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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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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 (ETa) 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. A precise and uniform assessment of reference crop evapotranspiration (ETo) is required due to its crucial role in estimating the crop water needs in irrigated agriculture. The aim of this work was to estimate evapotranspiration (ETc) in a semi-arid environment using freely accessible earth observation

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datasets and a regionally distributed crop coefficient (Kc). Based on a regionally distributed crop coefficient (Kc), the SEBAL and Makkink models were used to anticipate the actual evapotranspiration (ETc). The Makkink model fared adequately when compared to the standard Penman-Monteith model estimate (R^2=0.88), according to statistical tests for model comparison. 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 ETo and Makkink model estimations of ETo are very similar. ETc estimated by SEBAL was also compared with PM ETc with the help of crop coefficient. Additionally, the validation of model's was performed with the analysis of correlation between models ETc 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 etc.

Keywords: Evapotranspiration; SEBAL; CROPWAT; penman-monteith and makkink model.

1. 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 crucial part of the hydrologic cycle and is categorized as water loss through both plants (transpiration) and surface processes (evaporation). Evapotranspiration is the process through which 60–90% of rainwater evaporates back into the atmosphere. Many sections of India have been experiencing the issue of little rainfall and fast diminishing groundwater for a few decades [1-3]. To fulfil the demands of a rising population, India's industries and agricultural sector face an ever-increasing demand for water. More water is needed to irrigate the crops due to the constant expansion of the area covered by agricultural fields. Daily reference evapotranspiration forecasting must be done in real-time for irrigation management and water resource distribution (ETo). Simplified Empirical Regression Method is a category for ET models that use data from remote sensing [4]. To extract the surface fluxes from collections of remotely sensed data, many techniques have been developed. Single Source Energy Balance and Two Source Energy Balance models are the categories under which these techniques fall. The Single Source Energy Balance Model focuses on the following aspects Mapping Evapotranspiration at High Resolution with Internalized Calibration, Surface Energy Balance System, Simplified Surface Energy Balance Index, and Surface Energy Balance Algorithm for Land (SEBAL), all of which were developed by Roerink et al (METRIC) [5,6]. The Two-Source Energy Balance (TSEB) [7], and [8] developed a Two-Source(soil + canopy) Model (TSM) and [9] examined and tested the Two-Source Time Integrated Model (TSTIM), subsequently was named as Atmosphere-Land Exchange Inverse (ALEXI) [10]. [11,12] 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. At the field scale, they discovered that seasonal scale precision was higher (95%) than daily scale accuracy (85%). Using SEBAL, ET estimations for both irrigated and dry land fields [13]. SEBAL has been used effectively in a number of nations, including Spain, Sri Lanka, China, and the United States, for ET estimate, crop coefficient computation, and basin-wide irrigation performance assessment under varied agro-climatic circumstances [14,15].It also has the following drawbacks: it can only be used on flat surfaces, and anchor pixel identification is unclear. Due to all these factors, the SEBAL model is frequently used to calculate ET from agricultural and vegetative environments [16-18]. 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.

1.1 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[19,20].

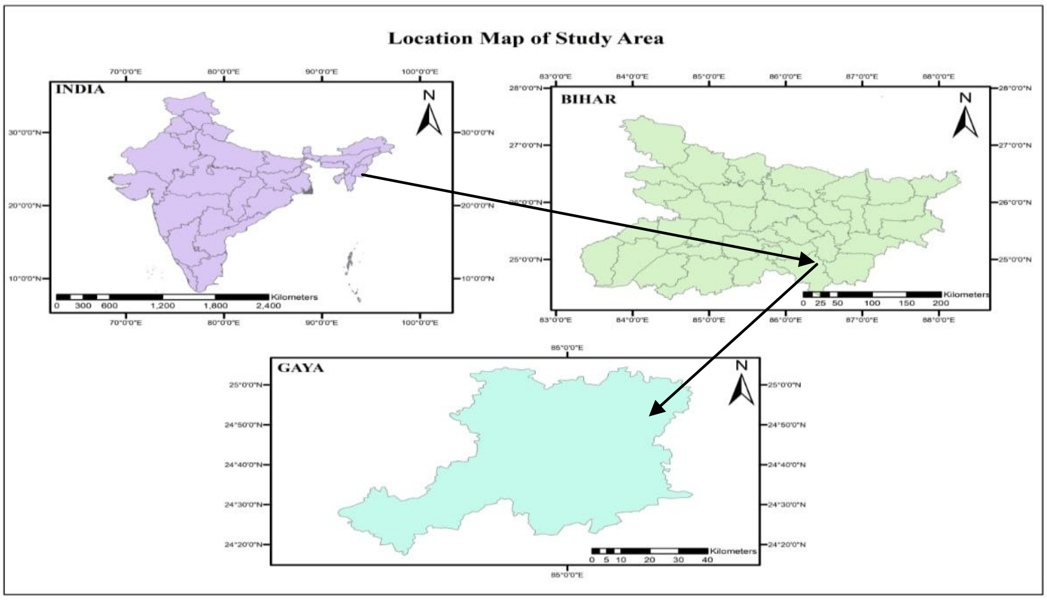

Fig:1 Study Area

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 [21-23]. 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 [24-26]. The data is presented in tabular format. Satellite data were recently employed in studies [27] 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 radiometrically calibrated. Multiplying potential evapotranspiration by the vegetation and moisture coefficient yielded the satellite-estimated evapotranspiration (VMC).

1.2 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 ^{0}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.

2. EVAPOTRANSPIRATION ESTIMATION METHOD

The evapotranspiration estimation method described here is based on the calculation of reference evapotranspiration (ETo), to be multiplied by the crop factor (Kc), resulting in crop evapotranspiration (ETcrop). 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”. ETcrop 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. Several reduced-set methods are employed to estimate ETo, including the Makkink model Ma; [28] (radiation-based), the Hargreaves model Ha; [29], the Hargreaves and Samani model Hs; [30], and the Jensen-Haise model Je; [31]. Other models, such as Priestley-Taylor [32], Blaney-Criddle [33], Turc-radiation [34], and Thornthwaite, can be used to calculate real evapotranspiration [35].

2.1 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 [12] is a parameterization of the energy balance and surface fluxes based on spectral satellite measurements [11]. 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 [36]. 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.

2.2 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:

$$ET\ crop = KC\ ETo \ \ldots\ldots\ldots\ldots \quad (1)$$

Where, KC is the crop coefficient and ETo 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:

$$ETo = 0.62 \times \frac{\Delta}{\Delta+\gamma} \times \frac{Rs}{58.5} - 0.012 \quad \ldots\ldots\ldots\ldots (2)$$

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 $°C^{-1}$) is the psychometric constant.

3. RESULTS AND DISCUSSION

3.1 Performance and Selection of Optimal ETo Model

In order to assess Mankkink Model (Ma) ETo models, the daily ETo was calculated using the PM method. When compared to one another, the ETo pattern shows a similar trend. According to statistical analysis, the Mankkink Model is the most effective approach. The calculated ETo value from the Ma was statistically compared to the PM reference ETo, and the results show that the calculated ETo value from the Makkink is highly like the PM reference ETo, with an R2 value of 0.82, respectively. The estimated ETo by the Ma technique is comparable to the reference ETo based on R2 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 [37].

Table 1. Stage wise ETc value of Makkink Model

Makkink Model							
		2017-18	2018-19			2017-18	2018-19
Sr. No.	Stage	ETc(mm/day)		Sr. No.	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)		Sr. No.	Stage	Etc (mm/day)	
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

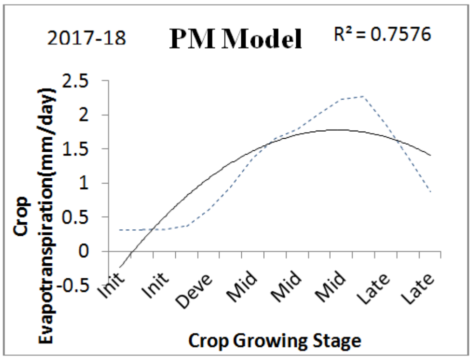

Fig. 2. ETc obtained by PM Model Wheat Growing Stage (2017-18)

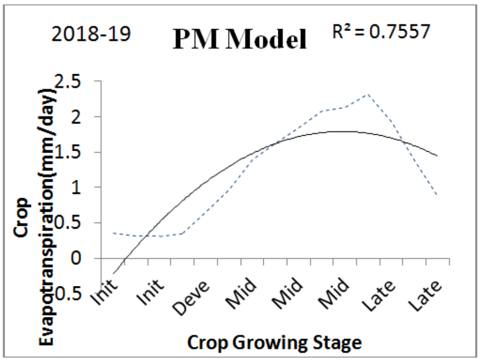

Fig. 3. ETc obtained by PM Model Wheat Growing Stage (2018-19)

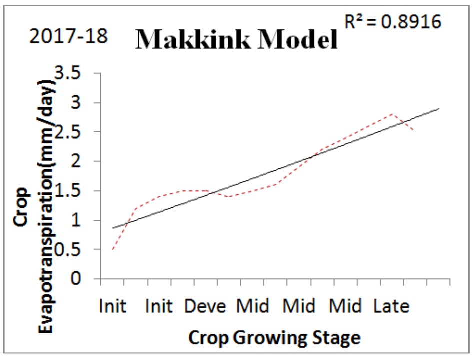

Fig. 4. ET obtained by Makkink Model Wheat Growing Stage (2017-18)

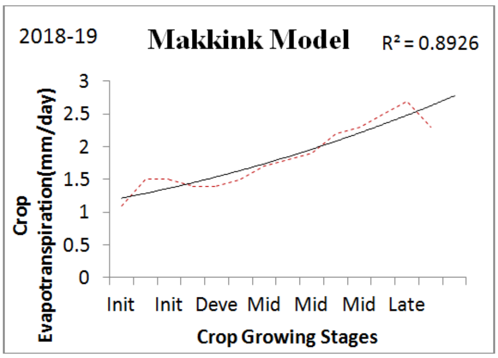

Fig. 5. ET obtained by Makkink Model Wheat Growing Stage (2018-19)

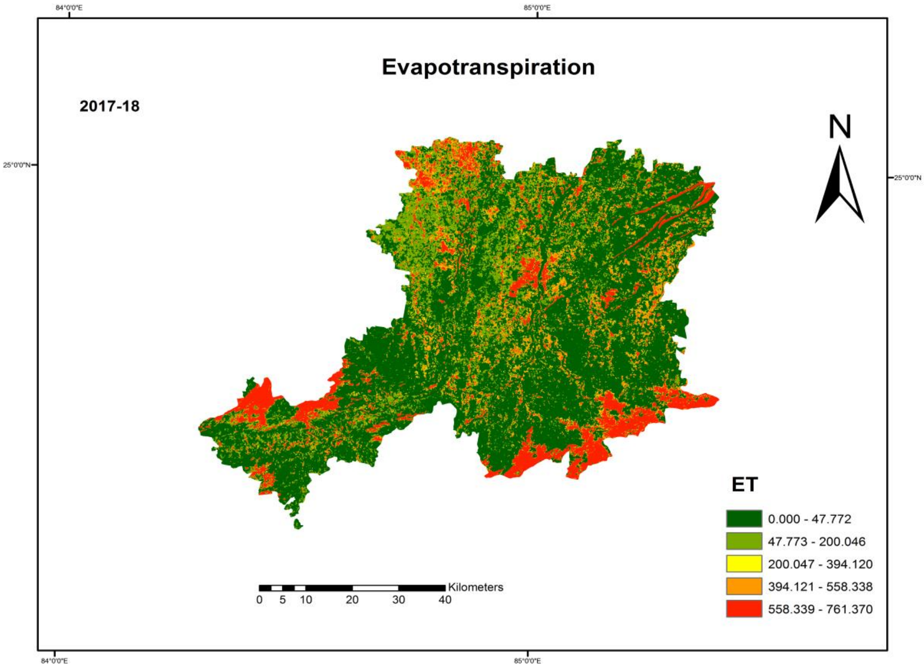

Fig. 6. ET rate obtained by satellite data for Wheat

The spatial variation of daily ETa 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 ETa value of about 390 mm for the whole area. Higher values of ETa appeared in the northern part of the study area, while the southern part showed a lower ETa. The highest Eta occurred in northern part. And the lowest ETa appeared in the constructed areas and the overflow lands.

4. CONCLUSIONS

In this study, the application of the SEBAL technique was conducted to map spatial variation in actual evapotranspiration (ETa) of the Gaya disrict, using Landsat-8 ETM+ image of 2017-2018 rabi season. And the prediction of ETa 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. Using meteorological information, the Makkink Model assessed ET. The results of the comparison show that the CROPWAT data are usually lower, whilst the Makkink Model data are generally greater than the ETcrop data. The availability of high-tech satellite data with 7 ETM+ photos acquired at intervals of 16 days provides a less expensive option for calculating evapotranspiration. The ability to get data and information on wheat fields via anytime-useable satellite photographs lowers the expense of field data collection and the error of missing data. The estimation of evapotranspiration using satellite data will produce an accurate representation of worldwide variations. The variation of estimated ETa 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 ETa. A full time series of SEBAL would be needed to evaluate seasonal differences in ETa from different vegetation types. Moreover, further studies in the interpretation of ETa values depends critically on understanding the vegetations' phenology and cropping cycle at the time of image acquisition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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