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ORIGINAL PAPER

Assessing sowing window and water availability of rainfed crops in eastern Indian state of Bihar for climate smart agricultural production

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Abstract

An agro-climatic study was carried out in eastern Indian state of Bihar (middle Indo-Gangetic Plains) to identify optimum planting schedules and water availability of rainfed crops based on moisture availability index (MAI), i.e., the ratio of weekly assured rainfall and potential evapotranspiration (PET) for delineating safe growing period and crop production potential at micro-level in order to develop climate smart agricultural production system. For this purpose, historical weekly rainfall data for a period ranging from 30 to 55 years of 110 rain-gauge stations and normal weekly PET were employed. The assured weekly rainfall at different probability levels, viz. 25, 50, and 75%, was computed employing incomplete gamma distribution technique. The study revealed that at 50% probability (i.e., 50 out of 100 years), the sowing window of rainfed crops with MAI $\geq$ 0.33 ranged from 19 to 24 SMW (standard meteorological week) over different districts in Zone I (North west alluvial plains), 18 to 23 SMW in Zone II (North east alluvial plains), 23–24 SMW in Zone IIIA (Part of South Bihar alluvial plains), and 24–25 SMW in Zone IIIB (Part of South Bihar alluvial plains). The districts under Zone II recorded the earliest sowing week for starting sowing of rainfed crops, and the most delayed start of sowing was recorded in the districts under Zone IIIB at all probability levels. Kishanganj District recorded the highest duration of water availability followed by West Chamaparan District at all MAI and probability levels. In terms of longer length of water availability and higher values of MAI, Zone II appeared to be the most potential agroclimatic zone followed by Zone I and Zone IIIA. The Zone IIIB was adjudged as the least potential Zone in terms of shorter water availability period for rainfed crop production.

1 Introduction

Crop production in an area under rainfed condition has a direct relation with amount and distribution of rainfall. It is a very important natural resource for crop production. Fulfilling water demand of crops is an important aspect in achieving potential productivity under rainfed condition. Accordingly, length of water availability period in a given location influences the crop production differently (Ramana Rao et al. 1979). As several risks are involved in rainfed agriculture, it is necessary to slice down the climatic risks in crop production to achieve desired crop yield. In this context, information on potential evapotranspiration (PET), rainfall and on derived outputs such as onset of growing season, length of growing period, and agro-climatic zones is vital in deciding the success of weather sensitive agricultural sectors (Tilahun 2006; Geerts et al. 2006; Garcia et al. 2007; Arya and Stroosnijder 2010). Several climatic factors such as rainfall distribution, onset, and termination of rainy season affect crop yields and determine the agricultural calendar of a region (Sivakumar 1988; Maracchi et al. 1993). More importantly, the onset of crop growing season is the most critical information (Marteau et al. 2011) for agricultural management, as it determines the sowing window of crops (Raes et al. 2004). Farmers tend to decide crop sowing based on the occurrence of substantial rain (Bacci et al. 1999), which may lead to crop (sowing) failures due to dry spell as a result of false start of monsoon. Again, frequent dry spells during the monsoon season hinder the performance of rainfed crops. Hence, precise evaluation of agroclimatic potential in an area is an important pre-requisite for successful crop planning and development of supplemental irrigation under rainfed condition. This will help policy

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makers and farmers in identifying suitable crops and to amend the existing limitations to cropping systems, to avoid moisture stress during crop growing season at sensitive crop phases, as well as to chalk out tactical and strategic plans for rainfed crop production under climate change scenarios.

Moisture availability index (MAI) is a very important index in assessing adequacy of rainfall in supplying water need and delineating crop production potential in an area as this parameter is an integration of probabilistic rainfall with PET. While applying the concept of MAI of Hargreaves (1974) for evaluating crop potential in dry farming tract of India, Sarker and Biswas (1986, 1988) introduced three modifications in the methodologies of Hargreaves (1974) which were (i) weekly MAI instead of monthly MAI, (ii) different risk factors (e.g., 40, 50, 60, and 70% probability level) in place of one risk factor (75% probability level) giving options to a planner for choosing his own risk level, and (iii) taking MAI ≥ 0.3 and ≥ 0.7 depending upon crop growth phases instead of 0.34 throughout the crop growth period. The period when MAI was equal or greater than 0.3 was taken as crop growing period. They developed a theory for agroclimatic classification based on MAI and recommended suitable cropping pattern for boosting up agricultural productivity. Biswas and Nayar (1984) determined drought prone area and crop potential under dry farming tract of India based on MAI. Huda et al. (1989) employed MAI to assess water availability over 209 locations in sub-humid India. Banik and Sharma (2009) studied rainfall pattern and estimated MAI at different probability levels in relation to rice crop at Giridih, Jharkhand (India), and suggested the possibility of rice cultivation based on MAI. Kovilavani et al. (2012) while working on variability in length of growing period in Coimbatore district observed that MAI greater than 0.33 prevailed for 10 weeks and suggested cropping plan based on MAI under rainfed condition. Hence, the MAI is of immense practical utility in rainfed crop planning based on water availability duration estimated through MAI.

There are three crop growing seasons in eastern India commonly known as *kharif*, *rabi*, and *zaid*. According to traditional concept followed in agricultural planning, the average lengths of *kharif*, *rabi*, and *zaid* seasons are considered as 120–125, 145–150, and 80–85 days, respectively. The important *kharif* season crops are rice (*Oryza sativa*), maize (*Zea mays*), pigeon pea (*Cajanus cajan*), sorghum (*Sorghum bicolor*), and bajra (*Pennisetum glaucum*), whereas wheat (*Triticum aestivum*), winter maize (*Zea mays*), chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), rapeseed (*Brassica campestris*), mustard (*Brassica juncea*), potato (*Solanum tuberosum*), barley (*Hordeum vulgare*), and sugarcane (*Saccharum officinarum*) are major *rabi* crops. *Zaid* crops, which are cultivated in short growing season between *rabi* and *kharif* seasons, are also called summer crops, which include green gram (*Vigna radiata*), cowpea (*Vigna unguiculata*), muskmelon (*Cucumis melo*), watermelon (*Citrullus lanatus*), bottle gourd (*Lagenaria siceraria*), etc.

Successful cultivation of crops depends on the availability of optimum soil moisture during the growing period. Appropriate time of sowing is also vital in achieving higher yield as it ensures favorable soil moisture regime during sowing and early growing periods. Hence, identification of safe growing period in a region based on MAI at different probability levels would be an important aspect of smart agricultural planning under rainfed condition. However, the choice of crops, crop varieties, and crop rotation vary with water availability period and agroclimatic zones. Rainfed crops during both *kharif* and *rabi* seasons in the state mostly experience moisture stress at different phases of growth and produce lesser yield. The information on optimum sowing window, safe growing period, and crop suitability based on water availability down to district level for the entire state of Bihar is not available, and hence, it is necessary that such information needs to be made available to the farmers, planners, and policy makers for undertaking strategic decision for sustainable agricultural production. Usually, farmers grow crops according to their own experiences. At present, farmers tend to adopt cropping pattern and package of practices for growing crops based on recommendations given by policy makers at state and national levels and by state agricultural universities. In view of the above, an attempt has been made in this paper to assess optimum planting schedules and safe growing period based on MAI for efficient agroclimatic resource utilization towards sustainable and climate smart agricultural production.

2 Materials and methods

2.1 Study area details

2.1.1 Location of study area

The state of Bihar is located in the eastern part of India under middle Indo-Gangetic Plains (Fig. 1). The study was conducted for all 38 districts located under different agroclimatic zones of the state. The state is situated between 24° 17′ and 27° 31′ N latitudes and between 83° 19′ and 88° 17′ E longitudes covering an area of 9.38 million hectares. The economy of Bihar comprising of 38 districts is highly dominated by agriculture and allied sectors. Around 80 to 85% of the population lives in rural areas, where agriculture is the primary source of their livelihood. Rice (*Oryza sativa*), wheat (*Triticum eastivum*), maize (*Zea mays*), and pulses are grown all across the state of Bihar. Around 60% of net cropped area in the state is rainfed (Anon 2008). Rainfed agro-ecosystem has a distinct place in Indian agriculture having diverse farming systems with a large variety of crops, cropping systems, and agroforestry practices. It occupies 58% of the cultivated area contributing 40% of the total food grain production, and supports 40% of the human and 65% of the livestock

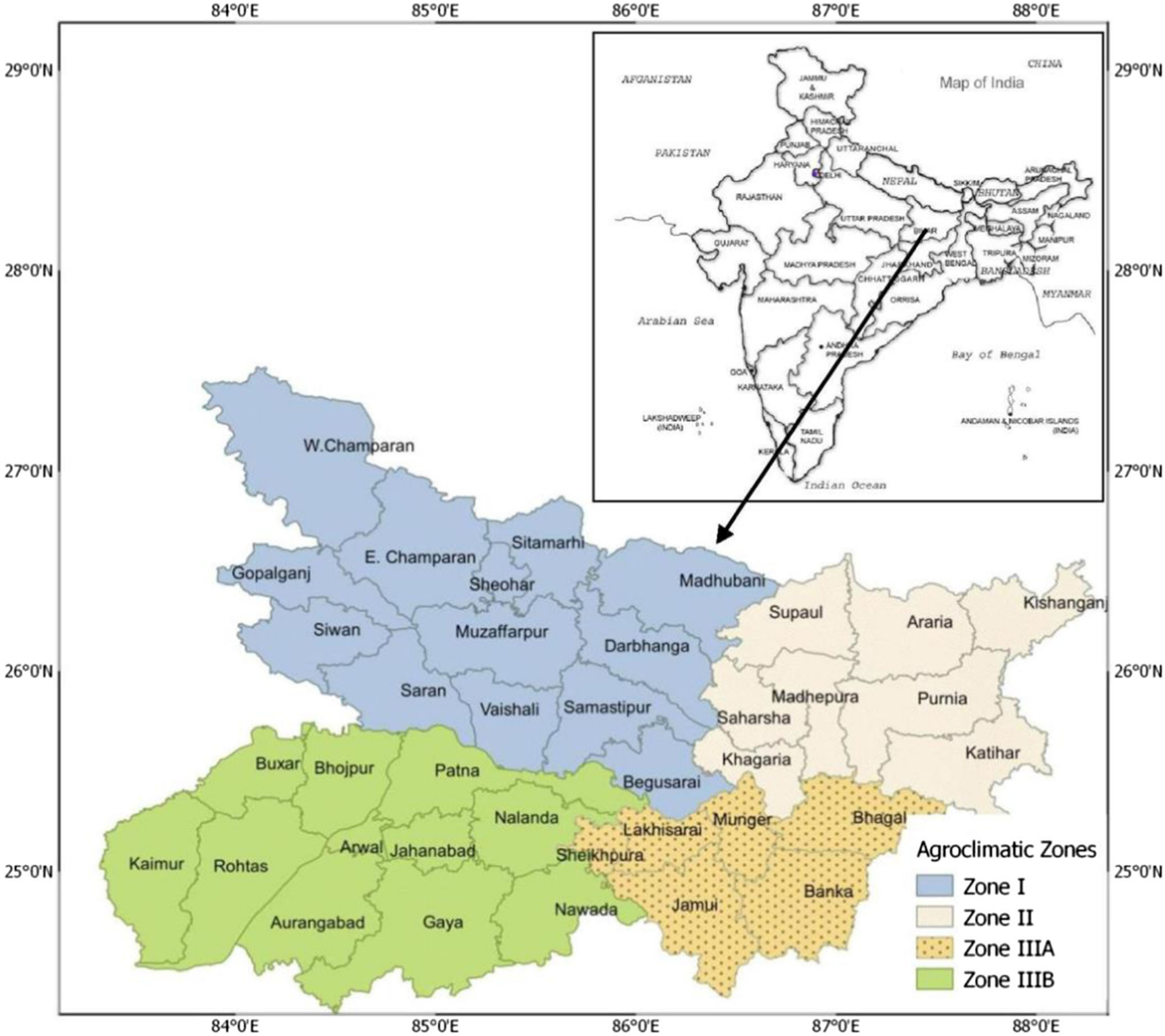

Fig. 1 Location of the study area (Bihar, India) with agroclimatic zones

population (Venkateswarlu and Prasad 2012). In the state of Bihar, the methods of irrigation are border, check basin, furrow, sprinkler, and drip irrigations (Michael 1978). Micro irrigation methods which include sprinkler and drip irrigations are practiced by farmers of the state in a limited scale. Out of 5.6 million hectares of net sown area, the acreage under micro irrigation is only 0.103 million hectares (ICFA 2015).

2.1.2 Climate and soils of the study area

The region comes under sub-humid subtropical monsoon climate. About 85% of annual rainfall (1180 mm) occurs during monsoon season, synonymously also called as *kharif* season considering different crop growing seasons. The state of Bihar experiences four seasons viz. Summer (March–May), Monsoon (June–September), Post Monsoon (October–November), and Winter (December to February). It is broadly divided into three agro-climatic zones (Fig. 1) 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 IIIA and Zone IIIB on the basis of rainfall variability, topography, and cropping pattern. Zone I and Zone IIIA have rice- and maize-based cropping systems, while Zone II has rice- and jute-based cropping systems. Although short duration rice is widely grown in Zone IIIB, crops like oilseeds and pulses play dominant role in the cropping system. According to moisture regimes of revised classification of Thorthwaite and Mather (1955), the entire state could be categorized under four types of climate viz. semi-arid, dry sub-humid, moist sub-humid, and humid (Fig. 2, Sattar 2015). Most of the districts (Jahanabad, Arwal, Kaimur,

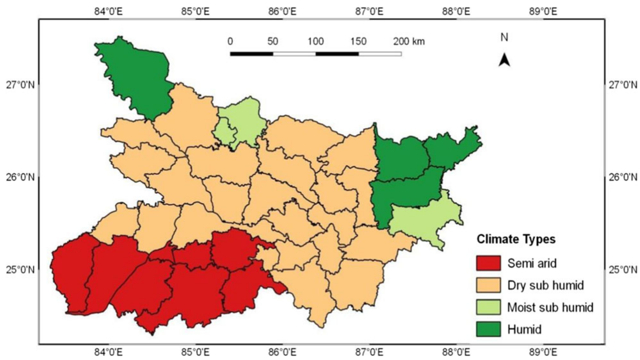

Fig. 2 Climate types of Bihar, India

Rohtas, Aurangabad, Gaya, Nawada, Nalanda) under Zone IIIB, except Buxar, Bhojpur, and Patna, have semi-arid climate, indicating its agro-ecological vulnerability. Humid climate is observed in the extreme north eastern parts (Kishanganj, Purnia, and Araria Districts) of the state. 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. Soil pH varies from 6.5 to 8.4.

2.2 Data and methods used in the study

2.2.1 Climate data

Rainfall We used historical weekly rainfall data for a period of 30 to 55 years collected from the India Meteorological Department, Pune, and Agrometeorology Division, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India. Altogether, rainfall data of 110 rain-gauge stations were utilized for the study. The names of rain-gauge stations used in the study are given in Fig. 3.

PET The PET data required for running the Thornthwaite and Mather (1955) climatic water balance model was calculated using PET Calculator software (V 3.0) developed by Central Research Institute for Dryland Agriculture (CRIDA), Indian Council of Agricultural Research, Hyderabad (Bapuji Rao et al. 2011). Monthly PET as estimated for different stations of Bihar using meteorological parameters in the PET calculator software was converted into weekly total values by interpolation method (Rao and Vyas 1983). The weekly values of PET were used in the computation of MAI.

2.2.2 Determination of water availability period

The concept of MAI postulated by Hargreaves (1974) and as adopted by Sarker and Biswas (1986, 1988) has been used in the present study as an index of water availability for assessment of crop potential under rainfed condition. The MAI, which is the ratio of weekly total assured rainfall determined at 25, 50, and 75% probability levels to PET, was computed for all 38 districts for assessing production potential of rainfed *kharif* crops. The water availability period has been synonymously used in this paper as crop growing period. The growing periods with consecutive weeks having MAI ≥ 0.34 (Hargreaves 1974), ≥ 0.70 and ≥ 1.00 (Sarker and Biswas 1988) providing different degrees of moisture availability, have been estimated at 25, 50, and 75% probability levels for potential productivity evaluation under rainfed condition in different districts of Bihar.

By employing the database on standard meteorological week (SMW) basis, the assured weekly rainfall amounts at 25, 50, and 75% probability levels were computed employing incomplete gamma distribution technique developed by Thom (1958) and as adopted by Sarker and Biswas (1986, 1988). Weekly rainfall data of all districts of Bihar for a period of 30–55 years were utilized for the study. For each district, rainfall data of three rain-gauge stations were used. The assured weekly rainfall estimated at different probability levels constitutes a series of data that may be expected in different years, and hence, risk involved in getting a certain amount of rainfall during a particular period would be obtained from this analysis. The following equations, which are the mixed Gamma distribution, given by Sarker et al. (1982) and Sarker and Biswas (1986) were used for computation of assured rainfall at different probability levels:

$G(X) = q + \mathrm{p}F(X)$

$F(X)$ = gamma distribution function

q = probability of zero precipitation and $p = 1 - q$

$$F(X) = \int_0^x \frac{x^{\gamma-1} e^{-x/\beta}}{\left(\beta\right)^{\gamma} \Gamma\gamma} dx \tag{1}$$

$$X, \gamma, \beta > 0 \tag{2}$$

$F(X) = 0$, when $X \leq 0$.

where γ and β are the shape and scale parameters, respectively.

$\Gamma\gamma$ is the gamma function

$H(X)$ = Probability of rain $\leq X$

The probability of rain $< X$, $H(X) = [Q + (1-Q]\int_0^x \frac{x^{\gamma-2} e^{-x/\beta}}{(\beta)^{\gamma}\Gamma\gamma} dx$, Q is the empirical probability of zero rain, being the ratio of occasions of zero rain to the total number of occasions and X includes zero rain also.

The probability of rain $\geq X$, $P_x = 1 - H(X) = (1 - Q) \left\{1 - \int_0^x \frac{x^{\gamma-1} e^{-x/\beta}}{(\beta)^{\gamma}\Gamma\gamma} dx\right\}$

2.2.3 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

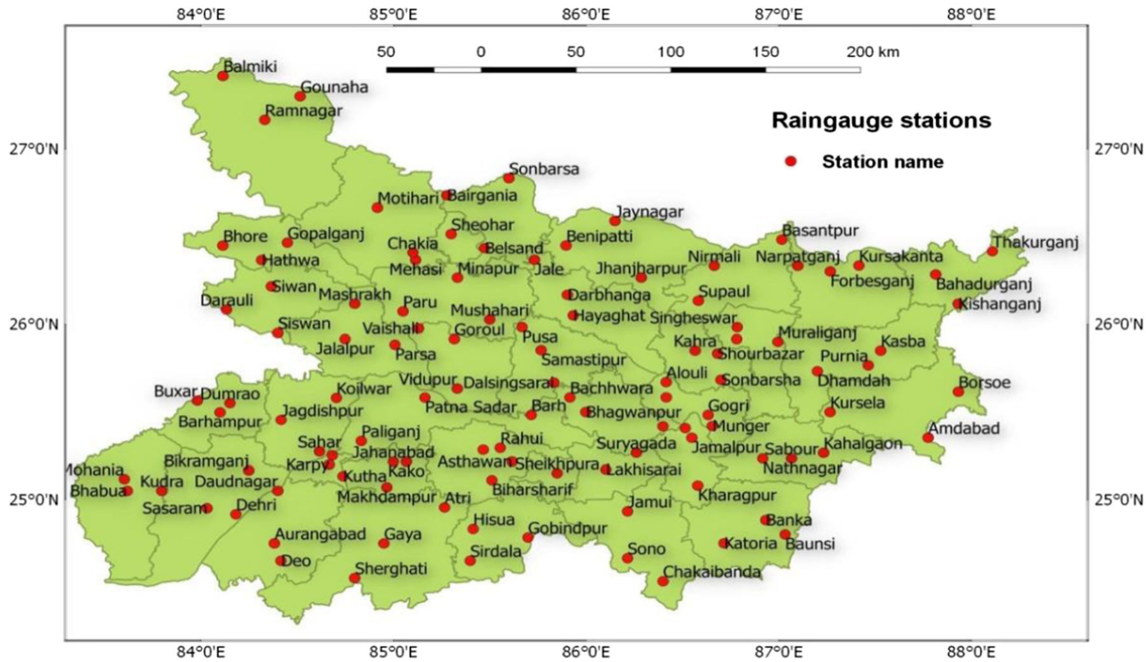

Fig. 3 Names of rain-gauge stations used in the study

carried out. Interpolation using inverse distance to power method was done for generating thematic maps pertaining to MAI and assured rainfall at different probability levels.

3 Results and discussion

3.1 Sowing window of rainfed crops

Moisture regime is an important agroclimatic factor governing the planting time of a crop. The sowing window, which is a range of time for sowing of crops, is narrower for rainfed crops than those grown with irrigation. In areas with limited or no irrigation facilities, identification of sowing windows is necessary for guiding the farmers to sow their crops at appropriate times for achieving higher yield. At 25% probability level, i.e., in 25 out 100 years, the earliest period of sowing of rainfed crops with MAI ≥ 0.33 varied from 16 to 23 SMW over all the districts in the state. While considering agroclimatic zones of the state, the earliest sowing weeks with attainment of MAI ≥ 0.33 varied from 16 SMW in West Champaran District to 21 SMW in Vaishali, Saran, and Siwan Districts under Zone I. In Zone II, it was observed to vary from 15 to 20 SMW, 16 to 21 SMW in Zone IIIA, and 21 to 23 SMW in Zone IIIB, where 9 out 11 districts recorded sowing week at 23 SMW. At 50% probability level (i.e., 50 out of 100 years), the sowing weeks over different districts ranged from 19 to 24 SMW in Zone I, 18 to 23 SMW in Zone II, 23–24 SMW in Zone IIIA, and 24–25 SMW in Zone IIIB. At 75% probability level, the sowing with MAI ≥ 0.33 was observed to be delayed considerably across the districts of different agroclimatic zones. The sowing week at 75% probability level varied from 24 to 26 SMW in Zone I, 20 to 25 SMW in Zone II, and 24–25 SMW in Zone IIIA. However, all the districts under Zone IIIB recorded sowing week together during 26 SMW. To identify the start of growing period for Madhya Pradesh, India, the week when MAI was greater than or equal to 0.30 was taken as the beginning of growth period (Das 1987). The results revealed that, on an average, the districts under Zone II recorded the earliest sowing window for starting the sowing of rainfed crops, and the most delayed start of sowing was recorded over the districts under Zone IIIB at all probability levels. Accordingly, in order to utilize the advantage of the earliest sowing window, the farmers need to be alerted through agrometeorological advisories to undertake sowing operation. For rainfed crop planning, most important task is to match the reproductive phase of a crop with a period where the moisture is adequate, i.e., MAI ≥ 0.70 (Sarker and Biswas 1988). The information on sowing window could be useful guidelines for the farmers to take up sowing of rainfed crops and transplanting of low land rice at appropriate times, according to actual sowing window, as it is one of the key factors, which strongly affect crop production (Ati et al. 2002) in rainfed agriculture. Moreover, late sowings of crops in an area shorten the length of crop growing period and increase the infestation of weeds (Vaksmann et al. 1996), leading to significant reduction in productivity. Sattar and Khan (2015) opined that agrometeorological appraisal of sowing window worked out through probabilistic rainfall analysis is a useful and rational approach for potential productivity evaluation under rainfed condition.

3.2 Length of growing period/water availability period for rainfed crops

Durations in weeks with MAI ≥ 0.33, ≥ 0.70, and ≥ 1.00, accumulated assured rainfall (AAR) calculated at 25, 50, and 75% probability levels and PET for various districts of Bihar are presented in the Table 1. Following the study conducted by Sarker and Biswas (1986, 1988), the water availability periods with MAI ≥ 0.33, 0.70, and ≥ 1.00 in various districts at 25, 50, and 75% levels have been discussed in this paper.

3.2.1 Growing period at 25% probability level

At 25% probability level, i.e., 25 out 100 years, MAI ≥ 0.33 prevailed for a period of 22 weeks in Vaishali, Saran, and Siwan Districts, as against 27 weeks in West Champaran District. Periods with MAI ≥ 0.70 ranged from 19 weeks in Siwan and Madhubani Districts to 25 weeks in West Champaran District with AAR at MAI ≥ 0.33 varying from 1299.9 to 2279.0 mm in the districts under Zone I. In Zone II, the durations in weeks with MAI ≥ 0.33 and ≥ 0.70 were 23 to 28 weeks and 19 to 26 weeks, respectively, whereas the AAR ranged from 1460.8 to 2797.6 mm across various districts of this Zone. The districts under Zone IIIA recorded MAI ≥ 0.33 and ≥ 0.70 for the periods ranging from 22 to 28 weeks and 19 to 22 weeks, respectively, with AAR ranging from 1321.0 to 1625.5 mm. However, such durations with MAI ≥ 0.33 and ≥ 0.70 were shorter over the districts under Zone IIIB, compared to those in other zones of the state. At 25% probability level, the water availability periods with MAI ≥ 0.33 and ≥ 0.70 were 20 to 22 weeks and 16 to 18 weeks, respectively, in Zone IIIB, where the values of AAR were much lower than those recorded in the districts under the remaining agroclimatic zones. As compared to other zones, small variability in duration with MAI ≥ 0.33 and ≥ 0.70 was also observed in the districts under Zone IIIB. Crop prospect is high in all the districts at 25% probability level because of higher duration with MAI ≥ 0.33 and ≥ 0.70 (Sarker and Biswas 1986, 1988). The longer growing period provides better prospects for rainfed crops giving rise to more productivity and well-being of the farmers (Sattar and Khan 2015).

3.2.2 Growing period at 50% probability level

Sarker and Biswas (1986, 1988) considered MAI ≥ 0.33 and ≥ 0.70 using assured weekly rainfall at 50% probability as optimum moisture availability index (OMAI). At this probability level, the shortest duration of water availability (17 weeks) with MAI ≥ 0.33 was observed in Saran, Begusarai, and Vaishali Districts, as against the longest duration of 23 weeks in West Champaran District under Zone I (Table 1). At MAI ≥ 0.70, such duration varied from 14 weeks in Siwan and Vaishali Districts to 18 weeks in Sitamarhi and West Champaran Districts. At 50% probability level, AAR varied from 628.8 to 1143.8 mm in Zone I. Considering MAI and AAR, West Champaran District appears to be the most productive district among all the districts under Zone I. Similarly, Vaishali District seems to be the vulnerable one to produce low in terms of water availability period. The districts under Zone II recorded a cropping period varying from 19 weeks in Saharsha and Khagaria to 25 weeks in Kishanganj District with MAI ≥ 0.33, whereas at MAI ≥ 0.70 Saharsa and Khagaria Districts recorded a cropping period of 15 weeks, as against 21 weeks in Kishanganj District. The highest AAR of 1636.2 mm was recorded in Kishanganj, as against the lowest of 695.9 mm in Saharsa District. In Zone IIIA, duration with MAI ≥ 0.33 extended from 18 weeks in Jamui, Lakhisarai, and Sheikhpura Districts to 20 weeks in Banka and Bhagalpur districts. With MAI ≥ 0.70, the duration of water availability extended from 14 weeks in Sheikhpura District to 17 weeks in Banka District. At MAI ≥ 0.33, the districts under Zone IIIB exhibited rainfed crop growing period of 15 weeks in Kaimur and Arwal Districts to 17 weeks in Patna, Gaya, and Bhojpur Districts. Water availability durations with MAI ≥ 0.70 varying from 12 weeks in Aurangabad District to 14 weeks in Patna, Nawada, Gaya, Jahanabad, Buxar, and Kaimur Districts were recorded (Table 1). The excess moisture (MAI ≥ 1.00) prevailed for 12–16 weeks in the districts under Zone I, 13–17 weeks under Zone II, 14–15 weeks under Zone IIIA, and 10–13 weeks under Zone IIIB at 50% probability level. Water availability period calculated based on MAI ≥ 0.33, 0.70, and 1.00 at 50% probability levels showed a wide variability across the state (Figs. 4, 5, and 6). The growing period thus evaluated could be utilized for devising location specific efficient climate smart crop production.

3.2.3 Growing period at 75% probability level

As compared to 50% probability level, the water availability period at 75% probability level reduced by 5 to 7 weeks with MAI ≥ 0.33 and MAI ≥ 0.70 over different districts under Zone I. The water availability periods with MAI ≥ 0.33 and MAI ≥ 0.70 attained 2–5 and 2 weeks later, respectively, than those at 50% probability level. In Zone II, at 75% probability, the growing period reduced by 5 to 6 weeks with MAI ≥ 0.33 and 5 to 7 weeks with MAI ≥ 0.70 as compared to 50% probability level. All districts under Zone IIIA recorded a growing period of 15 weeks, a reduction of 3 to 5 weeks with MAI ≥ 0.33 when compared with 50% probability. At MAI ≥ 0.70, the water availability period of 9 to 11 weeks was observed, as against 14–17 weeks with similar MAI level at 50% probability level. The districts under Zone IIIB registered a cropping duration of 12 to 13 weeks with a reduction of 3 to 4 weeks with MAI ≥ 0.33 as compared to 50% probability. However, a large variability in growing period with MAI ≥ 0.70 was observed across the districts of Zone IIIB. At this moisture level

Table 1 Moisture availability index (MAI) based water availability duration, potential evapotranspiration (PET), and accumulated assured rainfall (AAR) at 25, 50, and 75% probability levels and suggested crops for different districts of Bihar

District	25% probability					50% probability					75% probability					Suggested crops
	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	
	≥0.33	≥0.70	≥1.00			≥0.33	≥0.70	≥1.00			≥0.33	≥0.70	≥1.00			
Zone I (north west alluvial plains)																
Darbhanga	26	20	17	1502.9	826.8	18	15	14	682.3	515.5	14	10	–	279.0	415.7	Medium duration rice, lentil, pigeon pea, sesame
Samastipur	24	22	18	1582.2	785.3	19	15	15	715.5	564.5	15	10	–	278.1	439.1	Medium duration rice, pigeon pea, sesame, lentil, pigeon pea
Muzaffarpur	23	20	18	1559.4	741.5	18	15	14	722.1	541.5	14	8	–	286.3	416.5	Medium duration rice, pigeon pea, sesame, lentil, lentil, rapeseed
Madhubani	25	19	18	1565.7	753.4	18	15	15	752.2	579.5	14	9	2	299.3	399.4	Medium duration rice, *kharif* maize, pigeon pea, lentil, mustard
E. Champar-an	25	22	18	1747.9	776.3	18	17	15	847.8	580.7	14	12	4	346.7	415.4	Medium duration rice, jute, pigeon pea, sugarcane, lentil, wheat
Goapalganj	23	20	18	1541.5	733.0	18	15	12	732.7	538.3	12	11	3	289.7	354.6	Short duration rice, *kharif* maize, sesame sunflower, rapeseed
Saran	22	20	16	1445.9	655.0	17	15	12	685.8	505.3	13	7	–	264.7	357.8	Short duration rice, *kharif* maize, sesame, lentil, rapeseed
Sitamarhi	26	22	18	1735.6	770.6	20	18	15	801.5	589.8	13	11	4	294.2	399.0	Medium duration rice, pigeon pea, sesame, lentil, rapeseed
Sheohar	26	22	17	1740.5	776.5	19	17	15	790.2	570.4	13	11	4	299.4	385.4	Medium duration rice, sesame, lentil, chick pea, rapeseed
Siwan	22	19	18	1459.9	706.2	18	14	13	692.3	545.7	13	7	3	268.3	358.8	Medium duration rice, sesame, *kharif* maize, sesame, lentil, rapeseed
Vaishali	22	18	16	1299.9	653.6	17	14	14	628.8	518.1	13	8	–	254.6	358.7	Medium duration rice, sesame, lentil, lentil, rapeseed
W. Champar-an	27	25	19	2279.0	838.0	23	18	16	1143.8	720.0	16	13	9	475.4	483.5	Long duration rice, pigeon pea, sugarcane, chick pea, mustard, wheat, *rabi* maize, green gram
Begusarai	25	20	16	1469.0	784.8	17	15	15	691.1	528.9	15	8	–	294.4	425.7	Medium duration rice, mustard, sesame, lentil, chick pea
Zone II (North east alluvial plains)																
Araria	27	26	22	2298.6	809.4	24	20	17	1196.9	706.0	17	13	12	526.5	497.8	Long duration rice, sugarcane, jute, lentil, mustard, *rabi* maize
Katihar	27	24	21	1880.0	796.4	22	18	17	965.4	667.8	17	14	4	413.6	454.6	Long duration rice, jute, lentil, mustard, *rabi* maize
Khagaria	23	19	18	1563.6	802.0	19	15	13	709.1	569.4	13	8	–	272.0	432.9	

Table 1 (continued)

District	25% probability					50% probability					75% probability					Suggested crops
	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	
	≥0.33	≥0.70	≥1.00			≥0.33	≥0.70	≥1.00			≥0.33	≥0.70	≥1.00			
																Medium duration rice, *rabi* maize, mustard, chick pea
Kishanganj	28	26	23	2797.6	858.8	25	21	20	1636.2	760.0	19	16	13	861.8	594.5	Long duration rice, sugarcane, jute, wheat, mustard
Madhepura	28	23	19	1760.8	927.7	23	18	14	898.8	730.4	15	11	6	363.4	411.3	Medium duration rice, *kharif* maize, mustard, lentil
Saharsha	23	20	19	1470.7	774.0	19	15	14	695.9	602.0	14	8	2	267.6	396.0	Medium duration rice, *kharif* maize, mustard, lentil
Supaul	25	23	18	1836.7	878.0	21	18	15	910.2	726.7	15	12	4	370.8	498.5	Medium duration rice, jute, mustard, lentil
Purnia	28	25	21	2265.4	832.4	24	18	17	1146.7	706.2	16	15	11	471.9	453.9	Long duration rice, sugarcane, jute, mustard, lentil
Zone IIIA (South Bihar alluvial plains)																
Banka	23	20	18	1425.6	689.4	20	17	15	750.9	563.9	15	9	2	344.6	437.7	Medium duration rice, lentil, *kharif* maize, mustard, chick pea
Bhagalpur	28	22	20	1625.5	892.5	20	16	15	798.3	646.1	15	10	4	327.2	412.9	Medium duration rice, *kharif* maize, chick pea, lentil, mustard
Jamui	23	20	17	1514.0	674.6	18	16	15	799.1	561.2	15	11	7	365.4	405.7	Medium duration rice, *kharif* maize, chick pea, mustard, lentil
Lakhisarai	22	19	16	1328.0	656.9	18	15	15	686.8	541.5	15	10	2	312.4	410.1	Medium duration rice, *kharif* maize, lentil, chick pea
Sheikhpura	22	20	16	1321.0	650.8	18	14	14	697.4	547.8	15	9	2	320.2	418.2	Medium duration rice, lentil, mustard
Munger	24	19	18	1548.4	783.3	19	15	15	728.3	546.8	15	10	–	294.5	414.6	Medium duration rice, mustard, chick pea
Zone IIIB (South Bihar alluvial plains)																
Gaya	21	17	17	1268.8	722.2	17	14	10	655.5	591.8	12	6	3	297.4	468.0	*kharif* maize, very short duration rice, black gram, sorghum, sunflower, rapeseed
Auranagabd	21	17	15	1323.9	726.3	16	12	11	668.1	547.9	12	6	4	302.0	410.0	*kharif* maize, short duration rice, black gram, sorghum, sunflower, rapeseed
Jahanabad	20	17	15	1176.5	649.7	16	14	12	554.1	469.7	12	1	–	223.0	381.9	Short duration rice, *kharif* maize, black gram, sorghum, rapeseed, sunflower
Kaimur	20	16	15	1295.2	604.0	15	14	12	635.2	460.9	12	7	5	265.3	339.9	Short duration rice, black gram, sorghum, rapeseed, sunflower
Nalanda	21	16	16	1105.9	649.7	16	13	13	526.2	469.7	13	3	–	217.7	380.9	Medium duration rice, *kharif* onion, *kharif* maize, sorghum, sunflower, rapeseed
Nawada	21	17	14	1225.5	709.2	16	14	12	577.7	561.0	12	1	–	221.6	397.2	Short duration rice, *kharif* onion, *kharif* maize, sorghum, sunflower, rapeseed

Table 1 (continued)

District	25% probability					50% probability					75% probability					Suggested crops
	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	Duration in weeks with MAI			AAR (mm) with MAI ≥0.33	PET (mm)	
	≥0.33	≥0.70	≥1.00			≥0.33	≥0.70	≥1.00			≥0.33	≥0.70	≥1.00			
Rohtas	20	16	15	1283.3	616.5	16	13	12	659.5	471.4	12	7	6	300.0	347.5	Short duration rice, *kharif* maize, sorghum, sunflower, rapeseed,
Bhojpur	20	17	16	1340.4	695.6	17	13	12	650.3	508.7	12	9	–	258.0	353.3	Short duration rice, *kharif* maize, rapeseed, chick pea
Buxar	20	16	16	1400.5	613.9	16	14	13	698.2	468.5	13	10	3	302.5	400.1	Medium duration rice, *kharif* maize, *kharif* onion, mustard
Arwal	20	18	15	1187.9	605.8	15	13	11	554.4	472.9	12	4	–	223.0	384.7	*kharif* maize, short duration rice, black gram, sorghum, sunflower, rapeseed
Patna	22	18	16	1367.2	745.1	17	14	13	657.1	535.4	13	10	–	265.0	381.8	Medium duration rice, *kharif* maize, sunflower, mustard

(MAI ≥ 0.70), cropping duration of only 1 week was observed in Jahanabad and Nawada Districts. Patna and Buxar Districts recorded the highest cropping period of 10 weeks during which AAR varied from 217.7 mm in Nalanda District to 302.5 mm in Buxar District (Table 1). While scrutinizing the results on water availability based on MAI, it was found that Kishanganj District recorded the highest duration of water availability period followed by West Chamaparan District at all MAI and probability levels. The districts under Zone IIIB recorded shorter duration of water availability as compared to the districts under the remaining agroclimatic zones. Hence, in terms of longer length of water availability period and higher values of MAI, Zone II appeared to be the most potential agroclimatic zone followed by Zone I and Zone IIIA. The Zone IIIB was adjudged as the least potential zone in terms of shorter water availability period for rainfed crop production. The assessment of sowing windows and length of growing period based on MAI at different probability levels are useful findings of agronomic relevance for their field application for further augmentation of grain yield of rainfed crops in the state of Bihar under middle Gangetic plains of India. Using MAI, safe cropping period and optimum dates of sowing were worked out (Subba Rao and Rama Mohan Rao 1985; Banik and Sharma 2009). Saha et al. (2012) working at Mohanpur, West Bengal, India, observed that moisture availability periods at 50 and 75% probability levels with MAI ≥ 0.34 was found to occur from 19 to 42 SMW and from 23 to 39 SMW, respectively, in Birbhum District of West Bengal and on the basis of MAI, they recommended the sowing of rainfed crops in 23 and 25 SMWs at 50 and 75% probability levels, respectively.

The AAR with MAI ≥ 0.33 presented in Figs. 7 and 8 revealed that long duration rainfed crops could be grown successfully even in Zone IIIB at 50% probability level. However, at 75% probability level, major area of the state having AAR to the tune of 250–300 mm implied that in a vast tract of the state, only short to medium duration crop varieties will be able to produce at potential level. Sarker and Biswas (1986) while working on agroclimatic classification for assessment of crop potential in the dry farming tract of India opined that a short duration crop (10–12 weeks) requires 250 mm of AAR with MAI ≥ 0.33. Similarly, a medium duration crop of 12 to 16 weeks will require about 350 mm of AAR, and a long duration crop of more than 16 weeks will require more than 400 mm AAR.

3.3 Exploring crop possibilities based on agroclimatic potential

In terms of longer length of water availability and higher values of MAI, Zone II is adjudged as the most potential zone for rainfed crop production followed by Zone I, Zone IIIA, and Zone IIIB. It is vital that farmers should grow crop

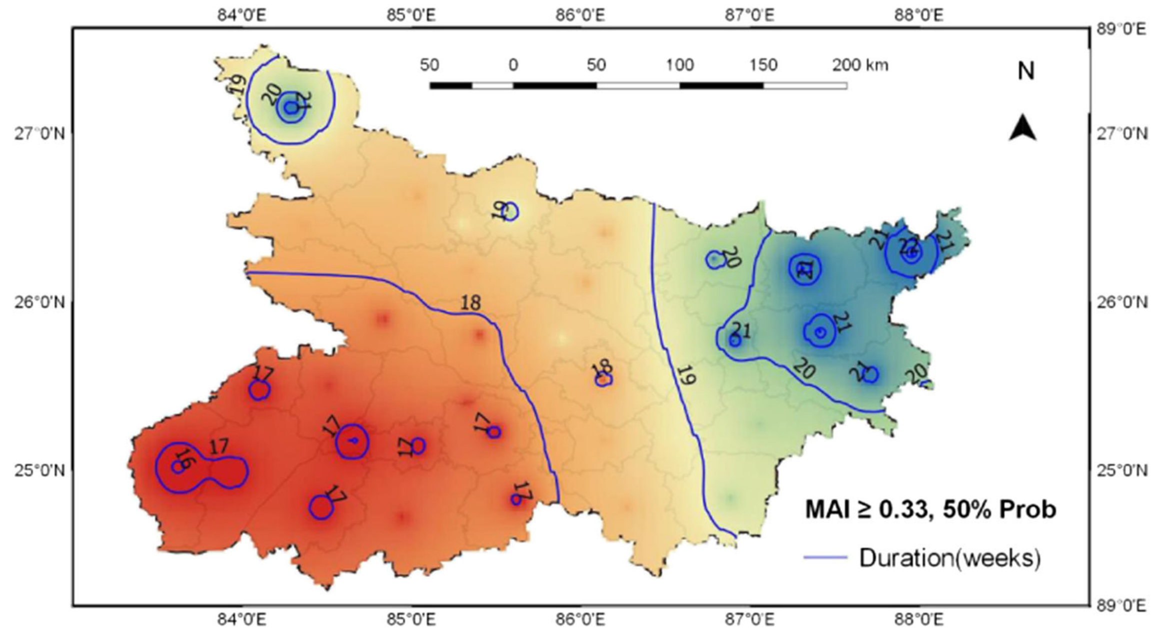

Fig. 4 Water availability period based on moisture availability index (MAI) ≥ 0.33 at 50% probability level in Bihar, India

varieties according to water availability period available in their areas, which would help produce 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. Bihar being an ecologically vulnerable state, the impacts of climate change on agriculture would be much more pronounced. The direct impact of climate changes is that the *kharif* agriculture will become vulnerable due to increased frequency of extreme weather events such as erratic rainfall and frequent dry spell during monsoon. The principal *kharif* crop of the region is rice, which is grown with receipt of monsoon rainfall. So, any change in rainfall pattern would be detrimental to sustainable rice production (Sattar et al. 2016). Rabi crop production may become comparatively more vulnerable due to increase in temperature, asymmetry of day and night temperature. Changes in temperature play an important role in determining crop productivity (Fiscus et al. 1997). Singh and Sontakke (2002) observed a decreasing trend of summer monsoon rainfall of about 50 mm per 100 years during 1900–1984 followed by an increasing trend of 48 mm per 100 years during 1984–1999 over eastern Indo-Gangetic Plains. Das and Lohar (2005) have shown a maximum 4%

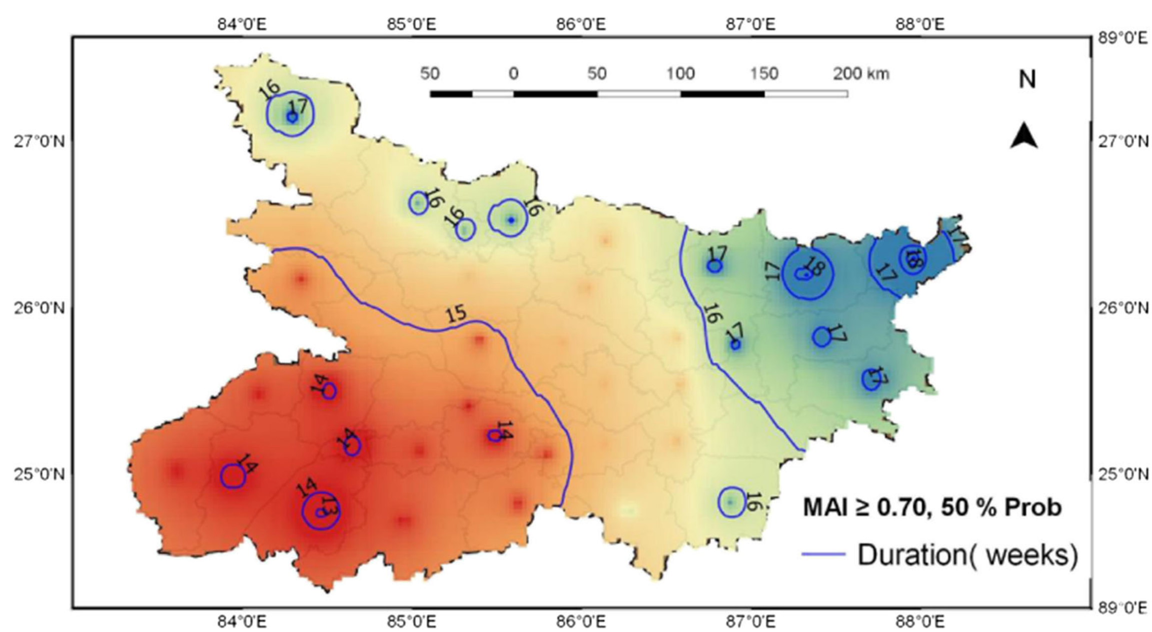

Fig. 5 Water availability period based on moisture availability index (MAI) ≥ 0.70 at 50% probability level in Bihar, India

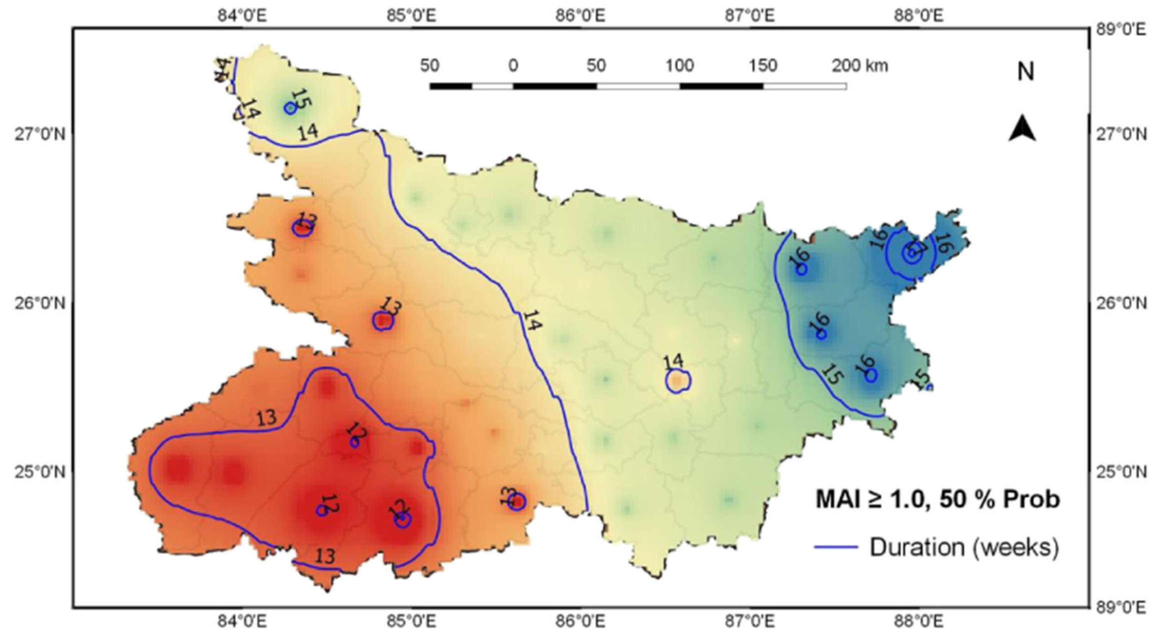

Fig. 6 Water availability period based on moisture availability index (MAI) ≥ 1.00 at 50% probability level in Bihar, India

change in rainfall for all seasons during 2010–2039 over eastern part of India using six GCMs from Third Assessment Report of IPCC. Simulations with regional climate models also project increasing temperature trends for future. During 2081–2100, the mean temperature increase may be in the tune of 3.6 °C for RCP 8.5 (IPCC 2013). For Eastern India, the mean temperature increase may be in the tune of 1 °C for 2020 and 3 °C in 2050 for A2 scenario (Boomiraj et al. 2010). Haris et al. (2013) observed decline in productivity of rice-wheat cropping system in Bihar owing to increase in temperature. Future scenarios indicated substitution of winter wheat by winter maize in regions unfavorable for wheat cultivation. Pathak et al. (2003) reported that decline in potential yield of wheat and rice was associated with negative trend in solar radiation and an increase in minimum temperature in the Indo-Gangetic Plains of India. Against this background, it is necessary to have climate-driven food production system in the eastern region of India to enhance resilience of agricultural production to changing climate. This would bring stability in the farmers' income and contribute to rural prosperity.

In this context, mechanisms for adapting to climate change could be developed by considering the agroclimatic zones

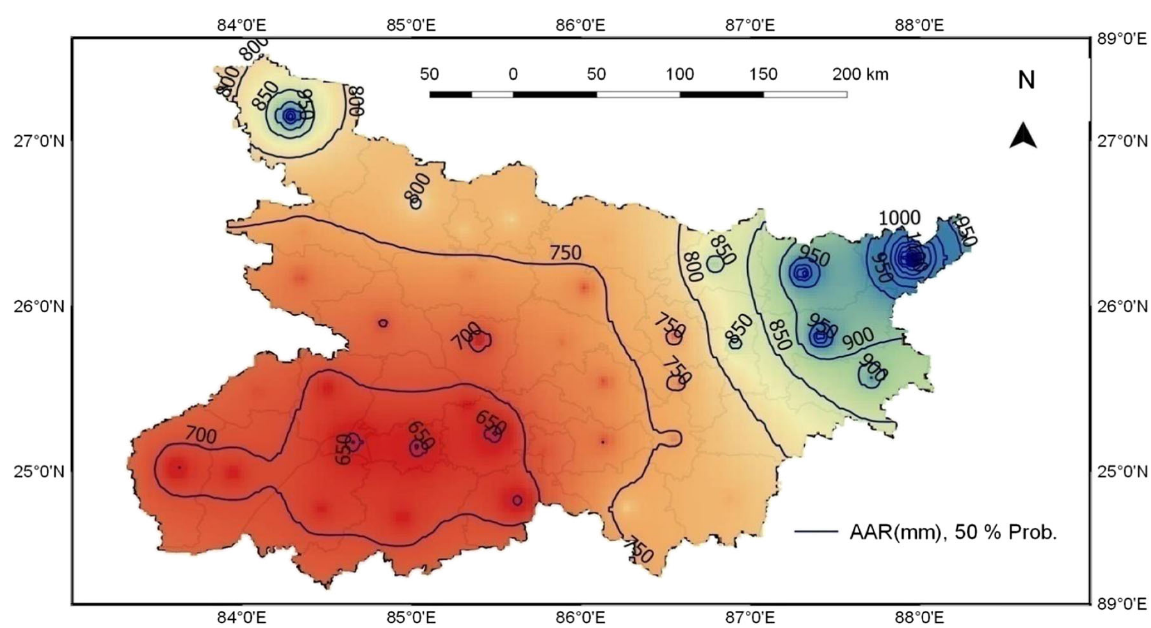

Fig. 7 Accumulated assured rainfall, AAR (mm) with MAI ≥ 0.33 at 50% probability level over different districts of Bihar, India

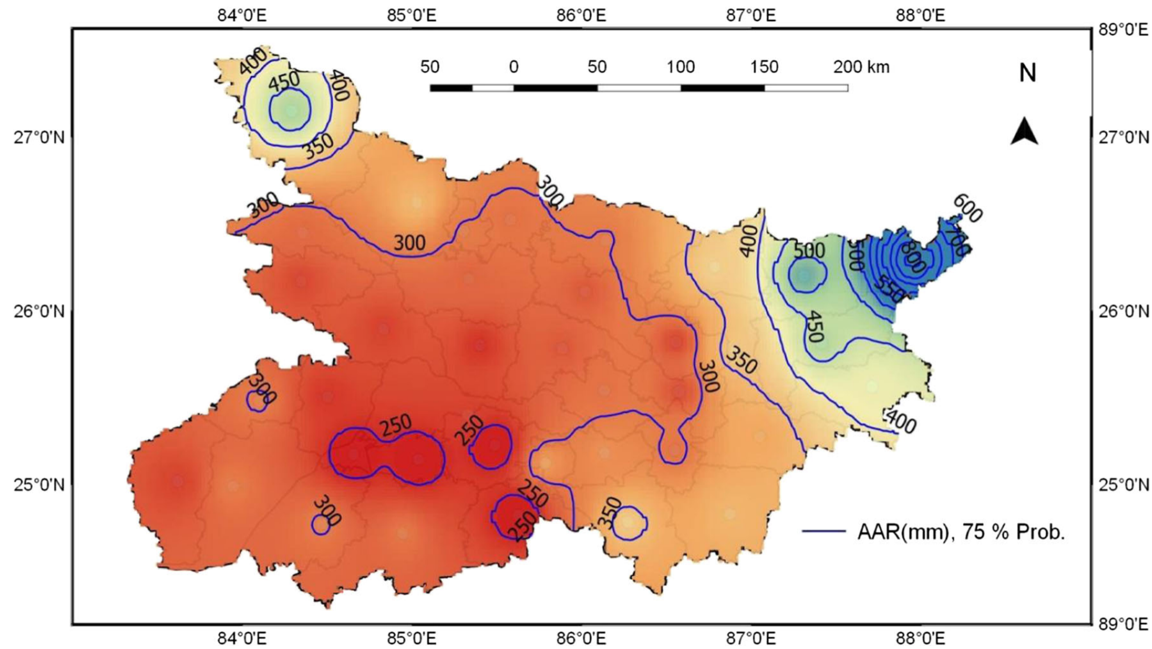

Fig. 8 Accumulated assured rainfall, AAR (mm) with MAI ≥ 0.33 at 75% probability level over different districts of Bihar, India

with precise information of water availability period at local level considering the soil type, rainfall, PET, and growing period. This will lead to have agricultural sustainability and food security in the vulnerable agro-ecosystem in the state of Bihar, where drought is a recurring phenomenon (Anon 2008). Among the four agroclimatic zones, agro-ecosystem of Zone IIIB is quite vulnerable due to having semi-arid climate. Drought-resistant and low water requiring crops should be selected for planting under 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 21 districts (Fig. 2), maize (*Zea mays*), pigeon pea (*Cajanus cajan*), sesame (*Sesamum indicum*), and chick pea (*Cicer arietinum*) could perform well. Usually 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 duration of 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 long duration rice (*Oryza sativa*), upland rice (*Oryza sativa*) and maize (*Zea mays*) are of shorter duration and 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) 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 north-western districts (West Champaran, East Champaran) under Zone I and some districts (Kishanganj, Araria, Purnia) of Zone II owing to higher MAI, longer growing period and humid climate.

Since the existing recommendation does not include appropriate rice varieties matching with actual water availability period, farmers tend to grow long duration rice cultivars in many districts without considering water availability period. The results emanated from the study revealed that long duration rice crop was not found suitable for growing in the districts under Zone I (except West Champaran District), Zone IIIA, and Zone IIIB. The crop suitability based on MAI at 50% probability has been worked out for different districts (Table 1). Short duration (10–12 weeks), medium duration (12–16 weeks), and long duration (> 16 weeks) rice crops have been recommended based on water availability period estimated at MAI > 1.00 at 50% probability level. Hargreaves (1975) considered MAI > 1.00 as adequate moisture. Other rainfed crops were suggested based on water availability in different districts of the state. The crops, such as lentil (*Lens culinaris*), chick pea (*Cicer arietinum*), rapeseed (*Brassica* *campestris*), mustard (*Brassica juncea*), sunflower (*Helianthus annuus*), wheat (*Triticum aestivum*), and *rabi* maize (*Zea mays*) are mostly grown on residual soil moisture after cessation of summer monsoon rain. Accordingly, these crops were suggested during *rabi* season based on estimated water availability period in different agroclimatic regions. However, provision of one irrigation during reproductive period of the crops like lentil (*Lens culinaris*), wheat (*Triticum aestivum*), and *rabi* maize (*Zea mays*) would be beneficial for greater growth and yield.

4 Conclusion

The information (viz. optimum sowing time and safe growing period) generated based on agroclimatic analysis at different risk levels could be a reliable guide in framing cropping plan to harness the climatic potential of the region. Moreover, it will help policy makers and farmers in identifying suitable crops 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 production under climate change scenarios. In most of the cases, farmers depend on 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. In this context, for climate smart agricultural production, farmers could be given advisory on sowing schedules and selection of crops varieties in their areas based on sowing window and matching with water availability period. The study also contributed substantially in delineating zone-specific efficient crops and cropping systems under rainfed condition and could assist plant breeders in identification of zones for which suitable rainfed crop varieties matching with growing period need to be bred. This would enhance the resilience of agricultural crop production system to climatic change and ensure rural prosperity through enhanced crop productivity and food security.

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