	1.5	13	Late	2.8	2.7
7	Mid	1.5	1.7	14	Late	2.5	2.3

Table 2: Stage wise ETc value of Penman-Monteith Model

Penman-Monteith Model							
		2017-18	**2018-19**			**2017-18**	**2018-19**
Sr.No.	**Stage**	**ETc(mm day $^{-1}$)**		**Sr.No.**	**Stage**	**ETc(mm day $^{-1}$)**	
1	Init	0.32	0.31	8	Mid	1.8	1.84
2	Init	0.32	0.31	9	Mid	2.03	2.08
3	Dev	0.37	0.35	10	Mid	2.23	2.14
4	Dev	0.62	0.65	11	Late	2.27	2.32
5	Dev	0.95	0.96	12	Late	1.86	1.93
6	Mid	1.37	1.39	13	Late	1.38	1.38
7	Mid	1.66	1.63	14	Late	0.87	0.89

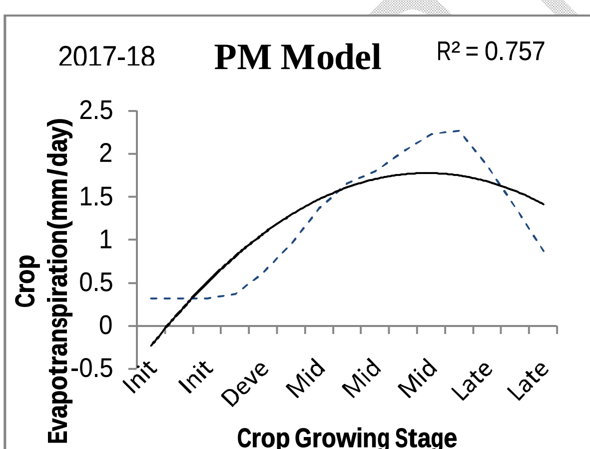

Fig-2 ETc obtained by PM Model Wheat Growing Stage (2017-18)

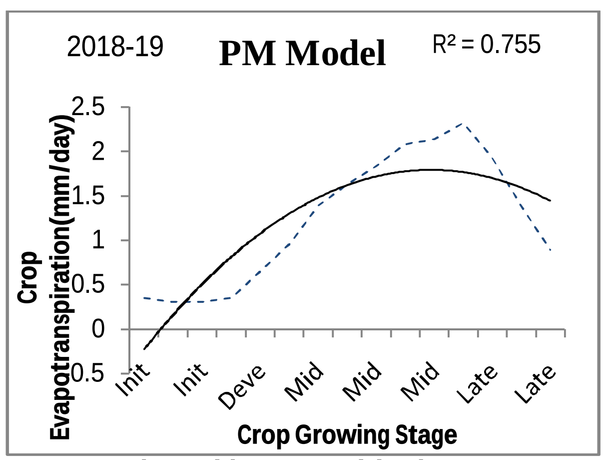

Fig-3 ETc obtained by PM Model Wheat Growing Stage (2018-19)

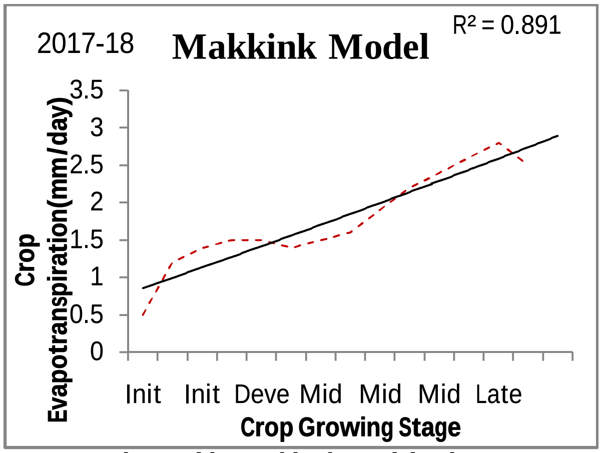

Fig-4 ET obtained by Makkink Model Wheat Growing Stage (2017-18)

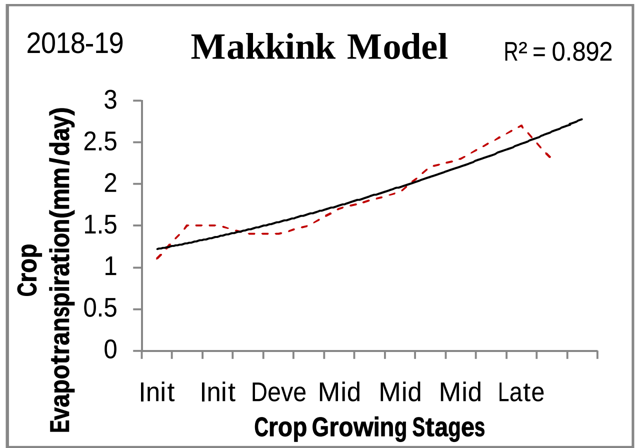

Fig-5 ET obtained by Makkink Model Wheat Growing Stage (2018-19)

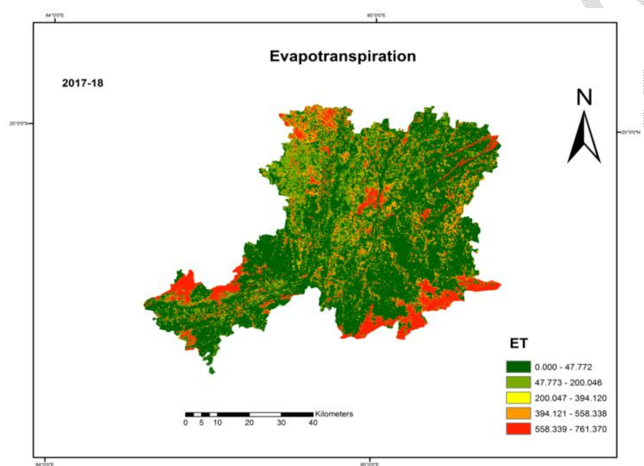

Fig-6 ET rate obtained by satellite data for Wheat

The spatial variation of daily ET_a across the study area is shown in Fig. 6. The estimated daily evapotranspiration ranged from 0 to 781 mm of rabi season with the average ET_a value of about 390 mm for the whole area. Higher values of ET_a appeared in the northern part of the study area, while the southern part showed a lower ET_a. The highest Eta occurred in northern part. And the lowest ET_a appeared in the constructed areas and the overflow lands.

Conclusions

In this study, the application of the SEBAL technique was conducted to map spatial variation in actual evapotranspiration (ET_a) of the Gaya disrict, using Landsat-8 ETM+ image of 2017-2018 rabi season. And the prediction of ET_a was compared with the recorded pan evaporation. The results calculated by SEBAL were comparable with the values derived from Makkink and Penman-Monteith model. This implies the considerable practicability to an estimation of the spatial actual evaporation via SEBAL using satellite imagery with visible, near-infrared, and thermal-infrared bands such as the Landsat ETM+ remote sensing images and routine meteorological measurements of wind speed at least.

Utilizing calculations based on weather characteristics and data acquired from satellites, estimates of evapotranspiration across the Gaya District were obtained. ET was calculated using CROPWAT software and the Penman-Monteith equation. ET was evaluated by the Makkink Model using meteorological data. The comparison's findings reveal that while the Makkink Model data are frequently higher than the ET_{crop} data, the CROPWAT data are typically lower. A less expensive option for estimating evapotranspiration is the availability of high-tech satellite data with 7 ETM+ images taken at intervals of 16 days. The cost of gathering field data and the mistake of missing data is both reduced by the availability of data and information on wheat fields via satellite photos, which may be used at any time. Using satellite data to estimate evapotranspiration will provide a good depiction of global changes.

The variation of estimated ET_a over different kinds of land use was accorded with the evapotranspiration theory, which hints the application of the SEBAL approach with some detailed field information such as crop or land use type. However, since the crops' water requirement or evapotranspiration is different for different growing stages, so the snapshot SEBAL results may not be representative of the annual ET_a. A full time series of SEBAL would be needed to evaluate seasonal differences in ET_a from different vegetation types. Moreover, further studies in the interpretation of ET_a values depends critically on understanding the vegetations' phonology and cropping cycle at the time of image acquisition.

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