

Remote Sensing Based Assessment of Crop Water Requirement of Boro Rice Using SEBAL Model

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Abstract

The study has been done to understand the behavior of crop water requirement of Boro rice in three different physiographic regions namely Mehendiganj, Barisal; Jamalpur sadar, Jamalpur; and Dowarabazar, Sunamganj. The main dominant cropping pattern of Mehendiganj and Jamalpur Sadar Upazila are Boro-Fallow-T. Aman; whereas for Dowarabazar upazila the main dominant cropping pattern is Boro-Fallow-Fallow. Boro water requirement maps have been derived from the 24-hour evapotranspiration data by extrapolating the ET_{24} proportionally to the reference evapotranspiration (ET_r). Evapotranspiration and ET_r values were calculated using the SEBAL algorithm and the FAO Penman-Monteith method respectively. The spatial CWR, on a pixel basis obtained through integration of periodical ET images from 1 January through 15 May, has determined as 301.78 – 623.4 mm (Mehendiganj); 256.44 – 639.73 mm (Jamalpur Sadar); 309.94 – 630.20 mm (Dowarabazar). Of the three research areas, Jamalpur Sadar Upazila has the lowest spatial value of CWR. The CWR has been devalued in some places where there may be mixed spectrum signatures of land cover / use such as roads, fallow lands and settlements.

Keywords: Evapotranspiration, Crop water requirement, SEBAL, Boro rice.

1. INTRODUCTION

Efficiently management of irrigated crop requires proper timing and applying the correct quantity of irrigation water. For this reason it is very important to quantify the specific crop water requirement. Crop water requirements (CWR) are defined as the depth of water [mm] needed to meet the water consumed through evapotranspiration by a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment [12]. CWR is the sum of crop evapotranspiration (ET_c) for the entire crop growth period [12]. Conventional method of evapotranspiration computation is based on climate data [2]. It is difficult to estimate spatio-temporal variations in evapotranspiration based on point observation of meteorological quantities. Better regional estimation of evapotranspiration can be retrieved from satellite images. Surface Energy Balance Algorithm for Land (SEBAL) is a robust remote sensing model that can be applied to estimate actual evapotranspiration (ET_a) [4]. This research used SEBAL model to calculate actual evapotranspiration, which is used to estimate the amount of water consumed by Boro rice. The main purpose of this study is to implement the SEBAL methodology to quantify spatial variation of crop water requirement of Boro rice using satellite data. Research methodology is applied by synthesizing SEBAL method and Boro rice phenology detection method. This study produced Boro crop water requirement map that will help to assess spatio-temporal water use patterns of Boro.

2. MATERIAL AND METHODS

2.1 Study area

The study area called Mehendiganj, Barisal represents the irrigated and non-irrigated coastal areas of Bangladesh. There are nineteen (19) crops that grown in the study area. Wheat, Potato, Mustard, Boro rice, winter vegetable etc. are main rabi crop in Bangladesh. According to BBS [3] Boro rice accounts for nearly 50803.7 hectare are the main crops grown in the Barisal district. Grasspea are the second-most favored crop, covering nearly 41735 hectare of the area. Other winter rabi crop includes Sweet potato, Potato, Mustard and winter vegetables. Boro-Fallow-T. Aman is the first dominant cropping pattern (6000 hectare 26.67% NCA). Grasspea-Fallow-T. Aman (4200 hectare 18.22% NCA) is the second dominant Grasspea-Aus-T. Aman is the third dominant (1000 hectare 4.44% NCA) cropping pattern [8]. In Mehendiganj 81%, 16%, and 2% of Net Cropped Area (NCA) covered by Double Cropped Area (DCA), Tripled Cropped Area (TCA), and annual crop respectively [8].

In Jamalpur sadar Boro-Fallow-T. Aman is the first dominant cropping pattern (25200 hectare 65.81% NCA). Mustard-Boro-T. Aman (3300 hectare 8.26% NCA) is the second dominant and Boro-Fallow-Fallow is the third dominant (100 hectare 0.26% NCA) cropping pattern [9].

In Dowarabazar Boro–Fallow–Fallow is the first dominant cropping pattern (8800 hectare 38.99% NCA). Boro–Fallow–T. Aman (4900 hectare 27.71% NCA) is the second dominant; Fallow–Fallow–T. Aman is the third dominant (4700 hectare 15.26% NCA) cropping pattern [11].

2.2 Data

Applied data in this study consist of Landsat OLI and weather data. Time-series Landsat OLI data of level 2 are employed. The Landsat OLI sensor has 11 spectral bands, seven of which are designed for the study of vegetation and land surfaces. Landsat OLI data downloaded from the USGS Data Center website (<http://glovis.usgs.gov>). Moreover, for detecting rice phenological stages, a complete one season data set of Landsat OLI data for 2021 are applied. The preprocessing parameters required for SEBAL include the Normalized Difference Vegetation Index (NDVI), surface emissivity (ϵ_0), broadband surface albedo (α) and land surface temperature (LST). Cloudless scenes availability of Landsat OLI data over the study site is limited. Three (3) to Four (4) dates of Landsat OLI data for each study area are selected during the period from January to May 2021. In addition to satellite data, SEBAL approach needed some weather data (wind speed, humidity, temperature and solar radiation). For this study, due to lack of other meteorological data daily maximum and minimum temperature data are obtained from three (3) weather stations adjacent to the study area.

Table 1: Landsat OLI Data to Estimate Seasonal Actual Evapotranspiration.

Data	Layer	Spatial Resolution	Temporal Resolution	Purpose	Date (DOY 2021)
Landsat OLI	Surface reflectance, band 1-7	30 m	16-day	Surface albedo, NDVI, SAVI, LAI	12,28,44,76 (Mehendiganj) 3,35,76,115(Jamalpur Sadar) 12,37,76,108,117 (Dowarabazar)
Landsat OLI	Thermal band, 11	60 m	16-day	Land surface temperature & emissivity	12,28,44,76 (Mehendiganj) 3,35,76,115(Jamalpur Sadar) 12,37,76,108,117 (Dowarabazar)

NDVI: Normalized Difference Vegetation Index; SAVI: Soil Adjustment Vegetation Index; LAI: Leaf Area Index

2.3 Typical cropping schedule

Average data on the regular crop stage can be obtained from the crop calendar, although the date of planting / sowing and harvest may vary because of different factors present in different years and geographical areas due to natural variations, farmer's decision, and weather etc. Fig. 2 shows the typical crop calendar of Bangladesh. During the Rabi season, sowing of Boro rice is usually done in November, December and January. February, March and April are considered as the growing stages of the crop. Harvesting is usually done in April and May.

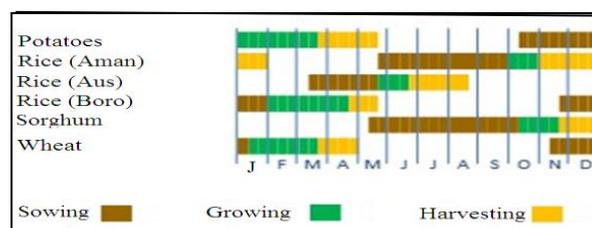


Fig.2 Crop calendar of Bangladesh

2.4 Field survey data

We carried out a field survey in the study areas during the period of March and April, 2021, when most paddy rice fields are in growing phase. For the paddy rice sites, we went into the paddy rice field at least 10 m away from the border in each direction and took the geo-referenced photo. All field survey sites are used in the validation process.

2.5 Estimation of crop evapotranspiration using SEBAL

The Surface Energy Balance Algorithm for Land (SEBAL) which uses minimal observation data to estimate instantaneous ET based on experimental and physical relationships has been used in this study. This algorithm

calculates the energy balance process based on the amount of heat flux and transmitted water vapor in each pixel. Detail procedures of estimating evapotranspiration are listed in following figure 3.

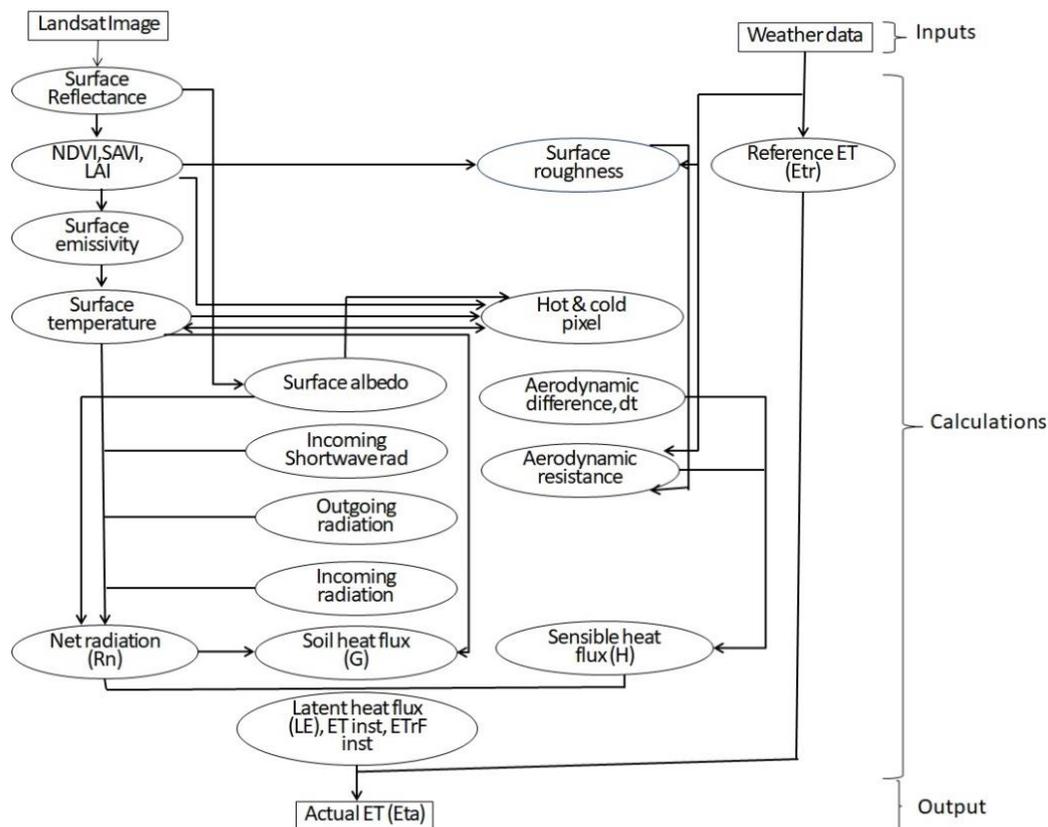


Figure 3: Methodological flowchart for estimating evapotranspiration

Boro water requirement maps have been derived from the 24-hour evapotranspiration data by extrapolating the ET_{24} proportionally to the reference evapotranspiration (ET_r). Other required weather-related data such as humidity, wind speed, solar radiation etc were not available, so the ET_r was determined using the FAO Penman-Monteith method with daily maximum and minimum temperature. To overcome the lack of satellite images on a daily basis, reference ET fraction (ET_rF) are calculated for each of the aforementioned satellite image acquisition dates. The Reference ET Fraction (ET_rF) is defined as the ratio of the computed instantaneous ET (ET_{inst}) for each pixel to the reference ET (ET_r) computed from weather data [1]. Cumulative ET_r data for each period was obtained by summing all the ET_r within the period. Cumulative ET_{period} for each period was computed by using following equation.

$$ET_{period} = ET_rF_{period} \sum_1^n ET_{r-24}$$

Boro water requirement maps were produced by summing all of the ET_{period} values for the Boro season. In this study, the images processing and SEBAL processes are conducted by ERDAS Imagine software. Reference ET is computed in the excel spreadsheet. The Maps are produced by ArcGIS.

3. Results and Discussions

Figure 4 depicts the CWR (mm) of Boro obtained by SEBAL method. The ET_r is estimated on a daily basis during the image-acquisition dates which range from January to May using Bangladesh Meteorological Department (BMD) daily maximum and minimum temperature using FAO Penman-Monteith method. In Mehendiganj ET_r is approximately 3.89 mm d^{-1} at the beginning of the season in January-February, and gradually increased to 5.48 mm d^{-1} around the middle of the growing season in March, then decreased thereafter to 5.28 mm d^{-1} at the end of the season in April-May. In Jamalpur sadar ET_r is approximately 3.39 mm d^{-1} at the beginning of the season in January-February, and gradually increased to 5.16 mm d^{-1} around the middle of the growing season in March-April. In Dowarabazar ET_r is approximately 3.66 mm d^{-1} at the beginning of the season in January-February, and gradually increased to 5.32 mm d^{-1} around the middle of the growing season in

March- April. The CWR is estimated for Boro rice grown at the study area. The spatial CWR on a pixel basis obtained through integration of periodical ET images from 1 January through 15 May is determined as 301.78 – 623.4 mm (Mehendiganj); 256.44 – 639.73 mm (Jamalpur Sadar); 309.94 – 630.20 mm (Dowarabazar), which is similar to the result achieved by other researchers. Hossain et al. (2021) [7] found that the average CWR of Boro rice of Bangladesh in 2015 was 405 mm and Maulvibazar and Chandpur respectively recorded the highest demand for 445 mm and a minimum of 358 mm of CWR. Shahid S. (2011) [13] found that the potential value of CWR of Boro rice in the northwestern part of Bangladesh was 423 mm to 483 mm. Hossain et al. (2017) [6] showed that the average evapotranspiration value of Boro rice (Lifespan 150-day) of northwest hydrological region of Bangladesh was 505 mm. In the study area the CWR has been devalued in some places where there may be mixed spectrum signatures of land cover / use such as roads, fallow lands and settlements.

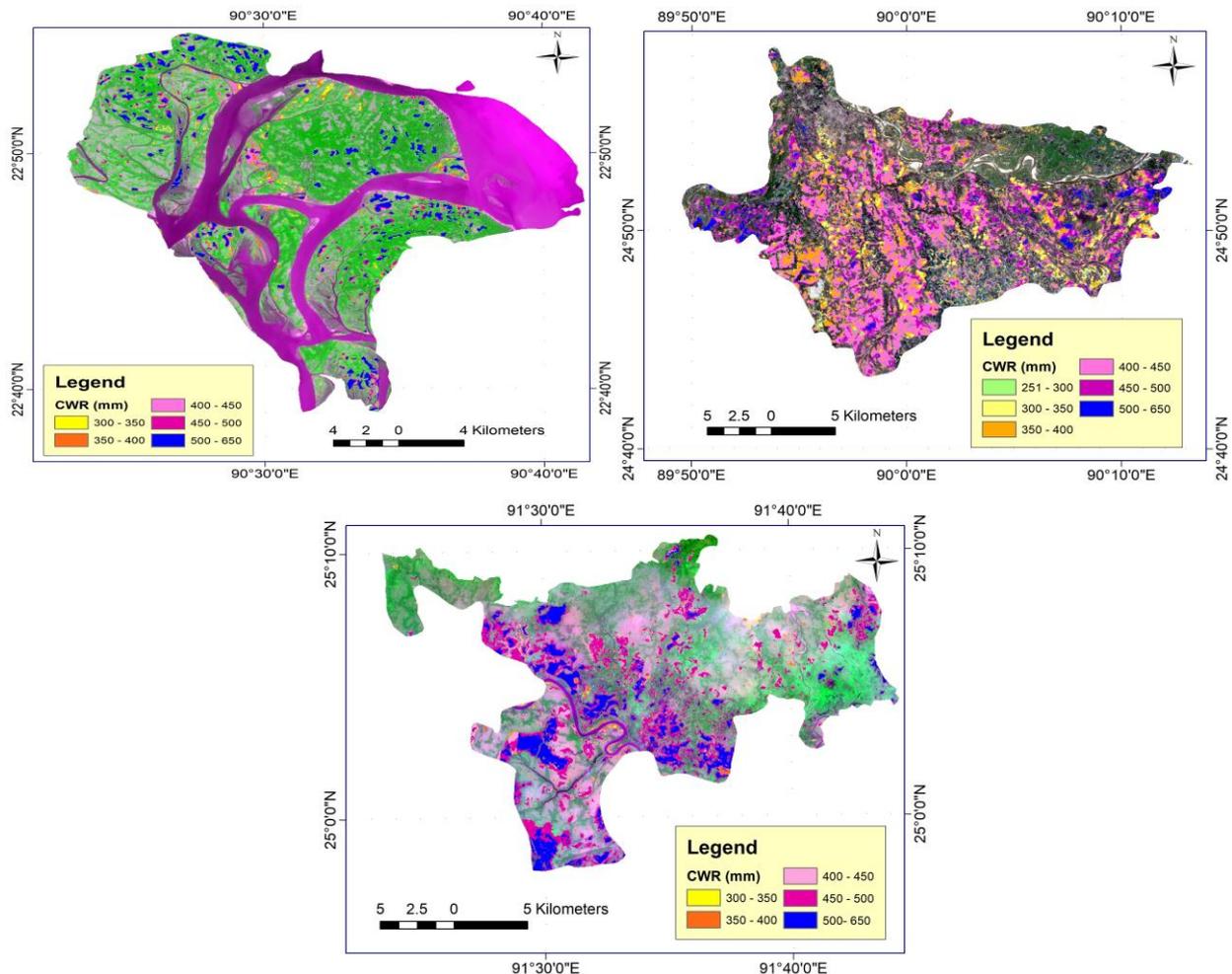


Fig. 4 Boro crop water requirement map

4. Conclusion

Evapotranspiration (ET), one of the driving parameters of the Earth's aquatic and energy cycle, needs to be fully understood for sustainable water management. Over the past few decades, Remote Sensing technology has been playing an increasingly important role in determining the value of ET. This paper evaluates ET using Surface Energy Balance Algorithm for Land (SEBAL). The study area includes three different physiographic regions Mehendiganj, Barisal; Jamalpur sadar, Jamalpur; and Dowarabazar, Sunamgangj. The crop water requirement (CWR) of Boro rice, one of the main agricultural crops, has been estimated. The spatial CWR on a pixel basis obtained through integration of periodical ET images from 1 January through 15 May is determined as 301.78 – 623.4 mm (Mehendiganj); 256.44 – 639.73 mm (Jamalpur Sadar); 309.94 – 630.20 mm (Dowarabazar). The CWR has been devalued in some places where there may be mixed spectrum signatures of land cover / use such as roads, fallow lands and settlements. Future research plans should have dual goals of increasing water and land productivity using innovative water management techniques and agricultural practices.

References

- [1] Allen, R.G., Tasumi, M., Trezza, R., Waters, R., Bastiaanssen, W.G.M., 2002. Surface Energy Balance Algorithms for Land, Advance Training and User's Manual–Idaho Implementation, Version 1. 97 p.
- [2] Allen RG, Pereira S, Raes D, Smith M., 1998, Crop evapotranspiration, guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Rome, Italy: Food and Agricultural Organization of United Nations (FAO).
- [3] Bangladesh Bureau of Statistics (BBS), 2020, Yearbook of Agricultural Statistics-2019, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh.
- [4] Bastiaanssen, W.G.M., Menenti, M., Feddes, R.A., Holtslag, A.A.M., 1998, A Remote Sensing Surface Energy Balance Algorithm for Land (SEBAL). 1. Formulation. *Journal of Hydrology*, 212-213:198212.
- [5] Biradar, C.M., Thenkabail, P.S., Platonov, A., Xiao, X., Geerken, Noojipady, R., Hugh,T., Vithanaged,J., 2008, Water productivity mapping methods using remote sensing, *Journal of Applied Remote Sensing*, Vol. 2, 023544.
- [6] Hossain, M., Yesmin, S., Maniruzzaman, M., and Biswas, J., 2017, Irrigation scheduling of rice (*Oryza sativa* L.) using CROPWAT model in the Western region of Bangladesh, *The Agriculturists*, vol. 15, no. 1, pp. 19–27.
- [7] Hossain, M.B., Roy,D., Maniruzzaman, M., Biswas, J.C., Naher, U.A., Haque, M. M., and Kalra, N., 2021, Response of Crop Water Requirement and Yield of Irrigated Rice to Elevated Temperature in Bangladesh, Volume 2021,Article ID 9963201, <https://doi.org/10.1155/2021/9963201>
- [8] Ibrahim, M., Zaman, M. A .U., Mostafizur A. B.M., and Shahidullah, S.M., 2017, Diversity of Crops and Land Use Pattern in Barisal Region, *Bangladesh Rice J.* 21 (2): 57-72.
- [9] Khatun, A., Parvin, N., Dewan, M.M.R., and Saha, A., 2017, Cropping Patterns in Mymensingh Region: Diversity, Constraint and Potential, *Bangladesh Rice J.* 21 (2): 217-235.
- [10] Molden, D. J., 1997, Accounting for water use and productivity, SWIM Paper 1, IWMI, Colombo, 1-16.
- [11] Muttaleb, M. A., Shahidullah, S.M., Nasim, M., and Saha, A., 2017, Cropping Systems and Land Use in Sylhet Region, *Bangladesh Rice J.* 21 (2): 273-288.
- [12] Pereira, L.S. and Alves, I., 2013, Crop Water Requirements, Universidade Te´cnica de Lisboa, Lisboa, Portugal, Elsevier Inc. Earth Systems and Environmental Sciences <http://dx.doi.org/10.1016/B978-0-12-409548-9.05129-0>.
- [13] Shahid, S., 2011, Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh, *Climatic Change*, vol. 105, no. 3-4, pp. 433–453.