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Climatic water balance for assessment of growing season in the eastern Indian state of Bihar

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सार – सतत फसल उत्पादन सुनिश्चित करने के लिए किसी क्षेत्र में जल उपलब्धता की अवधि का सही मूल्यांकन महत्वपूर्ण है। इस पृष्ठभूमि में, बारिश की स्थिति के अनुसार प्रभावी फसल उपयुक्तता योजना के लिए जलवायविक जल संतुलन मॉडल को लागू करके भारत के पूर्वी राज्य बिहार के लिए फसल की बुआई की शुरुआत, समाप्ति और विकास अवधि की लंबाई (LGP) का मूल्यांकन करने के लिए कृषि-जलवायविक अध्ययन किया गया। इस प्रयोजन के लिए 30 से 55 वर्ष की अवधि के 110 वर्षा-मापी स्टेशनों के ऐतिहासिक साप्ताहिक वर्षा डेटा, सामान्य साप्ताहिक संभावित वाष्पोत्सर्जन (पीईटी) और उपलब्ध जल धारण क्षमता का उपयोग किया गया। राज्य के प्रत्येक जिले में मोटे, मध्यम और महीन संरचना वाली मृदाओं की बढ़ती अवधि की लंबाई (LGP) के लिए नमी पर्याप्तता सूचकांक (I_{ma}) के साप्ताहिक मानों के आधार पर काम किया गया, जो पीईटी और वास्तविक वाष्पोत्सर्जन (AET) का अनुपात है। राज्य के विभिन्न जिलों में बारिश की फसल की इष्टतम रोपण समय, सुरक्षित विकास अवधि और जलवायविक अनुकूलता की पहचान करने के लिए भौगोलिक सूचना प्रणाली (जीआईएस) का उपयोग करके वर्षा आधारित फसलों की जलवायविक उपयुक्तता आरंभिक कृषि जलवायु क्षमता को बढ़ाने की शुरूआत, समाप्ति और बढ़ती अवधि की लंबाई विषय से संबंधित मानचित्र तैयार किए गए। प्राप्त परिणामों ने एलजीपी में व्यापक बदलाव के संकेत दिए हैं, जो राज्य के विभिन्न जिलों में 121 से 272 दिनों तक रहा। LGP के आधार पर, बिहार के विभिन्न जिलों में बारिश के फसल की क्षमता और क्रॉपिंग प्लान को रेनफेड स्थिति के तहत टिकाऊ फसल उत्पादन के लिए काम किया गया है।

ABSTRACT. Correct evaluation of water availability period in a region is vital to ensure sustainable crop production. In this backdrop, an agro-climatic study was carried out for the eastern Indian state of Bihar to evaluate the onset, cessation and length of growing period (LGP) by employing climatic water balance model for effective crop suitability planning under rainfed condition. For this purpose, historical weekly rainfall data of 110 rain-gauge stations for a period ranging from 30 to 55 years, normal weekly potential evapotranspiration (PET) and available water holding capacity were used. Lengths of growing periods (LGP) for coarse, medium and fine textured soils in each individual district of the state were worked out based on weekly values of moisture adequacy index (I_{ma}), which is the ratio of actual evapotranspiration (AET) to PET. Thematic maps of onset, cessation and length of growing period for delineating agroclimatic potential were generated using geographical information system (GIS) to identify the optimum planting schedule, safe growing period and climatic suitability of rainfed crops across various districts in the state. Results indicated a wide variation in LGP, which ranged from 121 to 272 days over different districts in the state. Based on LGP, rainfed crop potential and cropping plan in different districts of Bihar have been worked out for sustainable crop production under rainfed condition.

Key words – Climatic water balance, Moisture adequacy index, Length of growing period, Crop planning.

1. Introduction

Rainfall is a very important natural resource for crop production under rainfed condition. To ensure better and efficient utilization of natural endowment of rainfall for crop production, it is imperative to analyze the long term rainfall data based on modern agroclimatic methods. Information on potential evapotranspiration, temperature and rainfall and on derived outputs such as onset, cessation and length of growing season and agro-climatic zones is very crucial aspect in weather sensitive agricultural crop production (Raes *et al*., 2004; Tilahun, 2006; Geerts *et al*., 2006; Kipkorir *et al*., 2007; Garcia *et al*., 2007; Arya and Stroosnijder, 2010). Climatic factors such as seasonal rainfall, intra-seasonal rainfall distribution and dates of onset and termination of the rainy season affect crop yield and determine the agricultural calendar of a region (Sivakumar, 1988;

Maracchi *et al*., 1993). The onset of growing period is a very critical factor (Ingram *et al*., 2002; Barbier *et al*., 2009; Marteau *et al.*, 2011) in agricultural crop management as it determines the sowing window of crops (Sivakumar, 1992; Omotosho *et al*., 2000; Raes *et al.*, 2004). Traore *et al.* (2007) stressed the differences between agro-climatic and farmers' definitions for onset of rainy season. The agro-climatic approach considers the onset as the optimum time for planting that ensures sufficient soil moisture during sowing and early growing periods to avoid crop failure after sowing (Sivakumar, 1988; Omotosho, 1992; Omotosho *et al*., 2000).

Stewart and Hash (1982) evaluated the suitability of a given crop for a semi-arid location in Kenya using a water balance approach, grouped seasons according to date of onset and adequacy of rainfall for maize (*Zea mays*) and gave recommendations on seed and fertilizer rates, thinning operations and yield predicted for planning purposes. Lineham (1983) employed a water balance method in determining the onset and cessation of the rainy season in Zimbabwe. FAO (1978) defined the start of the growing season as the date when precipitation exceeds half of the potential evapotranspiration. While employing water balance technique to compute the dates of the onset and termination of length of growing period from long term rainfall series in northern Nigeria, Oladipo and Kyari (1993) observed that recent trends in the length of growing season were more sensitive to large inter-annual fluctuations in the start of rains than to variations in the cessation dates. Mugalavi *et al*. (2008) identified rainfall onset, cessation and length of growing season of maize in western Kenya. Subramaniam (1991) identified six moisture adequacy zones in India based on climatological water balance approach and moisture adequacy index (I_{ma}) and recommended different crops and cropping patterns for Andhra Pradesh and Maharastra. Araya and Stroosnijder (2010) assessed and characterized the agroclimatic resources in Giba catchment of northern Ethiopia to ascertain the climatic suitability for growing of teff (*Eragrostis tef*) and barley (*Hordeum vulgare*) based on the concept of length of growing period and opined that this method could be used to develop agronomic strategies to cope with the anticipated increase in drought in the semi-arid tropics under climate change.

The economy of Bihar comprising of 38 districts is highly dominated by agriculture and allied sectors. Around 85 to 90 per cent of the population still lives in rural areas where agriculture, along with animal husbandry is the mainstay of their livelihood. More than 50 percent of net cropped area in the state is rainfed. Rainfed agro-ecosystem has a distinct place in Indian agriculture having diverse farming systems with a large variety of crops, cropping systems and agro forestry practices. Rainfed agriculture is besieged by a plethora of risks due to uncertainty of rainfall and recurring drought (Misra, 2005). Thus, crop production under rainfed condition requires agroclimatic measures to slice down the climatic risks. Hence, precise evaluation of water availability period is an important pre-requisite for crop planning under rainfed condition. However, due to high variability in onset and cessation of the rainy season, water availability period and consequently, the length of crop growing season have always been uncertain. The state of Bihar comes under the influence of monsoon climate. The soil textures in the state vary from sandy loam to heavy clay and predominant type belongs to loam category, which is ideal for crop cultivation. Farmers in the state mainly depend on the experience and traditional knowledge to decide the timings for planting of their crops and this leads to poor yield and on many occasions crop failure. Thus, it is essential to determine the exact length, onset and cessation of the growing season for the entire state in view of looming danger of less crop production owing to erratic monsoon rainfall. Correct evaluation of agro-climatic potential in terms of length of growing period will help policy makers, investors and farmers to derive the scope of identifying suitable crop and to amend the existing limitations to cropping, to avoid moisture stress during crop growing season, as well as to chalk out tactical and strategic plans for rainfed crop proudction under climate change scenarios. This paper aims to evaluate the onset and cessation and length of the growing season in order to achieve sustainable crop production through efficient agroclimatic resource utilization across various districts of the state.

2. Materials and method

2.1. *Study area*

The state of Bihar is located in the eastern part of India (Fig. 1). The study was conducted for all 38 districts located under different agroclimatic zones of the state. The State is broadly divided into three agro-climatic zones *viz.*, Zone I (North-west alluvial plains), Zone II (North east alluvial plains) and Zone III (South Bihar alluvial plains). Zone III is further subdivided into Zone III A and Zone III B on the basis of rainfall variability and topography. The map showing various agroclimatic zones of the state is presented in Fig. 1.

2.2. *Rainfall data*

Historical weekly rainfall data for a period of 30 to 55 years were collected from India Meteorological Department (IMD), Pune and Agrometeorology Division, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India. Altogether, rainfall data of 110 rain-gauge

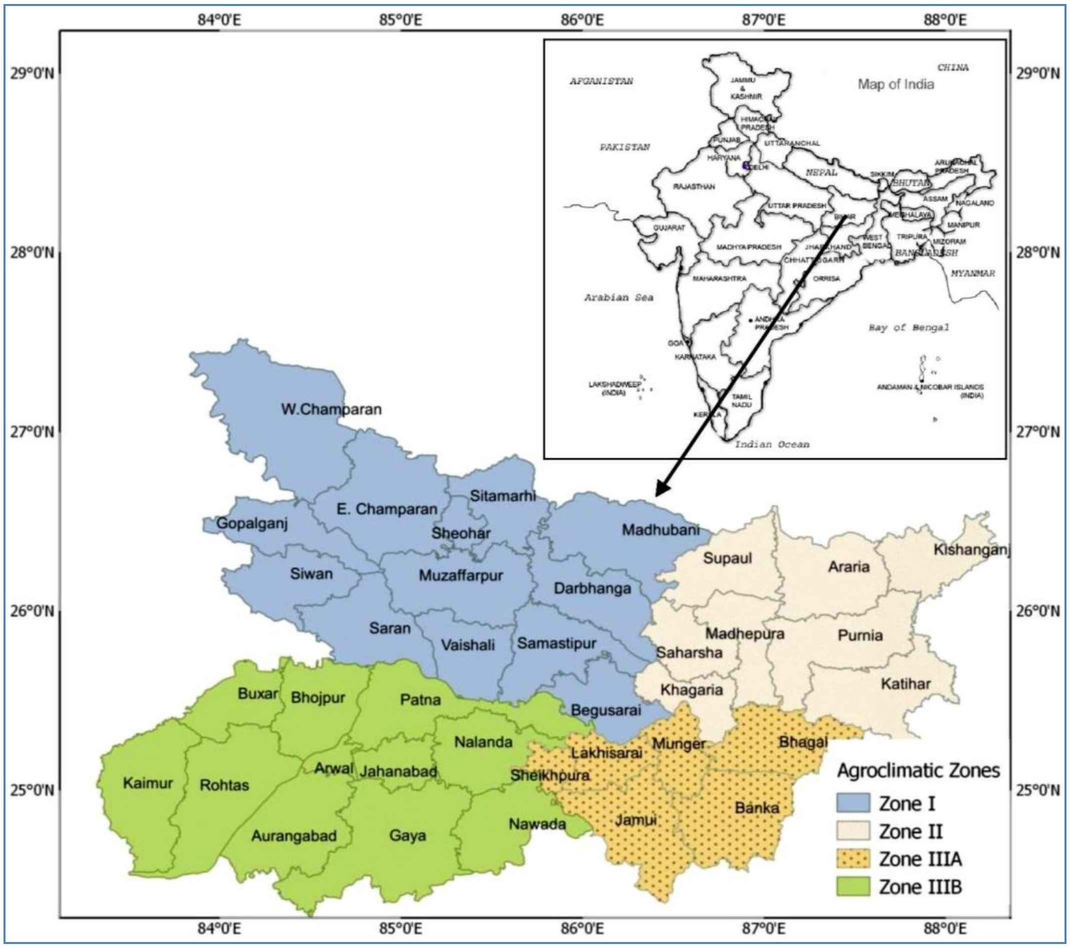

Fig. 1. Location of the study area (Bihar) with agroclimatic zones

stations were utilized for the study. The names of raingauge stations used in the study are given in Fig. 2.

2.3. *Potential evapotranspiration (PET)*

Weekly normal PET data is one of the input data for running the Thornthwaite and Mather (1955) water balance model. Monthly normal PET was calculated using PET Calculator software (V 3.0) developed by Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad (Bapuji Rao *et al.*, 2011) . Monthly PET data were converted into weekly total values by interpolation method (Rao and Vyas, 1983).

2.4. *Available water holding capacity (AWHC)*

Available soil water holding capacity is another input in water balance model. Available water holding capacity (AWHC) per meter depth of soil for various districts was estimated considering the layer wise soil textural classes up to one meter soil depth for each district as reported by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Indian Council of Agricultural Research, Nagpur (Haldar *et al.*, 1996) and following the procedures described by Saxton and Rawls (2006). AWHC per meter depth was calculated as the difference between field capacity and permanent wilting point (Doorenbos and Pruitt, 1977).

2.5. *Computation of length of growing period (LGP)*

Year-wise weekly water balance computation was carried out by using weekly total rainfall, normal weekly total PET and AWHC per meter soil depth of coarse, medium and fine textured soils following the procedure given by Thornthwaite and Mather (1955). Index of moisture adequacy (I_{ma}) was calculated from the model outputs, as the ratio between actual evapotranspiration (AET) and PET. Where rainfall was greater than PET, AET was considered as equal to PET. When rainfall was below the PET, AET was calculated as the sum of rainfall and change in soil moisture storage.

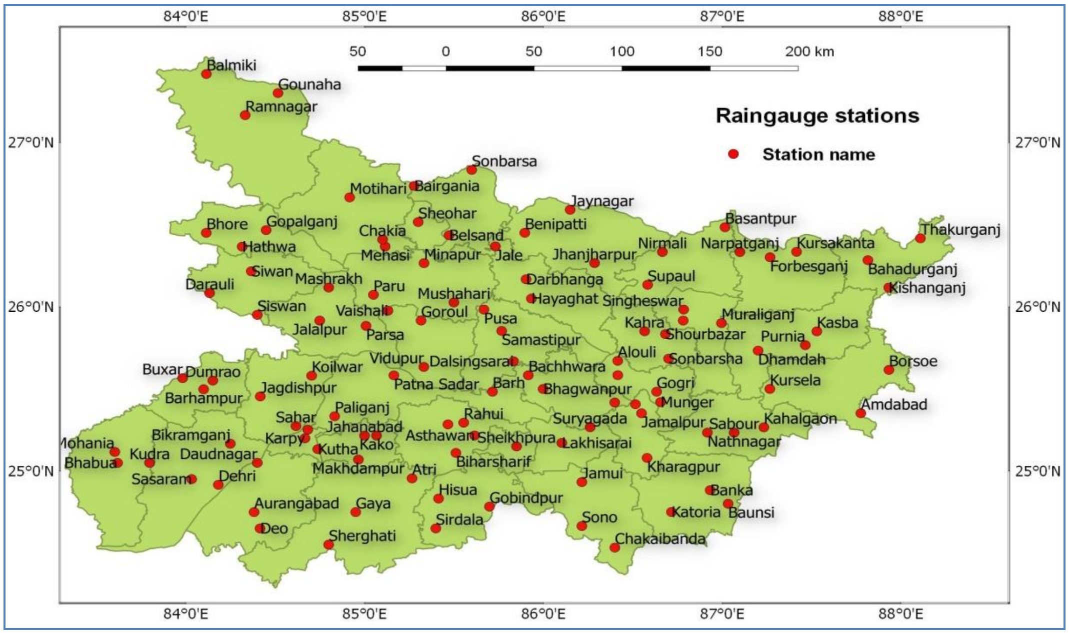

Fig. 2. Names of raingauge stations used in the study

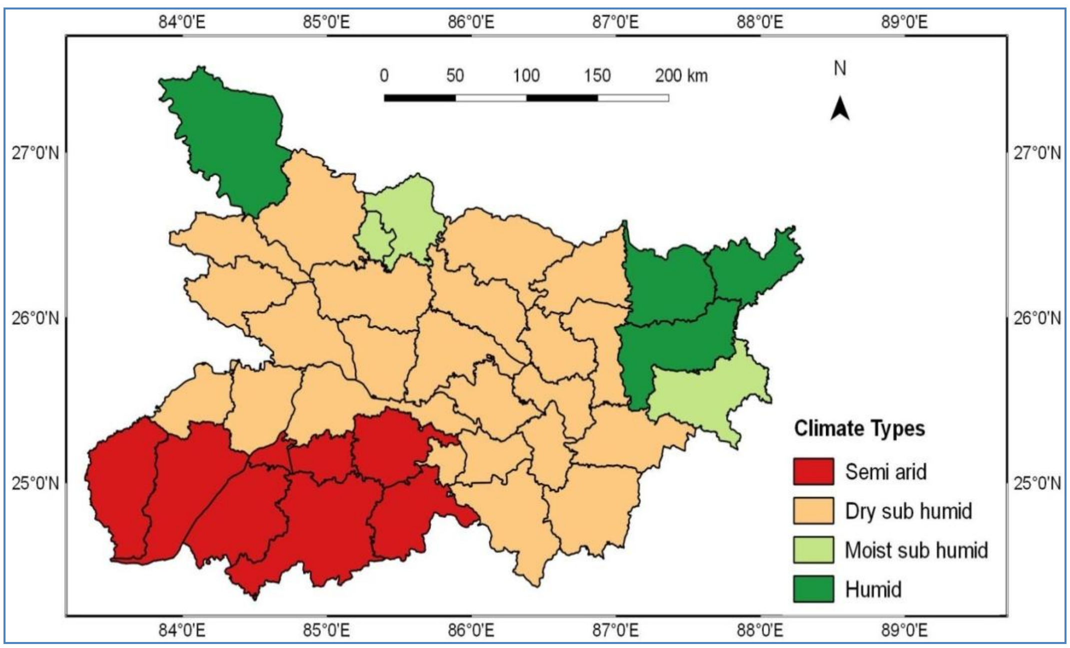

Fig. 3. Climate types in various districts of Bihar

For determining the length of growing period (LGP), which is also regarded as the water availability period under rainfed condition, the concept of moisture adequacy index (I_{ma}) was considered. The ratio of AET/PET which represents the rate at which moisture becomes available to crops compared to demand has been used as an index of moisture availability to crops as suggested by Virmani (1975) and Ramana Rao *et al.* (1979). As suggested by Gupta *et al*. (2010), the onset of growing season was considered as a week when I_{ma} was greater than or equal to 0.75**,** which is considered as the minimum moisture level for starting the planting and germination of crops like rainfed rice (*Oryza sativa*), maize (*Zea mays*), pigeon pea (*Cajanus cajan*) and sunflower (*Helianthus annuus*). The LGP was estimated as that period with consecutive weeks having $I_{ma} \geq 0.75$ (onset) and $I_{ma} \geq 0.33$ (cessation). This amount of soil moisture (in terms of $I_{ma} \geq 0.75$) received through rainfall is sufficient for seedling emergence and survival (Ati *et al.*, 2002). The cessation of growing season was taken as a week from which I_{ma} is less than 0.33 (Virmani *et al.*, 1982; Khan and Saha, 1996) for consecutive three weeks (Krishnan *et al*., 1980). The length of growing period for a particular year is obtained from the difference between cessation week and onset week of that year. From the results of water balance, LGP of each individual year for the database period of each individual district was determined and then the average lengths of growing period and standard deviation (SD) were calculated.

2.6. *Moisture index (MI)*

To examine the type of climate prevailing in the study area, we introduced the concept of Thorthwaite and Mather (1955) moisture index (MI) in order to delineate different climatic zones across various districts of Bihar. Moisture index (MI) was calculated as $MI = \left[\frac{R-PET}{PET}\right] * 100$, where, R = Rainfall (mm) and PET = Potential evapotranspiration (mm). The mean annual rainfall and mean annual potential evapotranspiration for each district were used. The climate types as suggested by Thornthwaite and Mather (1955) were worked out based on MI as given in Table 1.

2.7. *GIS mapping*

QGIS 2.2, which is an open source and widely used GIS software in research and development purposes, was employed in this study. Geo-referencing of administrative map of Bihar and digitization of district boundaries were carried out. The process of geo-referencing and digitization of soil textural map (related to coarse, medium and fine textured soils) sourced from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Indian Council of Agricultural Research (ICAR), Nagpur (Haldar *et al*., 1996) was done with utmost care in GIS environment. Thematic maps pertaining to moisture index, onset, cessation and length of growing periods were generated using QGIS 2.2 software.

TABLE 1

Moisture regions and climatic types according to revised classification of Thorthwaite and Mather (1955)

S. No.	Moisture index	Climatic types
1.	-66.7 to -100	Arid
2.	-33.3 to -66.6	Semi arid
3.	0 to -33.2	Dry sub humid
4.	0 to +20	Moist sub humid
5.	+20 to + 99.9	Humid
6.	≥ 100	Per humid

TABLE 2

Climate types on the basis of Thorthwaite and Mather (1955) moisture index computed for different districts

S. No.	Ranges of moisture index (MI) of the districts falling under a particular climate type	Type of climate	Districts with MI values under parenthesis
1.	-34.5 to -44.1	Semi arid	Jahanabad (-40.9), Arwal (-40.1), Kaimur (-34.5), Rohtas (-35.5), Aurangabad (-39.4), Gaya (-40.9), Nawada (-44.1), Nalanda (-42.1)
2.	-1.4 to -32.4	Dry sub humid	East Champaran (-1.4), Gopalganj (-11.3), Siwan (-18.6), Saran (-16.9), Muzaffarpur (-12.6), Madhubani (-11.3), Darbhanga (-11.5), Samastipur (-10.7), Begusarai (-19.9), Vaishali (-24.4), Saharsha (-32.6), Supaul (-16.3), Khagaria (-30.0), Madhepura (-16.1), Bhagalpur (-14.6), Lakhisarai (-30.9), Jamui (-21.1), Munger (-20.5), Banka (-22.9), Bhojpur(-31.3), Buxar (-32.4)
3.	0.7 to 3.9	Moist sub humid	Katihar (3.9), Sitamarhi (0.7)
4.	30.0 to 58.0	Humid	Araria (30.0), Kishanganj (58.0), Purnia (27.4), West Champaran (33.3)

3. Results and discussion

3.1. *Climate types in the state of Bihar*

Climatic types according to moisture regions (Table 1) of revised classification of Thorthwaite and Mather (1955) have been determined and presented in Table 2 and Fig. 3. Fig. 3 revealed that in accordance with moisture index (MI), the entire state could be categorized under four types of climate *viz.*, semi arid, dry sub-humid, moist sub-humid and humid. At present, most of the existing agricultural decisions and planning of the state revolve around the concept of traditional agroclimatic zones (Fig. 1) which is based on rainfall, soil and traditional crop cultivation practices. As this study considered the evaporative demand of the atmosphere in terms of potential evapotranspiration in tandem with long term rainfall series, it holds more scientific rationale in delineating the climatic zones *vis-a-vis* crop production potential. Such climatic information in association with traditional agroclimatic zonations will contribute to better planning of resources and environmental sustainability

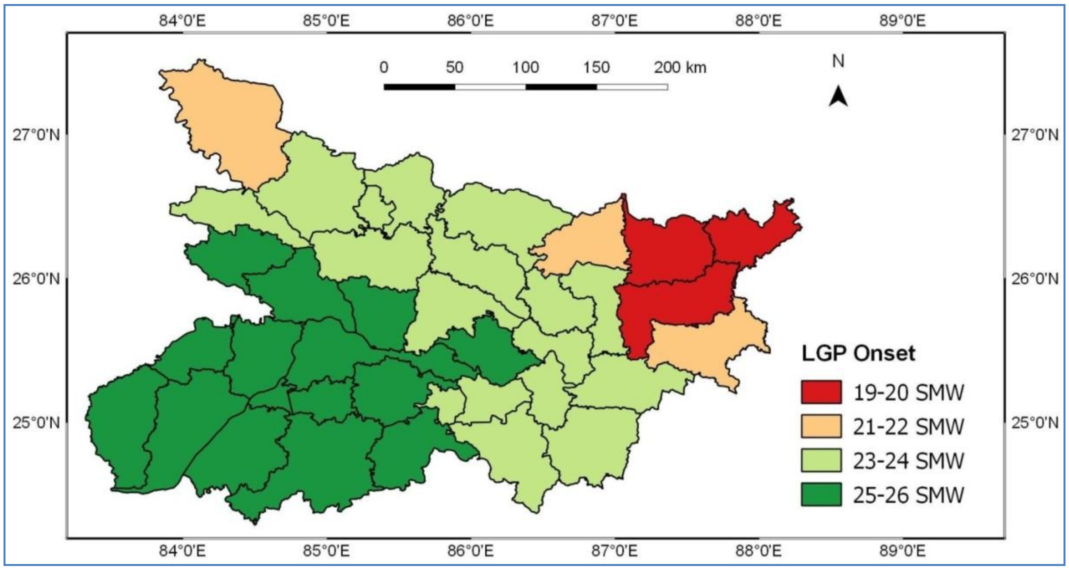

Fig. 4. Onset of LGP (in SMW) in various districts of Bihar

(De Pauw *et al*., 2000) and helps identify agricultural potential and constraints. Fig. 3 shows that most of the state comes under dry sub-humid followed by semi arid climate. Most of the districts (Jahanabad, Arwal, Kaimur, Rohtas, Aurangabad, Gaya, Nawada, Nalanda except Buxar, Bhojpur and Patna) under Zone III B have semi arid climate, indicating its agro-ecological vulnerability and thus it necessitates giving special attention by the planners for sustainable rainfed crop production. Humid climate is observed in the extreme north eastern parts (Kishanganj, Purnia and Araria districts) of the state, where rainfed crops like sugarcane (*Saccharum officinarum*) and rice *(Oryza sativa*) could be successfully cultivated (Table 2, Fig. 3). After analyzing historical rainfall data of sub-humid zones of India, Huda *et al*. (1983) reported that as per Thorthwaite and Mather (1955) classification method, the climate of Bhagalpur, Darbhanga, Patna and Sabour stations of Bihar is dry sub-humid and Purnia is having moist sub-humid climate.

3.2. *Onset of growing period*

Proper understanding of the onset and cessation of length of growing period (LGP) indicates the climatic suitability of crops in a region (Mugalavi *et al*., 2008). In view of wide variability in onset weeks, we categorized districts, according to the onset of LGP into four groups with sowing window spanning over two weeks, during (*i*) 19-20 SMW, (*ii*) 21-22 SMW, (*iii*) 23-24 SMW and (*iv*) 25-26 SMW (Fig. 4). The earliest onset of growing period was observed in Kishanganj, Araria and Purnia districts located in agroclimatic zone II. This happens due to early arrival of monsoon rains in these districts. Farmers of this region of agroclimatic zone II can avail the opportunity of earliest sowing rain and start the planting of rainfed *kharif* crops. Only three districts (West Champaran, Supaul and Katihar) registered onset during 21-22 SMW. Gopalganj, East Champaran, Sitamarhi, Muzaffarpur, Darbhanga, Samastipur under Zone I and Madhepura, Shaharsha, Khagaria under Zone II and all districts of Zone III A come under the LGP onset group of 23-24 SMW. All districts of Zone III B (considered as dry zone of Bihar) and some adjoining districts such as Siwan, Saran, Vaishali and Begusarai under Zone I, exhibited very late onset. Such district wise information on the start of growing season in the state would help farmers of individual districts undertake programmes concerning land preparation, procurements of seeds, fertilizers and other agricultural inputs beforehand and accordingly initiate planting operation of rainfed crops. Planting of crops in appropriate times according to actual sowing window is one of the key factors, which strongly affect crop production in rainfed agriculture (Hussein, 1987; Latham *et al*., 2000; Ati *et al*., 2002). Moreover, late sowings of crops in an area shorten the length of crop growing period and increase the infestation of weeds (Stoop *et al*., 1981; Vaksmann *et al*., 1996), leading to significant reduction in crop productivity.

3.3. *Cessation of growing period*

The cessation weeks of LGP for each soil textural classes, *viz.*, coarse, medium and fine textured soils in all 38 districts were worked out and presented in Table 3. There were large variations in the termination of LGP even among various districts lying within an agroclimatic zone. Based on the large variability, cessation weeks were categorized in six groups, *viz.*, 43-45 SMW, 46-48 SMW,

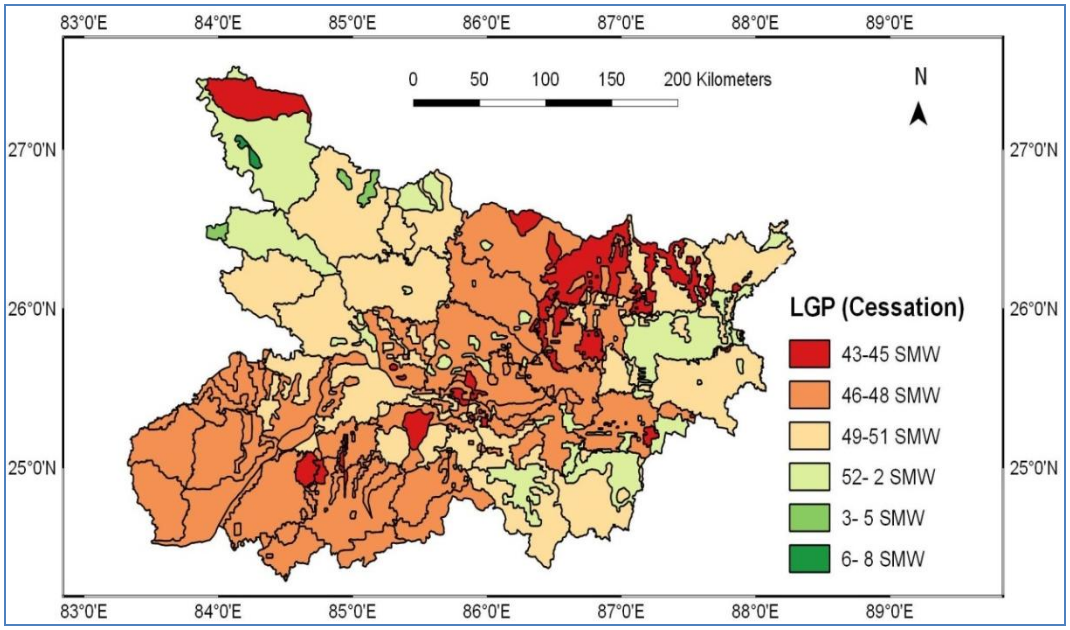

Fig. 5. Cessation of LGP (in SMW) in different regions of Bihar

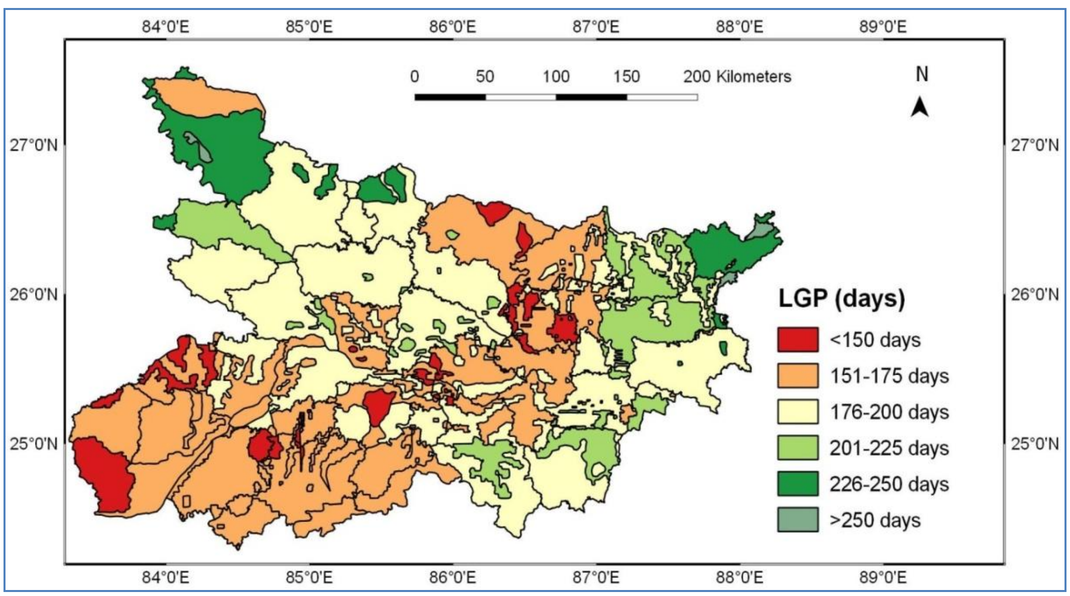

Fig. 6. Variability in length of growing period (LGP) in Bihar

49-51 SMW, 52-2 SMW, 3-5 SMW and 6-8 SMW (Fig. 5). The majority of earliest cessation period in LGP could be observed in Zone II and few pockets in Zone I and III (A & B) corresponding to the areas where coarse textured soil dominates. Most of the cessation in the state happens in two categories, *i.e.*, during 46-48 SMW and 49-51 SMW. Very late cessation (>3 SMW) was observed in northwestern part of state and limited areas in Zone I and some pockets in Zone II and Zone III B. Such categorization in the termination of crop growing period provides a clear picture about areas of the state as to where LGP starts and terminates early or late or persists longer and thus this information could help the policy makers in undertaking strategic as well as tactical decisions beforehand. Late cessation implies longer LGP which could be utilized for adopting double cropping sequence under rainfed condition.

3.4. *Length of growing period (LGP)*

The LGP was determined by considering consecutive weeks with I_{ma} of 0.75 at planting and 0.33 at the end of

TABLE 3

Onset, cessation and length of growing period under coarse, medium and fine textured soils in different districts of Bihar

Zones/Districts	Coarse textured soil			Medium textured soil			Fine textured soil		
	Onset (SMW)	Cessation (SMW)	LGP (days)	Onset (SMW)	Cessation (SMW)	LGP (days)	Onset (SMW)	Cessation (SMW)	LGP (days)
Zone I (North west alluvial plains)									
Darbhanga	23	43	143 ± 19	23	48	18 0 ± 30	23	52	209 ± 36
Samastipur	23	43	149 ± 20	23	47	184 ± 35	23	52	210 ± 42
Begusarai	25	44	141 ± 19	25	46	164 ± 33	25	47	185 ± 38
Madhubani	24	43	142 ± 18	24	47	174 ± 29	24	52	202 ± 35
Sitamarhi	23	44	157 ± 28	23	50	195 ± 40	23	2	226 ± 42
Muzaffarpur	24	44	144 ± 17	24	50	189 ± 31	24	2	214 ± 33
Sheohar	23	44	159 ± 28	23	50	196 ± 39	23	2	227 ± 41
Vaishali	25	44	139 ± 18	25	47	165 ± 22	25	51	188 ± 34
Saran	25	43	136 ± 18	25	50	183 ± 35	25	2	212 ± 40
Siwan	25	43	138 ± 26	25	51	189 ± 35	25	1	207 ± 37
Gopalganj	24	44	144 ± 29	24	52	203 ± 43	24	4	228 ± 37
E. Champaran	23	45	162 ± 28	23	49	200 ± 41	23	4	239 ± 45
W.Champaran	21	45	175 ± 31	21	52	226 ± 43	21	7	272 ± 45
Mean	24	44	148 ± 12	24	49	189 ± 17	24	1	217 ± 23
Zone II (North east alluvial plains)									
Katihar	22	45	172 ± 24	22	49	197 ± 30	22	2	235 ± 35
Purnia	20	45	176 ± 27	20	51	220 ± 30	20	2	243 ± 30
Kishanganj	19	44	181 ± 20	19	51	233 ± 30	19	2	253 ± 28
Araria	20	44	177 ± 21	20	50	222 ± 34	20	2	248 ± 36
Supaul	22	43	156 ± 22	22	46	176 ± 25	22	49	194 ± 26
Madhepura	23	44	158 ± 24	23	48	182 ± 25	23	50	202 ± 31
Saharsha	24	43	142 ± 25	24	46	165 ± 29	24	48	176 ± 29
Khagaria	24	43	139 ± 22	24	46	161 ± 27	24	48	177 ± 32
Mean	22	44	162 ± 16	22	48	194 ± 28	22	52	216 ± 32
Zone III A (South Bihar alluvial plains)									
Banka	24	45	152 ± 20	24	49	181 ± 25	24	1	212 ± 35
Bhagalpur	24	44	152 ± 20	24	46	187 ± 27	24	2	225 ± 32
Munger	24	44	147 ± 22	24	48	172 ± 3	24	52	199 ± 33
Lakhisarai	24	43	141 ± 17	24	48	173 ± 27	24	50	190 ± 26
Sheikhpura	24	44	144 ± 18	24	47	170 ± 26	24	51	196 ± 27
Jamui	24	45	152 ± 22	24	49	181 ± 27	24	1	205 ± 29
Mean	24	44	148 ± 5	24	48	177 ± 7	24	52	204 ± 13
Zone III B (South Bihar alluvial plains)									
Patna	25	43	134 ± 18	25	48	169 ± 26	25	51	190 ± 31
Nalanda	25	43	132 ± 24	25	48	167 ± 33	25	50	179 ± 37
Nawada	26	44	133 ± 21	26	47	156 ± 21	26	48	163 ± 25
Gaya	26	43	129 ± 23	26	47	157 ± 28	26	48	162 ± 26
Jahanabad	26	43	130 ± 16	26	48	161 ± 27	26	48	165 ± 29
Arwal	26	43	129 ± 16	26	48	162 ± 23	26	50	181 ± 31
Aurangabad	25	43	132 ± 18	25	46	156 ± 29	25	49	173 ± 36
Rohtas	25	43	131 ± 18	25	46	154 ± 23	25	48	171 ± 28
Bhojpur	25	42	125 ± 21	25	48	168 ± 34	26	51	182 ± 36
Buxar	26	42	123 ± 15	26	47	156 ± 26	26	48	174 ± 28
Kaimur	26	42	121 ± 19	26	46	144 ± 24	26	48	164 ± 26
Mean	25	43	129 ± 4	25	47	159 ± 7	25	50	173 ± 9

LGP. The values presented in Table 3 represent the length of growing period under rainfed condition for coarse, medium and fine textured soils in each individual district of the state. In coarse textured soil, the highest (181 days) and the lowest LGP (121 days) were recorded in Kishanganj (Zone II) and Kaimur (Zone III B) districts, respectively. These two districts also showed highest (233 days) and the lowest (144 days) length of rainfed crop growing period in medium textured soil. However, in fine textured soil, Nawada recorded the lowest LGP (170 days) followed by Rohtas (171 days) and Buxar (174 days). The highest LGP in fine textured soil occurs in Kishanganj district. Hence, Kishanganj district appears to be the most productive in terms of length of water availability period. While considering the traditional agroclimatic zones, the highest LGP was recorded in Zone II in all soil textural classes and the lowest LGP in Zone III B. Thus, it is evident that Zone II appears to be most productive and Zone III B least productive zone.

We made thematic map of LGP for coarse, medium and fine textured soils of all districts using GIS and categorized the LGP into six groups, *viz.*, LGP<150 days, 151-175 days, 176-200 days, 201-225 days, 226-250 days and >250 days (Fig. 6). Majority of LGP<150 days is observed in Zone III B (Kaimur district, parts of Buxar, north eastern part of Aurangabad, adjoining Gaya, Nalanda, Patna) and Zone II (parts of Madhepura, Saharsha and Madhubani districts) and in few pockets could be seen in northern part of Begusarai district. GIS presentation in Fig. 6 shows that a major part of geographical areas of the state has LGP in two groups *viz.*, 151-175 and 176-200 days. Most of Purnia, Araria and Gopalganj districts, south-eastern part of Bhagalpur, parts of Banka and Jamui recorded LGP within 201-225 days. Most of Kishanganj, West Chamaparan, northern part of Sitamarhi, a few pockets of East Chamaparan and Western fringe of Gopalganj districts registered LGP within 226-250 days. Araya (2005) has reported that a difference of 10-20 days in LGP produces differences not only in yield but also in the farmers' choice of crops and crop varieties. Accordingly, crops and varieties under a crop could be selected by matching with the length of growing period and thereby realization of potential yield of an area for rainfed crop production could be achieved. Dey (2008) observed that LGP was in the order fine>medium>coarse textured soil in West Bengal, India. In coarse textured soil, two different cropping systems, based on LGP of 185 days, were suggested. Similarly, in medium and fine textured soil, cropping systems for LGP within 210-240 days and those with more than 240 days were suggested separately.

3.5. *Cropping possibilities based on agro-climate and LGP*

It is vital that farmers should grow crop varieties according to length of growing period available in their areas, which would help production at potential rate and reduce the chances of crop failure due to moisture stress. This seems to be more pertinent in the wake of climate change scenario. Mechanisms for adapting to climate change could be developed by considering the agroclimatic zones with precise estimation of changes in water availability period at local level considering the soil type, rainfall amount and distribution, potential evapotranspiration and length of growing period with respect to a base period. This will lead to providing agricultural sustainability and food security in the vulnerable agro-ecosystem in the state of Bihar, where drought is a recurring phenomenon (Sattar and Singh, 2014). Among the four agroclimatic zones, agro-ecosystem of Zone III B is quite vulnerable due to being semi arid climate type. Drought resistant and low water requiring crops should be selected for planting under such rainfed condition. Crops like maize (*Zea mays*), pigeon pea (*Cajanus cajan*) and millets during *kharif* seasons and chick pea (*Cicer arietinum*) during *rabi* season could do well in this zone. Rice (*Oryza sativa*) which is also an important crop in Bihar could perform well in moist sub-humid and humid climatic conditions. However, under rainfed condition, only short duration varieties of rice in moist sub-humid and long duration varieties in humid condition could be planted. Under dry sub-humid climate, which prevails over twenty one districts (Table 2), maize (*Zea mays*), pigeon pea (*Cajanus cajan*), sesame (*Sesamum indicum*) and chick pea (*Cicer arietinum*) could perform well. Usually long and medium duration rice (*Oryza sativa*) or maize (*Zea mays*) or pigeon pea (*Cajanus cajan*) or sunflower (*Helianthus annus*) during *kharif* season followed by rapeseed (*Brassica campestris*), or chick pea (*Cicer arietinum*) or lentil (*Lens culinaris*) during *rabi* season are grown under rainfed condition and they mostly experience moisture stress at different phases of growth and produce lesser yield. Presently, before selection and sowing of a crop, the information on water availability period matching with duration of a given crop is not considered. Instead of adopting long duration varieties, emphasis should be given for selection of appropriate short duration varieties for making the sequential cropping during *kharif* and *rabi* seasons more successful. As compared to pigeon pea (*Cajanus cajan*) and long duration rice (*Oryza sativa*), upland rice (*Oryza sativa*) and maize (*Zea mays*) are of shorter duration, so the choice of improved short duration varieties of the latter crops is required to ensure the sowing of subsequent crops early in the season. Following the harvest of *kharif* crops, short duration varieties of *rabi* oil seeds (rapeseeds)

TABLE 4

Cropping systems based on length of growing period

S. No.	Length of growing period	Suggested cropping systems
1.	LGP<150 days	Maize in *kharif* season followed by short duration pulses in *rabi* season or pigeon pea followed by fallow or intercropping of pigeon pea with maize for coarse textured soil
2.	151-175 days	Double cropping with short duration rice / maize (90/110 days) followed by short duration pulses or oilseeds or vegetables in coarse and medium textured soils
3.	176-200 days	Double cropping with rice/maize followed by rapeseed or lentil or chick pea in medium textured soils
4.	201-225 days	Medium duration rice maturing in 110-115 days (transplanting to harvesting) followed by wheat/potato/rapeseed/ mustard/vegetables in medium and fine textured soils
5.	226-250 days	Medium (110-115 days) and long (130-135 days) duration rice followed by wheat/potato/mustard/pulses; sugarcane or maize followed by oil seeds/pulses/vegetables in fine textured soil
6.	> 250 days	Long duration rice (130-135 days) followed by wheat/mustard/potato/pulses; maize/pigeon pea followed by vegetables in upland ecosystem in fine textured soil

and pulses (chickpea, lentil) could be grown with greater success. Sugarcane (*Saccharum officinarum*), which is a long duration (10-12 months) and high water requiring crop, could be grown in northwestern districts (West Champaran, East Champaran) of Zone I and some districts (Kishanganj, Araria, Purnia) of Zone II owing to the availability of higher I_{ma} and longer growing period. Changes in sowing of crop with early maturing varieties offer scope for enhancing crop production under rainfed condition (Krishnan, 1983). Cropping systems according to LGP have been suggested for the state of Bihar (Table 4).

4. Conclusions

The study aims at evaluating agroclimatic potential and length of growing periods for crop planning under rainfed condition in the state of Bihar. An assessment of water availability in such a scale for rainfed agriculture covering the entire state was not available earlier to the planners and policy makers. We highlight the importance of assessing the agroclimatic potential for rainfed crop production, which appears to be most vulnerable under changing climatic condition. In the present study, exhaustive data set pertaining to rainfall, potential evapotranspiration and available soil water holding capacity of all soil series under each district, were used, which allowed us to obtain comprehensive results leading to assessing climatic potential precisely in terms of LGP *vis-à-vis* prospects for enhanced rainfed crop production. The information on onset of length of growing period in various districts will allow the farmers to sow their crops at appropriate times. The results suggest that there exists a large variability in length of growing period and climatic types across the state. This calls for micro level crop management practices for proactive monsoon management in order to have better drought management strategy and developing contingency crop planning to suit different rainfall patterns under changing climatic condition (Swaminathan, 2005). Keeping all this in mind, the onset, cessation and length of growing period for raising rainfed crops were identified for coarse, medium and fine textured soils spatially distributed over the districts of Bihar state. The information on climate type, onset, cessation and LGP presented in the thematic maps could be of great help for planning of rainfed agriculture in the state. Accordingly, the farmers can choose the types of crops of appropriate duration to suit in their region. The onset weeks of LGP in different districts and regions of the state could help the farmers in sowing their crops in appropriate time matching with LGP in that particular area to make maximum utilization of agroclimatic resources towards potential yield. Considering moisture index and length of growing period, most of the districts in Zone III B appear to be vulnerable to produce less. For this scarcity zone, intercropping system could enhance total production per unit land as compared to sole cropping. Intercropping of pigeon pea (*Cajanus cajan*) with maize (*zea mays*) and sequential cropping of short duration rice (*Oryza sativa*) followed by chickpea (*Cicer arietinum*) / lentil (*Lens culinaris*) could be efficient cropping system in the scarcity zone of Bihar (Singh *et al*., 1981). The districts like Katihar, Purnia, Kishanganj in Zone II and West Champaran district in Zone I have the highest length of growing period in the state facilitating the scope for intensive crop cultivation programme under rainfed condition.

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