

NDVI-rainfall correlation and irrigation water requirement of different crops in the Sone river-command, Bihar

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सार – बदलती हुई जलवायविक परिस्थितियाँ वनस्पति को प्रभावित करती हैं और यह बड़े पैमाने पर मानव जाति एवं पारिस्थितिकी के लिए संकट खड़ा करने वाली हैं। इस शोध पत्र में सोन नदी कमांड के मासिक वर्षा और एन डी वी आई (सामान्यकृत अंतर वनस्पति सूचकांक) आँकड़ों के बीच के संबंध को समझने का प्रयास किया गया है। सिंचाई के समय का निर्धारण और जल का इष्टतम प्रबंधन के लिए फसलों की सिंचाई के लिए जल की आवश्यकता का अनुमान लगाना अनिवार्य रूप से आवश्यक है। इस दिशा में अध्ययन के लिए सोन कमांड में चावल, गेहूँ और मक्का के लिए कुल सिंचाई की आवश्यकता का अनुमान लगाया गया है। सोन कमांड में भोजपुर और सासाराम के चार वर्षों (2012-2015) के माध्यम मौसम विज्ञान आँकड़ों का उपयोग करके एफ ए ओ पेनमन-मोंटीथ पद्धति द्वारा दैनिक वाष्पोत्सर्जन (ET_0) का अनुमान लगाया गया है। परिणाम दर्शाते हैं कि खरीफ ऋतु में वर्षा और एन डी वी आई के बीच अच्छा सहसंबंध रहा है। वार्षिक औसत संदर्भ वाष्पोत्सर्जन (ET_c) भोजपुर में 3.44 मि.मी. प्रतिदिन और सासाराम में 3.58 मि.मी. प्रति दिन पाया गया। खरीफ ऋतु में चावल की फसल के लिए कुल फसल वाष्पोत्सर्जन (ET_c) अधिकतम और रबी के मौसम में मक्का की फसल के लिए सबसे कम पाया गया शीतकालीन गेहूँ के लिए कुल सिंचाई जल की आवश्यकता सासाराम में अधिकतम 133.66 मि.मी. और भोजपुर में 112.4 मि.मी. थी और ग्रीष्मकालीन चावल के लिए न्यूनतम 35.6 मि.मी. एवं 61.8 मि.मी. क्रमशः भोजपुर और सासाराम में थी। सोन कमांड में वर्षा के साथ एन डी वी आई के उच्च सहसंबंध का उपयोग खरीफ मौसम के दौरान कुल सिंचाई आवश्यकता (NIR) की आवश्यकता को समझने के लिए एक विकल्प के रूप में किया जा सकता है।

ABSTRACT. The changing climatic conditions affect the vegetation posing a threat to ecology of the region in general and mankind at large. In this paper, an attempt has been made to understand the relationship between monthly precipitation and the NDVI (Normalised Difference Vegetation Index) data of the Sone river command. For irrigation scheduling and optimal management of water, estimation of irrigation water requirement of the crops is essentially required. Towards this direction, the study has been made to estimate the net irrigation requirement for rice, wheat and maize in the Sone command. The estimation of daily reference evapotranspiration (ET_0) by FAO Penman-Monteith method was done for 4 years (2012-2015) using mean meteorological data of Bhojpur and Sasaram in the Sone command. The results show that a good correlation exists between rainfall and NDVI in the kharif season. The mean annual reference evapotranspiration (ET_0) was found 3.44 mmday⁻¹ at Bhojpur and 3.58 mmday⁻¹ at Sasaram. The total crop evapotranspiration (ET_c) was found to be maximum for rice crop in kharif season and lowest for maize crop in rabi season. Net irrigation water requirement was maximum for winter wheat of 133.66 mm at Sasaram and 112.4 mm at Bhojpur and lowest in summer rice of 35.6 and 61.8 mm at Bhojpur and Sasaram respectively. The high correlation of NDVI with rainfall in Sone command can be used as an alternative to understand the requirement of net irrigation requirement (NIR) during the kharif season.

Key words – NDVI, Reference evapotranspiration (ET_0), Crop evapotranspiration (ET_c), Net irrigation requirement (NIR).

1. Introduction

Water is one of the most essential natural resource, which plays a vital role in maintaining biodiversity, our health, social welfare and our economic development (Donald, 1968). There is a growing reliability of studying spatial changes in vegetation using remote sensing. The estimation of reference evapotranspiration (ET_0) play an important role in estimating net irrigation requirement of

crops for agricultural planning, irrigation scheduling, regional water balance studies and agro-climatic zoning (Samani, 2000). The reference evapotranspiration is defined as the loss of water to the atmosphere by evaporation and transpiration from an extended surface of 8-12 cm tall green grass cover, usually well-watered, actively growing and completely shading the ground. By applying a crop coefficient (K_c) values, this ET_0 can be computed to estimate the crop evapotranspiration (ET_c),

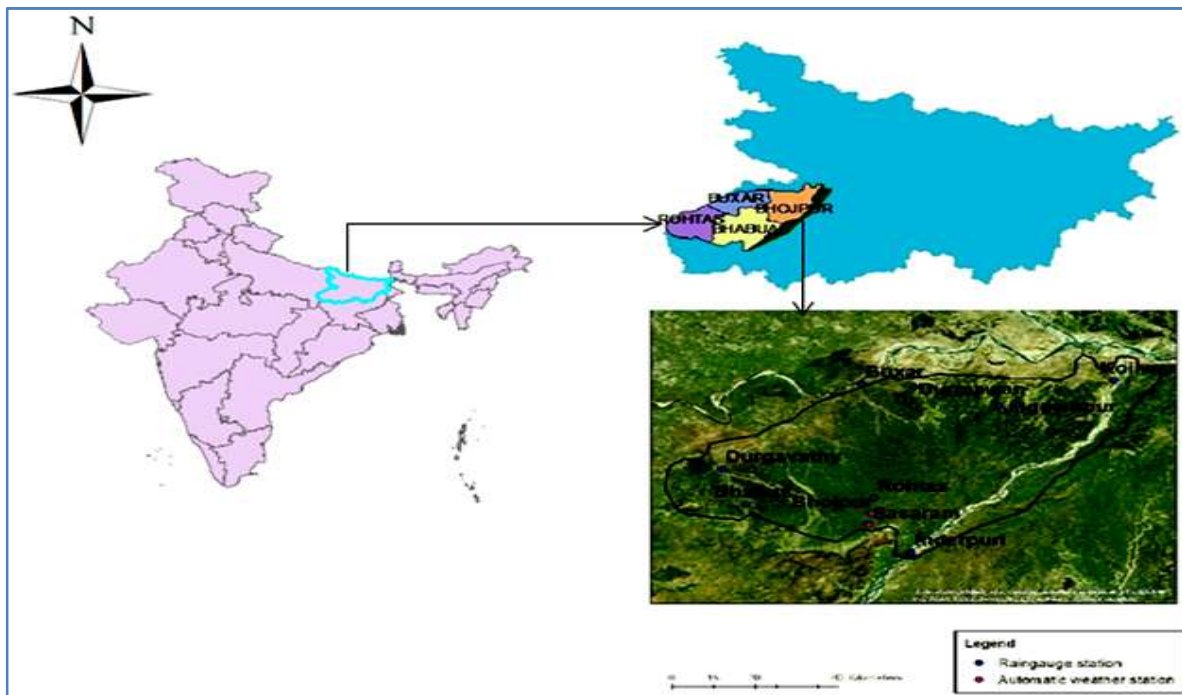


Fig. 1. Sone command area

(Doorenbos and Pruitt, 1977). The crop coefficient (K_c) is obtained with relation to plant type, maturity of plant and factors such as soil type (Jensen *et al.*, 1990). The adaptation of optimal amount of water and correct timing of application is very essential for scheduling irrigations to meet the crop's water use demands and for optimum crop production. As suggested by Brutsaert (1982) and Jensen *et al.* (1990) various techniques had been suggested for calculating reference evapotranspiration. Reference evapotranspiration is either calculated by weighing lysimeter or estimated from climatological data or water balance method. The different methods of ET_0 estimation can be grouped into (i) temperature methods, (ii) radiation methods, (iii) combination theory types and (iv) pan evaporation methods. The combination of energy balance and aerodynamic equations generally provides the most accurate results as a result of their foundation in physics and basis of rotational relationship (Jensen *et al.*, 1990). The evapotranspiration demand depends on variables such as: temperature, solar radiation, humidity, wind-speed and plant characteristics such as stomatal conductance and leaf area index (Priya *et al.*, 2014). Among all the methods Penman-Monteith method (Allen *et al.*, 1998) has been reported to yield more accurate reference evapotranspiration (ET_0) estimates across a wide range of climate conditions (Jensen *et al.*, 1990). Mehta and Pandey (2015) used Penman-Monteith method for estimation of reference evapotranspiration for wheat and maize crop in Gujarat. Net irrigation requirement for

different crops in kharif, rabi and summer seasons in Gujarat was estimated by Khandelwal and Dhiman (2015). Hence, Penman-Monteith method was adopted for (ET_0) estimation in the study area which was used for the estimation of net irrigation water requirement of different crops in different crop growing seasons. The advances made in the field of satellite remote sensing in terms of temporal, spatial and spectral radiometric resolutions lead to more strengthened and particular research on classification of crop, crop condition simulation and yield estimation. The satellite-derived values of NDVI are often used as an indicator of vegetation health both spatially and temporally (Mingjun *et al.*, 2007). Broad study on NDVI and its relationship with rainfall has been accomplished from time to time by various researchers (Ghorbani *et al.*, 2012; Richard and Pocard, 1998; Wang *et al.*, 2001; Acharjee *et al.*, 2012; Bhunia *et al.*, 2012; Chandrasekar *et al.*, 2006; Dubey *et al.*, 2012; Milesi *et al.*, 2010).

There is a need to generate and provide scientific information on the trend of seasonal vegetation and how well current practices are sustaining those vegetation. Frequently used method to find the trend in rainfall, NDVI and temperature is by Mann-Kendall test. This test is used to detect significant monotonic trend in time varying data. It was utilized in this investigation since it is a non-parametric positioned based technique which is strong to the impact of limits and useful for use with skewed factors. Mann Kendall test has been widely used for trend

TABLE 1
Range of data set for the study

Statistic	IMD Rainfall (mm)	NDVI
Maximum	1069.4	0.775
Minimum	0.10	0.225
Std.deviation	173.29	0.141
Average	241.22	0.490

analysis in hydrology and climatology (Fowler and Archer, 2006; Hamid *et al.*, 2013; Marco *et al.*, 2003; Pant and Kumar, 1997; Shrestha *et al.*, 1999; Gocic and Trajkovic, 2013). In places where rainfall coincides with the growing season the correlation shows higher value. Precipitation is the key factor for vegetation growth (Mingjun *et al.*, 2007). This study utilises satellite data and various meteorological data to study the temporal change characteristics of NDVI with respect to the precipitation and the relationship between NDVI and net irrigation water requirement in the Sone-river command (Bihar).

2. Materials and method

2.1. Study area and data acquisition

The examination region covers the Sone Irrigation Project (Fig. 1) in Bihar, India. The Sone venture is a diversion scheme worked over the waterway Sone.

The aggregate catchment zone of the waterway is 71,259 sq. km, of which 17,651 sq. km lies in Bihar. The remaining 53,608 sq. km lies in Chhattisgarh, Madhya Pradesh, Uttar Pradesh and Jharkhand states of India. The stream is a tributary of the waterway Ganga. The zone gets around 1100 mm of rain, more than 80% of which happens over the rainy season (June to September). Soils are alluvial and vary from light to heavy- textured clays in the top layer with coarse substrata. Plain in geography, it consistently slants towards the Ganga River. The above features make the zone perfect for watered (irrigation) farming. In this study, the command has been divided into four parts based on the districts Bhabua, Rohtas, Bhojpur and Buxar which lies on the right side of Sone River for the NDVI analysis. Table 1 shows the statistics of rainfall data for 8 stations obtained from IMD, Pune and the NDVI data obtained from Bhuvan data portal of NRSC/ISRO for the period 2012-2016. Rainfall data of Buxar, Koilwar, Bhabua, Durgavathy, Durmawan, Jagdishpur and Rohtas were available for the

period 1985-2011 and for Inderpuri the data availability was for the period 1985-2015. The weather data pertaining to rainfall, temperature, relative humidity etc. of the stations were collected from India Meteorological Department, Pune for a period of 4 years (2012-2015). The information utilized for computation of ET_0 are topographical directions of the station (*i.e.*, latitude, longitude and height above mean ocean level), maximum and minimum temperature ($^{\circ}C$), relative moistness greatest and least (%), wind speed (km/day) and sunshine hours. Since the availability of rainfall data for most of the stations was only for the period 1985-2011 the rainfall data of Inderpuri has been utilised as the rainfall for the command due to the data availability and the similar trend in rainfall occurring in the Sone-river command (Fig. 2).

2.2. Methodology

The FAO Penman-Monteith method (Allen *et al.*, 1998) was used to compute the reference evapotranspiration (ET_0). In this study, CROPWAT 8.0 model developed by FAO based on Irrigation and Drainage Paper of FAO 56 was used in calculating reference evapotranspiration (ET_0) using Penman-Monteith method.

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T + 273} \times U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where, ET_0 is the reference evapotranspiration, R_n is the net radiation at crop surface, G is soil heat flux, γ is psychrometric constant, U_2 is wind speed at 2 m height, e_s is saturation vapour pressure, e_a is actual vapour pressure, $(e_s - e_a)$ is the saturation vapour pressure deficit, Δ is slope vapour pressure curve and T is the temperature.

USDA Soil Conservation Service Method (USDA S.C.S.) method was used for calculating effective rainfall. It was calculated using the rainfall of the stations in CROPWAT Model. Rice is the primary crop yield in the territory during kharif season and wheat in rabi season. Harvests of other crops are covered under 2% of culturable command area (CCA). Two different stations Sasaram and Bhojpur were selected for the study. The major crops of the area, rice and kharif maize in the kharif season (June-September), wheat and rabi maize in rabi season (November-March) were studied at both the stations. Evapotranspiration (ET_c) was calculated using the crop coefficient approach (Table 2). In this method from the estimated ET_0 , total water requirement/crop evapotranspiration (ET_c) was worked out for specific crops using equation 2.

$$ET_c = K_c(ET_0) \quad (2)$$

TABLE 2

Stage wise crop coefficients (K_c), crop duration and height of different crops in Bihar (Allen *et al.*, 1998)

Crops	K_{cini}	K_{cmid}	K_{cend}	Duration (days)	Height (m)
Kharif season					
Rice	1.1	1.2	1.05	119	1.0
Rabi season					
Wheat	0.4	1.15	0.41	120	1.0
Maize	0.3	1.2	0.35	105	2.0

TABLE 3

NDVI statistic of the entire time series (2012-2016)

Study area	Mean	Std. deviation	Max	Min
Sone command	0.492	0.141	0.725	0.24
Bhabua	0.488	0.146	0.72	0.225
Rohtas	0.5	0.156	0.775	0.225
Buxar	0.484	0.138	0.69	0.25
Bhojpur	0.473	0.121	0.685	0.25

Net irrigation requirement (NIR) of the crop was determined by the following relationship:

$$NIR = ET_c - R_{eff} \tag{3}$$

where, NIR = net irrigation requirement (mm); ET_c = potential crop evapotranspiration (mm/day); R_{eff} = effective rainfall (mm). Effective rainfall (R_{eff}) was determined by evaporation precipitation ratiomethods. This method gives the value of effective monthly rainfall and mean monthly consumptive use (ET_c). If the NIR values are negative (for $R_{eff} > ET_c$), then the NIR of the crops was computed by adding the monthly NIR of corresponding crops.

The monitoring of the crop is done using vegetation indices which are obtained from technology using remote sensing. Significant research on vegetation indices had shown that NDVI is a very reliable index. NDVI stands for normalised difference vegetation index. It utilises multispectral remote sensing data to generate vegetation index. The bands of satellite responsive to vegetation information are near infrared and red bands. The higher the difference between near-infrared and red reflectance, the higher will be the vegetation in the area. The algorithm defined for calculating NDVI is the ratio of subtraction of the red reflectance values from the near-infrared and dividing it by the sum of near-infrared and red bands.

$$NDVI = (NIR - RED)/(NIR + RED) \tag{4}$$

where, NIR and RED are the reflectance in the near infrared and red region wavelengths respectively, of the electromagnetic spectrum. To establish the correlation rainfall data was obtained for a period of four years (2012-2015) of two meteorological stations of Bihar. The NDVI data was obtained from BHUVAN data portal and the values were obtained by extracting in GIS domain by utilising the monthly NDVI products of Oceansat-2 Ocean Color Monitor (OCM2) Global Area Coverage (GAC) sensor and MODIS NDVI data obtained from from Mahalanobis Crop forecasting Center of ICAR. The correlation of the IMD rainfall data was analysed with respect to the monthly NDVI data during the kharif season. Then study was done for understanding the relationship between rainfall and NDVI in monthly time scale.

Mann-Kendall test: This test is frequently utilised to detect monotonic trend, trends in environmental data, hydrological data or weather data. The chance of detection of series as having a trend is more. The null Hypothesis, H_0 symbolizes that the data came from population with independent realizations and are distributed identically. Let x_1, x_2, \dots, x_n represent n data points where x_j represents the data point at time j . Then the Mann-Kendall statistic (S) is defined as follows (Salas, 1993)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n sgn(x_j - x_k) \tag{5}$$

where, the number of sample points is denoted by n , x_j and x_k are the time varying sample values, where, $j > k$ and assuming $x_j - x_k = \theta$, $sgn(\theta)$ is the sign function as,

$$sgn(\theta) = \begin{cases} +1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \tag{6}$$

where, a very high positive value of (S) is an indicator of an increasing trend and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n , to statistically quantify significance of the trend. P -value is Mann Kendall statistical parameter symbolizing the probability value. This value tests the hypothesis whether it is correct or not. If the hypothesis is wrong, the trend is significant and it is declined. P -value < 0.05 signifies that there is trend and if Kendall's tau value is positive it signifies an increasing trend and if tau value is negative the trend is decreasing.

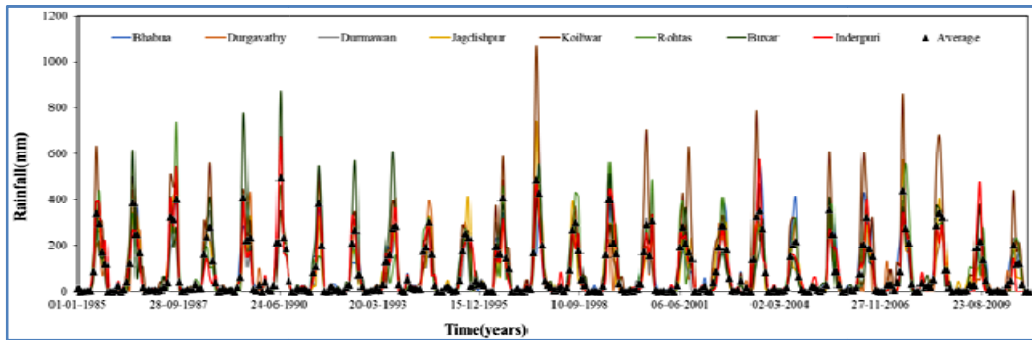


Fig. 2. Rainfall trend in Sone command for the period 1985-2010

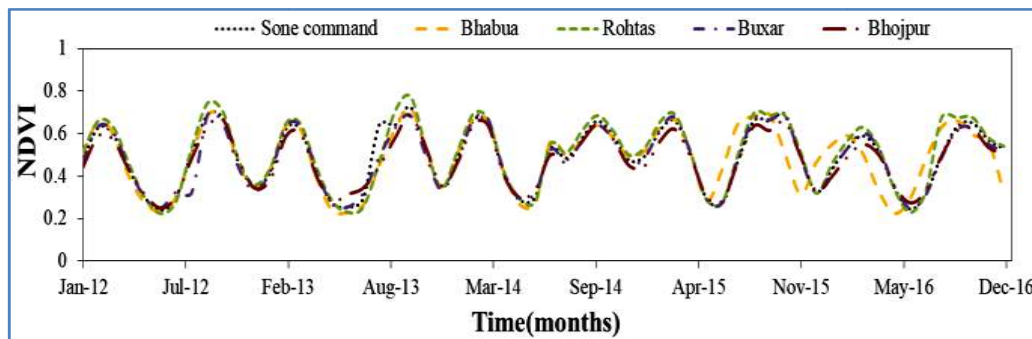


Fig. 3. NDVI trend for all the months of the year 2012-2016

P -value > 0.05 signifies that there is no monotonic trend. In this study Mann Kendall test has been carried out using XLSTAT 2018 which uses exact method for the calculation of p -value.

3. Results and discussion

The NDVI values emphasized a number of temporal variations in greenness in the Sone-river command as a whole as well as the different stations in the command area from 2012-2016 (Fig. 3). The NDVI dynamics of the different parts of the study area suggests that the patterns of different parts were similar to overall NDVI pattern, *i.e.*, Sone river-command. The peak NDVI generally occurred after June and December.

NDVI statistic of different sites selected is represented in Table 3. It shows that Rohtas is showing highest value of mean NDVI value, *i.e.*, 0.5 (standard deviation 0.156) followed by the Sone command in a whole that had a mean value of NDVI 0.492 (standard deviation 0.141). Rohtas shows the highest value over the period selected.

A trend detection using Mann-Kendall test suggested that the NDVI values of the study area were showing no

sign of trend (p -value is greater than 0.05) for the period 2012-2016 and is shown in Table 4.

Relationship between monthly rainfall and significance of relationship between monthly rainfall and vegetation was performed firstly based on determination of linear correlation between monthly NDVI and monthly rainfall. Tables 5&6 indicates correlation coefficient between average rainfall and average NDVI of various stations of the months June, July and August during the period 2012-2015. The values of correlation coefficients obtained from OCM 2 were in the range of 0.79-0.99. Also the MODIS derived NDVI correlation with rainfall varied from 0.49-0.98. The high value of correlation between rainfall and NDVI suggests that both are highly dependent on one another. In Table 7, the variation of ET_0 during different months at Sasaram and Bhojpur stations of Bihar are presented. At both the stations the lowest reference evapotranspiration was in the month of January and highest in the month of May. The mean monthly reference evapotranspiration at Sasaram was slightly higher than Bhojpur in all the months excluding April and May and is clearly shown in Fig. 4.

That part of the total rainfall which satisfies the needs of crops and can be used in the production of crops

TABLE 4

Trends (NDVI change per year) of the NDVI time series using Mann-Kendall test

Study area	Kendall's tau	p-value
Sone command	0.054	0.549 (Insignificant)
Bhabua	0.052	0.561 (Insignificant)
Rohtas	0.069	0.444 (Insignificant)
Buxar	0.076	0.400 (Insignificant)
Bhojpur	0.073	0.418 (Insignificant)

TABLE 5

Coefficients of correlation between NDVI and monthly rainfall data (OCM 2)

Year	Sone command	Bhabua	Rohtas	Buxar	Bhojpur
2012	0.81	0.82	0.79	0.97	0.82
2013	0.99	0.99	0.99	0.99	0.99
2014	0.96	0.97	0.95	0.98	0.97
2015	0.86	0.79	0.83	0.90	0.84

TABLE 6

Coefficients of correlation between NDVI and monthly rainfall data (MODIS)

Year	Sone command	Bhabua	Rohtas	Buxar	Bhojpur
2012	0.89	0.86	0.9	0.81	0.98
2013	0.98	0.98	0.97	0.98	0.81
2014	0.7	0.71	0.67	0.49	0.97
2015	0.64	0.51	0.69	0.52	0.87

TABLE 7

Mean monthly reference evapotranspiration (ET₀) (mm day⁻¹) at Sasaram and Bhojpur

Months	Sasaram	Bhojpur
January	1.65	1.32
February	2.47	2.25
March	3.76	3.73
April	4.78	4.9
May	5.57	5.72
June	4.98	4.87
July	4.66	4.22
August	3.9	3.56
September	3.95	3.8
October	3.24	3.23
November	2.34	2.27
December	1.65	1.37

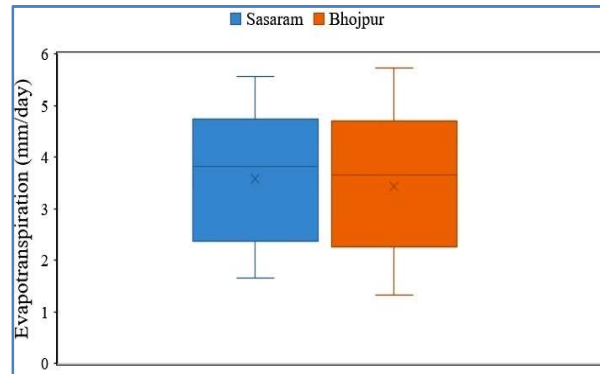


Fig. 4. Box plot of evapotranspiration

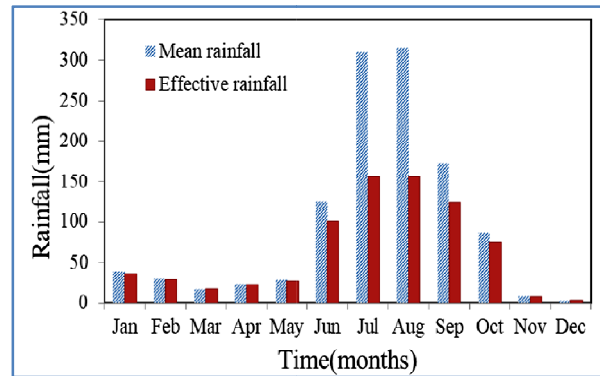


Fig. 5. Bar chart of effective rainfall and mean monthly rainfall

is called effective rainfall. In Fig. 5 the bar chart is made of effective rainfall and mean rainfall. Effective rainfall had shown an increasing trend generally after the month of May with the peak in the month of August.

In kharif season crops, crop evapotranspiration for rice crop was 496.06 mm and 470.47 mm at Sasaram station and Bhojpur station. Net irrigation water requirement for rice crop was 61.18 mm and 35.59 mm respectively for Sasaram station and Bhojpur station. The low value of net irrigation requirement of the rice crop can be due to the higher available moisture in the soil due to the monsoon rainfall in the Sone command. The total seasonal crop evapotranspiration varied between 194.5 and 215.76 mm for wheat and 146.23 and 170.46 mm for maize crop at Sasaram station and Bhojpur station respectively. The net irrigation water requirement for wheat crop varied between 112.4 and 133.66 mm and for maize crop it varied between 72.76 and 96.98 mm at Sasaram and Bhojpur station location respectively. The comparatively higher value of the wheat and maize can be attributed to the fact that the area receives very less rainfall or no rainfall during the winter season (Table 8).

TABLE 8

Total crop evapotranspiration (ET_c), effective rain and net irrigation water requirement of different crops at Sasaram and Bhojpur

Crop	Sasaram			Bhojpur		
	ET_0 (mm)	Effective rain (mm)	Irrigation water requirement (mm)	ET_c (mm)	Effective Rain (mm)	Irrigation water requirement (mm)
Kharif season						
Rice	496.06	434.87	61.18	470.47	434.87	35.59
Winter season						
Wheat	215.76	82.1	133.66	194.5	82.1	112.4
Maize	170.46	73.47	96.98	146.23	73.47	72.76

Also in the months of June, July and August the net irrigation requirement was very less as compared to the rabi season. This further suggests that if the correlation between NDVI and rainfall is high the water requirement will be less.

4. Conclusions

In this study, FAO Penman-Monteith was used to find the evapotranspiration in the Sone river-command for the period 2012-2015. It was observed that lowest reference evapotranspiration was in the month of January and highest in the month of May and there was slightly higher mean monthly reference evapotranspiration at Sasaram station than Bhojpur in all the months excluding April and May. The crop evapotranspiration ET_c and net irrigation water requirement was found to vary not only with the crops, but also with the season and locations as well. Rice in kharif season had the highest crop evapotranspiration and lowest net irrigation water requirement. Winter wheat crop evapotranspiration was lesser than that of rice but net irrigation water requirement was highest for wheat since the area receives very less rainfall in winter. The selection of crops and also the scheduling of irrigation in Bihar for different crops can be done depending on the net irrigation water requirement. Monthly correlation of rainfall and $NDVI$ during kharif season suggests that the values were highly correlated. In addition, since during the kharif season rice was the major crop and the NIR requirement was very less, it suggested that if the correlation was showing positive value the NIR would be less. In addition, this study can be utilised for extracting seasonal cropping patterns as the trend showed an increase during the kharif and rabi season.

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