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Estimation of evaporation and soil moisture index based length of growing period for enhanced agricultural production in Bihar

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सार – किसी क्षेत्र में फसल के सतत उत्पादन के लिए ऋतु के दौरान कृषि जलवायविक क्षमता को समझने और नमी के प्रतिबल से बचने के लिए उस क्षेत्र में फसल वृद्धि की अवधि का अनुमान एक महत्वपूर्ण पहलू है। इसे ध्यान में रखते हुए, मृदा की नमी क्षमता और मृदा नमी सूचकांक (SMI) के आधार पर ए ई ≥ 0.5 पीई और वृद्धि की अवधि में पौधे की लंबाई (एलजीपी) की अवधारणा का पालन करके अनावृष्टि मुक्त विकास अवधि (डीएफजीपी) का मूल्यांकन करने के लिए बिहार के सभी 38 जिलों का कृषि जलवायविक अध्ययन किया गया। इस अध्ययन में 110 वर्षामापी स्टेशनों के ऐतिहासिक वर्षा डेटा (30 से 55 वर्ष), सामान्य साप्ताहिक वाष्पीकरण-वाष्पोत्सर्जन क्षमता (पीई) और विभिन्न प्रकार की मृदा संरचनाओं में उपलब्ध जलधारण क्षमता (एडब्ल्यूसी) का उपयोग किया गया। राज्य के प्रत्येक जिले के लिए मोटी, मध्यम और महीन संरचना वाली मृदा में फसल के आरंभ, अंत और पौधे की वृद्धि की अवधि पर मृदा नमी सूचकांक ≥0.4 और मृदा नमी की क्षमता (SMI≥0.7) के आधार पर कार्य किया गया। समान फसल उत्पादन क्षमता वाले क्षेत्रों की पहचान करने के लिए फसल के आरंभ, अंत और पौधे की वृद्धि की अवधि से संबंधि मानचित्र तैयार किए गए। पौधे के विकास की अधिकतम अवधि जोन II में और सबसे कम जोन IIIB में पाई गई। बदलती जलवायविक परिस्थितियों में जिला स्तरीय फसल योजना तैयार करने में डीएफजीपी और एलजीपी के संबंध में प्राप्त जानकारी एक महत्वपूर्ण दिशानिर्देश साबित हो सकती है।

ABSTRACT. Estimation of length of growing period for a region is an important aspect in understanding agroclimatic potential and avoiding moisture stress during growing season for sustainable crop production. Keeping this in view, an agroclimatic study was carried out for all 38 districts of Bihar to evaluate drought free growing period (DFGP) by following the concept of AE ≥ 0.5 PE and length of growing period (LGP) on the basis of potential soil moisture and soil moisture index (SMI). Historical rainfall data (30 to 55 years) of 110 rain-gauge stations, normal weekly potential evapo-transpiration (PE) and available water holding capacity (AWC) of different soil textural classes were utilized in this study. The onset, cessation and LGP in coarse, medium and fine textured soils for each district of the state were worked out based on SMI≥ 0.4 and potential soil moisture (SMI ≥0.7). Thematic maps of onset, cessation and LGP were generated to identify areas having similar crop production potential. The highest LGP was found to prevail in Zone II and the lowest in Zone IIIB. The information generated with respect to DFGP and LGP could prove to be an important guideline in framing district level crop planning under changing climatic condition.

Key words – Soil moisture index, Available water holding capacity, AE/PE, Crop planning.

1. Introduction

Availability of optimum soil moisture utilized by crop as actual evapotranspiration (AE) is key to successful crop production in a region. Due to variation in rainfall and its distribution and available water holding capacity in different soils, the water availability period varies from year to year and from soil to soil and influences the crop production differently (Sattar *et al.*, 2019). Thus, assessments of agroclimatic potential and climatic risk at micro level are important aspects for allocation of resources and management of rainfed agricultural system. Analysis of historical rainfall data through modern agroclimatic methods will be useful for developing appropriate strategies for enhancing and stabilizing rainfed crop production under changing climatic

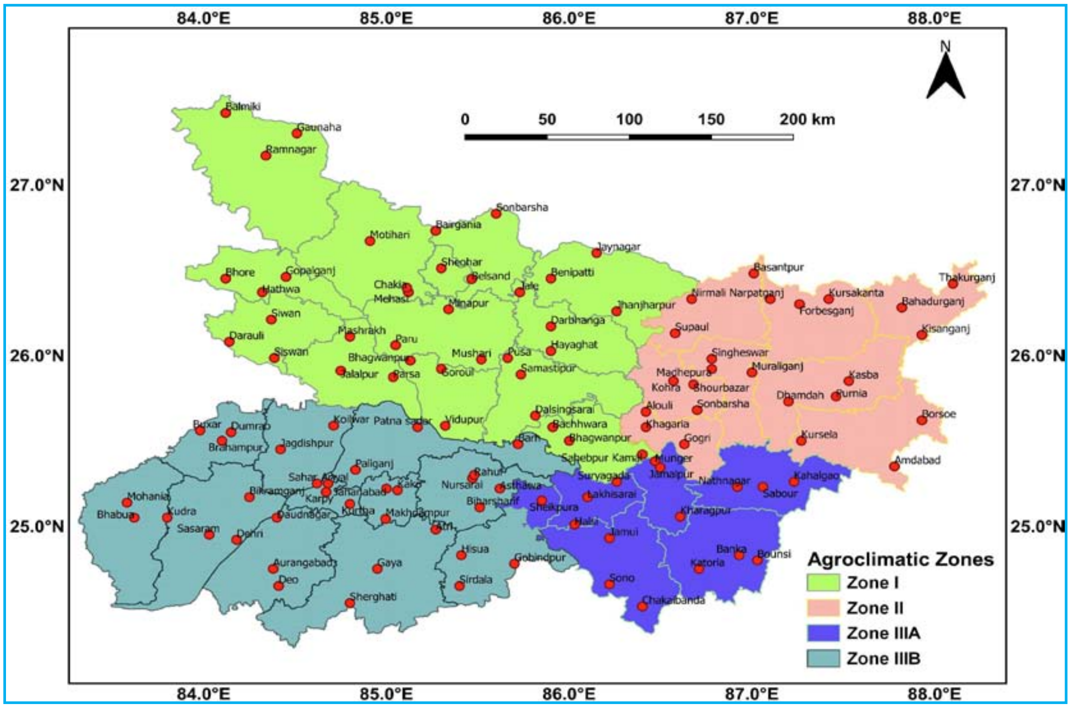

Fig. 1. Names of rain-gauge stations (under different agroclimatic zones) used in the study

condition. The information on potential evapotranspiration (PE), rainfall, onset of growing season, length of growing period (LGP) and agro-climatic zonation are very crucial aspects in weather sensitive agricultural sectors (Arya *et al.*, 2010; Sattar *et al.*, 2019). Therefore, proper understanding of seasonal rainfall distribution as well as the onset and cessation of the wet season contributes to better knowledge of the length of growing period and indirectly indicates the climatic suitability of the crop in a region. Swaminathan (2005) suggested for developing contingency crop planning for different rainfall patterns and work out comprehensive production programme at micro level for proactive monsoon management. He opined to change the saying "Indian agriculture is a gamble of the monsoon", into "India's strength lies in its ability to manage monsoons". The climatic water balance model of Thornthwaite and Mather (1955) is a unique tool for assessing agricultural potential of a region (Pandey and Shekh, 1999; Sattar and Khan, 2016a) and would help the farmers in preparing their crop calendar and improving crop productivity. The water balance approach has been widely investigated as the application of this method provides a clear picture of moisture deficiency and surplus water during the crop seasons and thus helping in better assessment of consumptive use, crop yields and evaluating crop potential of a region for successful crop production and undertaking effective management strategies under rainfed condition.

Soil moisture index (SMI) is considered to be directly related to the ratio of AE and PE (Baier, 1961). Victor and Sastry (1984) defined SMI as the ratio of actual available water to available water holding capacity in the root zone of a soil. Victor and Sastry (1984) studied weekly soil moisture budget for *kharif* cropping season using climatological water balance approach at Delhi region. They considered SMI value below 0.5 as stress and that of ≥ 0.7 as potential moisture condition based on which, frequency of occurrence of drought during *kharif* season in different growth stages was determined. Ramana Rao *et al.* (1979) worked out empirical probabilities for the ratio AE/PE being equal to or greater than 0.30, 0.60 and 0.75 in case of red sandy soils, 0.25, 0.50 and 0.75 in case of lateritic soils and 0.20, 0.40, 0.60 and 0.80 in case of medium and deep black soils generated from climatological water balance analysis for different types of soils of the Gulbarga region of Karnataka with varying water holding capacities ranging from 100 mm in red sandy soil to 250 mm in deep black soil. They used AE/PE for crop suitability planning in different soils. Sattar *et al.* (2016 b) used AE/PE as an important criterion for rainfed crop planning in Bihar.

Soil moisture and evaporation play crucial role in crop production. Hence, estimation of LGP based on these two agrometeorological parameters would provide realistic scenario of agricultural water availability for crops in a particular region, thus would help identify vulnerable areas of the state and support location-specific climate smart agricultural planning for enhanced production. Information on evaporation and soil moisture based LGP are rarely available and not found in literature for a state like Bihar, which faces the fury of droughts of different intensities every year. Hence, an attempt has been made in this article for correct evaluation of agro-climatic potential in terms of LGP based on evaporation and soil moisture with support of geographic information system (GIS), which will help policy makers and various stakeholders in agriculture to derive the scope for identifying suitable crops and to identify critical water resources, to amend the existing limitations to cropping, to avoid moisture stress during growing season and to formulate research priorities as well as to chalk out tactical and strategic plans for sustainable crop production. Keeping all these aspects in view, the present investigation was carried out with the objectives to assess evaporation and SMI based growing season in Bihar for enhanced agricultural production at micro level to bring in resilience of agricultural system to changing climate.

2. Materials and method

The present study was conducted for all 38 districts of Bihar, situated between 24°17' and 27°31' N latitudes and between 83°19' and 88°17' E longitudes. It has covers an area of 9.38 million hectares. The state 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. In this study, SMI and AE were estimated through "Thornthwaite and Mather (1955) climatic water balance model" based on historical rainfall data (30-55 years) of 110 rain-gauge stations distributed all across the state, normal weekly PE and available water holding capacity (AWC) of coarse-, medium- and fine-textured soils. Weekly rainfall data were collected from the India Meteorological Department, Pune and Agrometeorology Division, Centre for Advance Studies on Climate Change, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India. The rain-gauge stations used in the study are given in Fig. 1. The PE 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 (ICAR), Hyderabad (Bapuji Rao *et al*., 2011). Monthly PE of different stations across Bihar calculated using meteorological parameters through PET calculator software were converted into weekly total values by interpolation method (Rao and Vyas, 1983). When the rainfall is greater than PE, AE will be equal to PE. In that case, AE is equal to PE. When the rainfall is less than PE, the soil begins to dry out. In those weeks, the AE equals to the rainfall plus the amount of water drawn from the soil moisture storage.

AWC of soil was estimated for layer wise soil textural classes up to one meter soil depth of each soil series. All soil series as per NBSS & LUP, Nagpur falling under each district were considered to calculate the AWC of coarse, medium and fine textured soils of individual district (Saxton and Rawls, 2006 and Saxton, 2014). AWC per meter depth was worked as the difference between field capacity and permanent wilting point. Drought free growing period (DFGP) was worked out based on AE $\geq$ 0.5 PE. For determination of LGP meant for potential productivity evaluation under rainfed condition, the concept of SMI, which is the ratio between actual available soil moisture and AWC (FC-PWP) has been used. Following the methods of Baier (1961) and Victor and Sastry (1984), in the present study, weekly values of SMI were estimated as the ratio between available soil moisture and AWC for coarse, medium and fine textured soils for various districts of Bihar. Under sub-humid climate of Bihar, beginning of growing season was considered at a week when SMI $\geq$ 0.70 (Victor and Sastry, 1984) and cessation was considered when SMI $\leq$ 0.40 (Hargreaves, 1984). In case of potential moisture, the onset and cessation of growing season were considered in a week when SMI $\geq$ 0.70 and in a week when SMI $\leq$ 0.70, respectively. Accordingly, duration of potential moisture available for coarse, medium and fine textured soils in each district was worked out as difference between start and end week of potential moisture.

GIS software QGIS 2.2 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 NBSSLU&P was done in GIS environment. Thematic maps pertaining to onset, cessation and duration of potential moisture and AE $\geq$ 0.5 and SMI based LGP were developed using QGIS 2.2 software.

3. Results and discussion

3.1. *Drought free growing period*

3.1.1. *DFGP in Agroclimatic Zone 1*

In coarse textured soil, AE $\geq$ 0.5 PE, which is also regarded as drought free growing period (DFGP), recorded maximum duration (23 weeks) in West Champaran district as against the lowest of 18 weeks in

Vaishali, Siwan and Saran districts. Such period in medium textured soil was maximum (26 weeks) in West Champaran district and the lowest of 20 weeks in Muzaffarpur, Siwan and Saran districts. However, in fine textured soil, the period during which AE remained above 0.5 PE, was the highest (28 weeks), during 21-48 SMW, also in West Chamaparan district. The lowest duration (21 weeks) was recorded in Siwan, Saran, Begusarai and Muzaffarpur districts. The duration of DFGP was 2-5 weeks higher in fine textured soils than in coarse textured soil with the highest (5 weeks) being recorded in West Champaran and the lowest (2 weeks) in Muzaffarpur district. West Champaran district recorded the earliest commencement and delayed cessation of DFGP in all three categories of soil. In coarse textured soil, DFGP started during 21-25 SMW and terminated during 42-43 SMW in all districts. DFGP in medium textured soil started during 21-25 SMW and ended during 44-46 SMW. Considering fine textured soil, the onset of DFGP also varied between 21 and 25 SMW. However, the termination period was extended and it varied between 44 and 48 SMW. Krishnan *et al.* (1980) and Dey (2008) used the concept of AE ≥ 0.5 PE to work out drought free growing period. The week, from which AE was equal to or exceeded half of PE, was considered as the commencement of growing season and based on this concept, they suggested crop varieties suitable for the region. Hence, when all districts were considered together in Zone I, West Chamaparan district seemed to be the most productive district, while Vaishali, Saran and Siwan districts appeared to be less productive districts in terms of potential for rainfed crop production. The information on DFGP would add value to better planning and allocation of resources for enhanced crop production. Sattar *et al*. (2020) employed actual evapotranspiration for assessing climatic risk and moisture stress towards climate smart crop planning in Bihar.

3.1.2. *DFGP in Agroclimatic Zone I1*

Categorization of DFGP within an agroclimatic zone brings out areas with higher risk of crop production; thus helping planners and farmers to give more priority and attention in these districts. When AE ≥ 0.5 PE was considered, Purnia, Araria and Kishnaganj districts registered the longest duration of 25 weeks in coarse textured soil. On the other hand, shortest duration of 19 weeks was observed in Khagaria district. In medium textured soil, Kishanganj district recorded the highest duration (29 weeks) with AE ≥ 0.5 PE followed by Purnia district (28 weeks). The lowest duration (20 weeks) was associated with Khagaria district followed by Saharsha district (22 weeks). When fine textured soil was considered, the longest duration of 30 weeks with AE ≥ 0.5 PE was recorded in Kishanganj district followed by Purnia district (29 weeks). On the other hand, the shortest duration with AE ≥ 0.5 PE was also recorded in Khagaria district. There was a wide variation in the start week of DFGP in all textural classes across all districts. It started during 18-24 SMW in all three soils. The end of DFGP was registered during 42-43, 44-46 and 44-48 SMW in coarse, medium and textured soils, respectively. Based on moisture availability, Kishanganj district is adjudged as the best district in terms of agroclimatic potential and Khagaria and Saharsha seem to be less productive districts for rainfed crop production.

3.1.3. *DFGP in Agroclimatic Zone I1I A&B*

Considering AE ≥ 0.5 PE , it attained maximum durations of 23, 25 and 26 weeks in coarse, medium and fine textured soils, in Bhagalpur district respectively under Zone IIIA. In coarse textured soil, the lowest duration (18 weeks) with AE ≥ 0.5 PE was registered in Sheikhpura district. Lakhisarai and Sheikhpura districts showed the shortest duration of 21 weeks in medium textured soil and 22 weeks in fine textured soil. The highest amount of water surplus (482.5 mm) was observed in Jamui district and the lowest of 352.3 mm was recorded in Lakhisarai district. DFGP started during 21-24 SMW in all textural classes in this Zone. The cessation occurred during 41-43, 44-45 and 45-47 SMW in coarse, medium and fine textured soils, respectively. It could be concluded that among all the districts of agroclimatic zone IIIA, Bhagalpur appears to be the promising district. On the other hand, Sheikhpura and Lakhisarai districts are regarded as the most vulnerable ones in terms of lower agroclimatic potential for rainfed crop production.

Shorter duration with AE ≥ 0.5 PE (17-18 weeks) was observed across the districts in coarse textured soil of Agroclimatic Zone IIIB. Patna, Nalanda, Jahanabad and Arwal districts showed such duration as 18 weeks. Remaining districts showed 17-week duration. In medium textured soil, the longest duration (21 weeks) with AE ≥ 0.5 PE was recorded in Patna district and the shortest (17 weeks) in Nawada district. In fine textured soil, AE ≥ 0.5 PE prevailed for 20-21 weeks. The onset of DFGP was registered during 25-26 SMW in all types of soil. The cessation was recorded during 41-42 SMW, 43-45 SMW and 44-46 SMW in coarse, medium and fine textured soils, respectively. The lowest average water surplus (247.7 mm) was recorded in Nalanda district, as against the highest of 392.1 mm in Kaimur district. Hence, it is obvious that Patna district is adjudged to be the district with the highest agroclimatic potential for rainfed crop production. It is worthwhile to mention that estimated water availability parameters did not vary greatly over different districts under this agroclimatic zone.

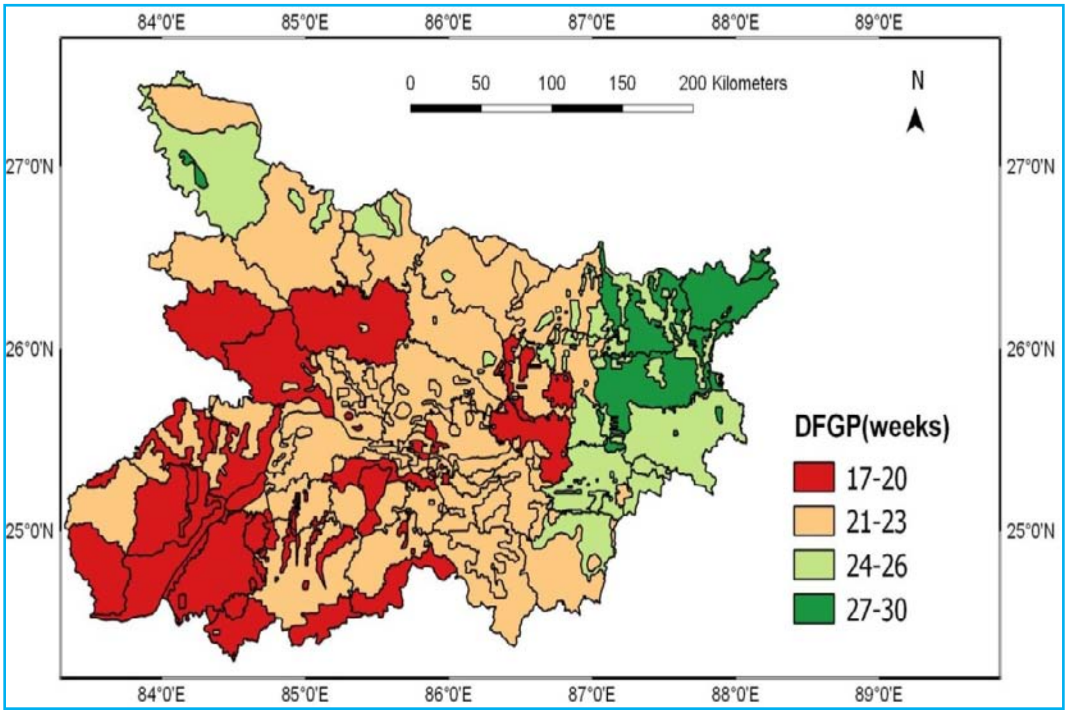

Fig. 2. Spatial variation in drought free growing period (DFGP) in Bihar

When all the districts under various agroclimatic zones of the state were considered together, it is evident that the districts of Zone II exhibited the highest agroclimatic potential. On the other hand, the districts of Zone IIIB appeared to be the most vulnerable ones as far as crop production under rainfed condition is concerned. When individual districts are considered, West Champaran district in Zone I and Kishanganj district in Zone II recorded the highest crop production potential under rainfed condition, whereas Arwal, Nawada, Gaya, Bhojpur, Buxar and Aurangabad districts situated in Zone IIIB exhibited the lowest potential. Thematic map super imposing soil textural map revealed clear picture of DFGP across the state (Fig. 2). For stabilizing crop production at certain level even in low rainfall years and areas, it is essential to know the real status of DFGP in a region so that agricultural planning is drawn up on rational scientific basis (Biswas and Nayar, 1984). The problem of erratic rainfall and consequently low production under rainfed condition may be overcome by understanding the sequence of DFGP and tailoring the crop plan on a rational basis with available rainfall resource for enhancing and stabilizing agricultural production (Sattar *et al.*, 2015). The study has appropriately brought out the agroclimatic potential for each individual districts of the state, which could be utilized in better planning and allocation of resources for enhancing crop production under rainfed condition.

3.2. *Variation in weekly soil moisture index and LGP*

Soil moisture, which is the major limiting factor for successful crop production in an area, plays a pivotal role in determining food sufficiency status of any nation (Mwale *et al.*, 2007). In this regard, SMI could be an important index for assessing agricultural drought. In the present study, weekly variations in SMI from 1 to 52 Standard meteorological weeks (SMW) under normal weather conditions for each district across various agroclimatic zones presented in Figs. 3-7 revealed that SMI values were maximum during *kharif* season, moderate during *rabi* season and minimum during summer season. During *kharif* season, the SMI values were almost same for all the soil textural classes, with relatively lower values for coarse textured soil. However, following *kharif* season, significant difference in SMI due to difference in soil texture and rainfall receipts was observed, but this difference gradually diminished with the approach of summer season. Soil moisture deficit during growing season is a measure of reflectance of agricultural drought intensity in that area, indicating stress condition for crop production (Carrão *et al.*, 2016; Vyas *et al.*, 2015). Hargreaves (1984) considered 0.40 SMI as the critical limit below which rainfed crops would suffer from moisture stress and consequently significant reduction in yield was observed. This level of moisture

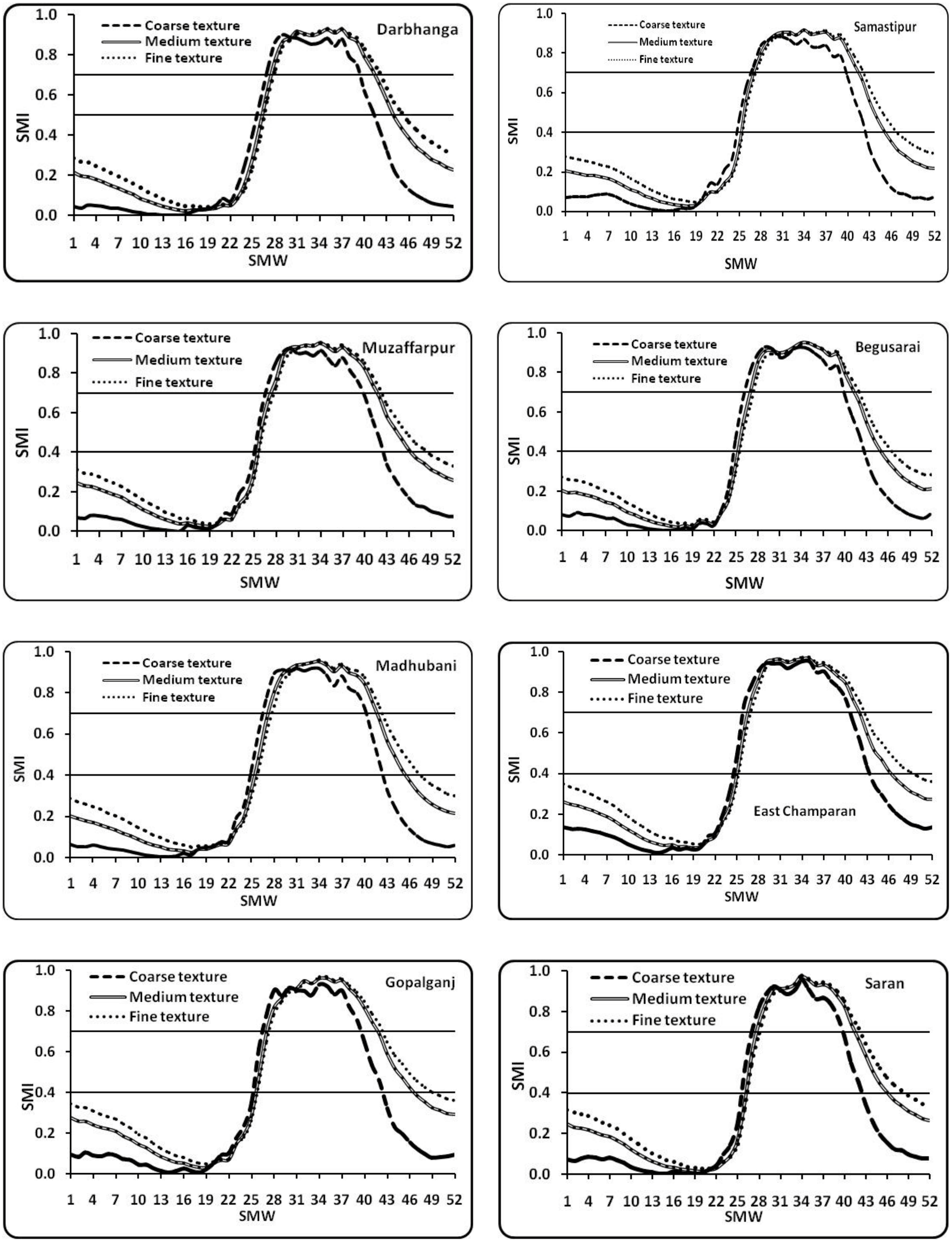

Fig. 3. Variation in weekly soil moisture index (SMI) in Darbhanga, Muzaffarpur, Madhubani, Gopalganj, Samastipur, Begusarai, East Champaran and Saran districts under Zone I

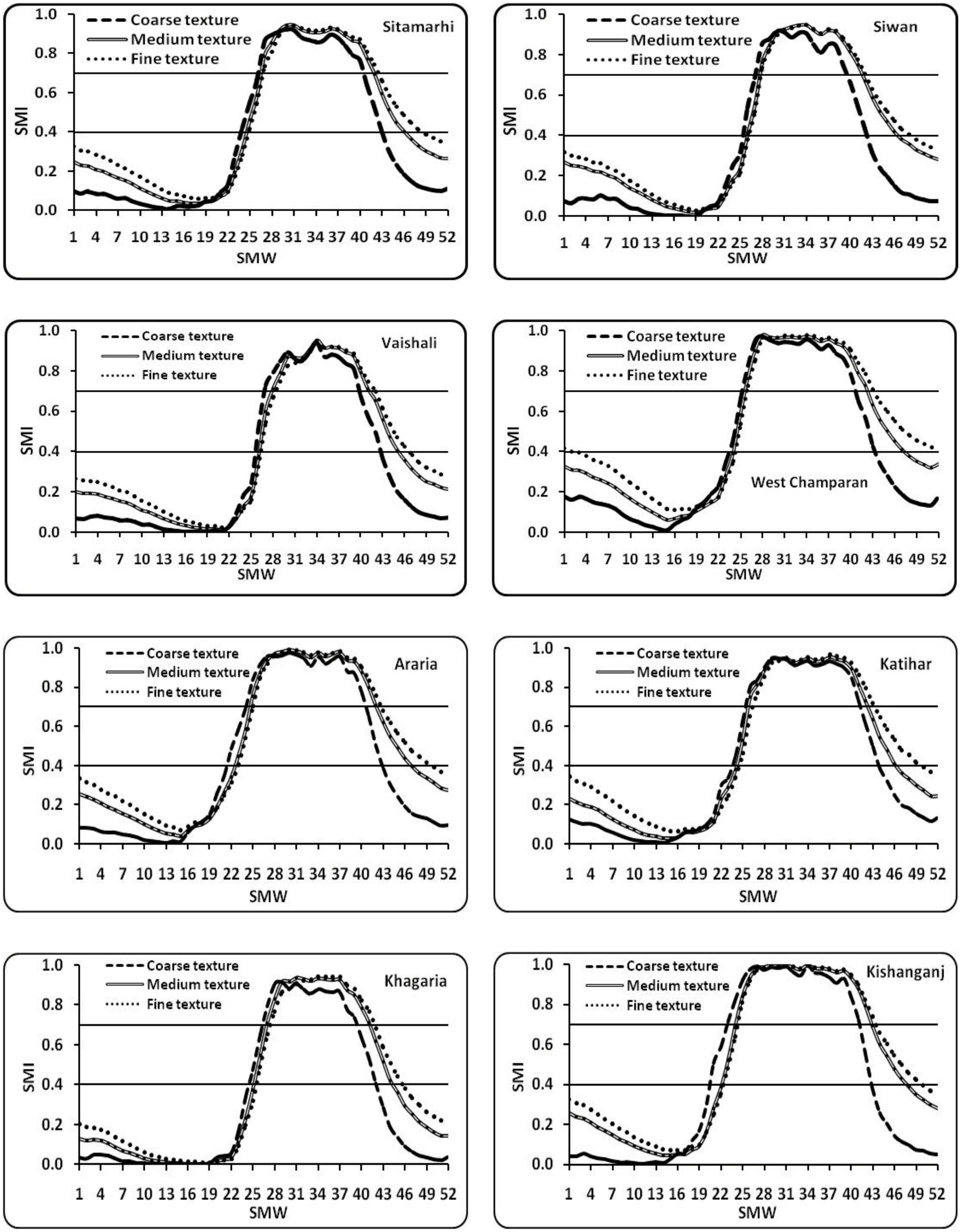

Fig. 4. Variation in weekly soil moisture index (SMI) in Zone 1 (Sitamarhi, Siwan, Vaishali and West Champaran districts) and Zone II (Araria, Katihar, Khagaria and Kishanganj districts)

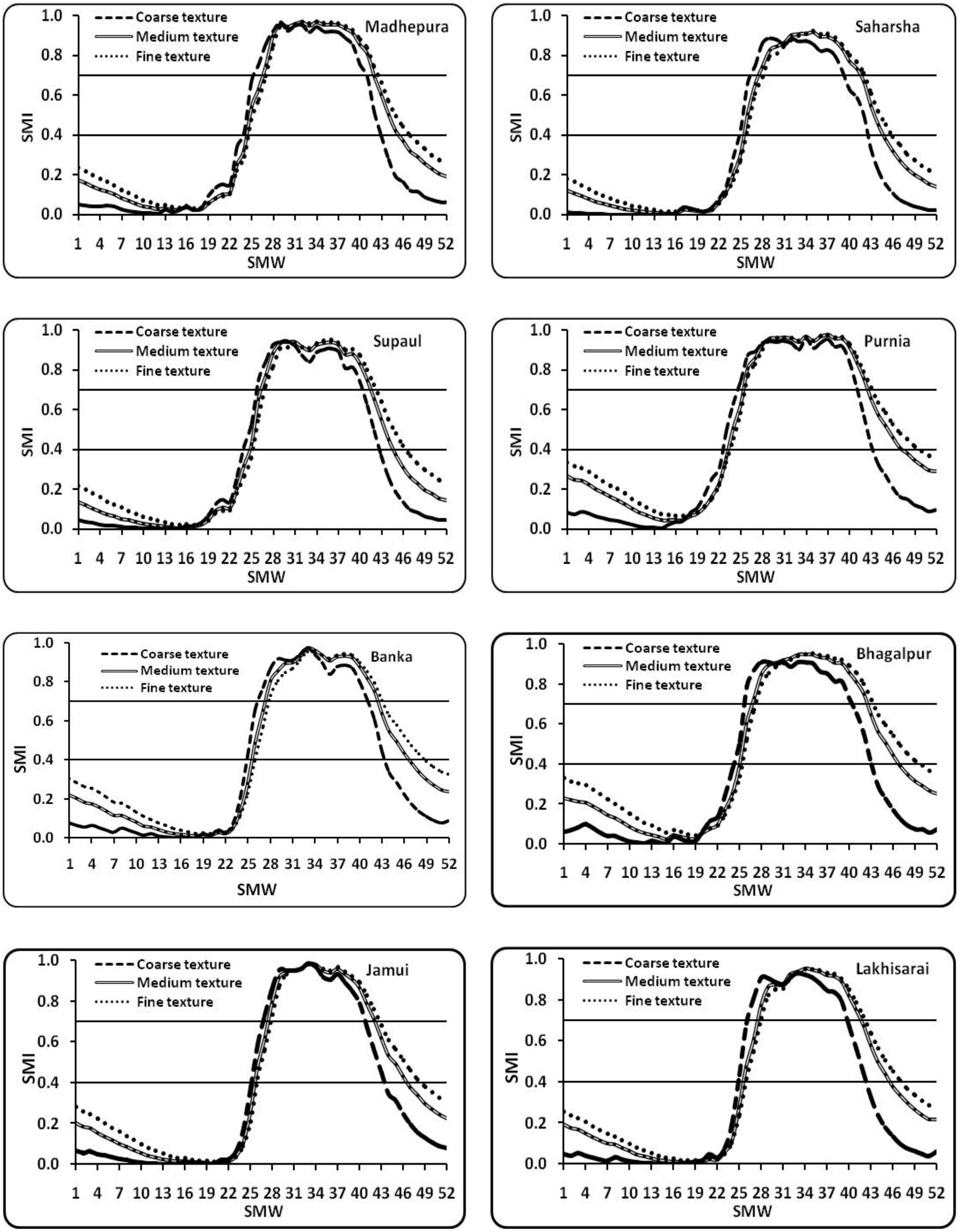

Fig. 5. Variation in weekly soil moisture index (SMI) in Zone I1 (Madhepura, Saharsha, Supaul and Purnia districts) and Zone IIIA (Banka, Bhagalpur, Jamui and Lakhisarai districts)

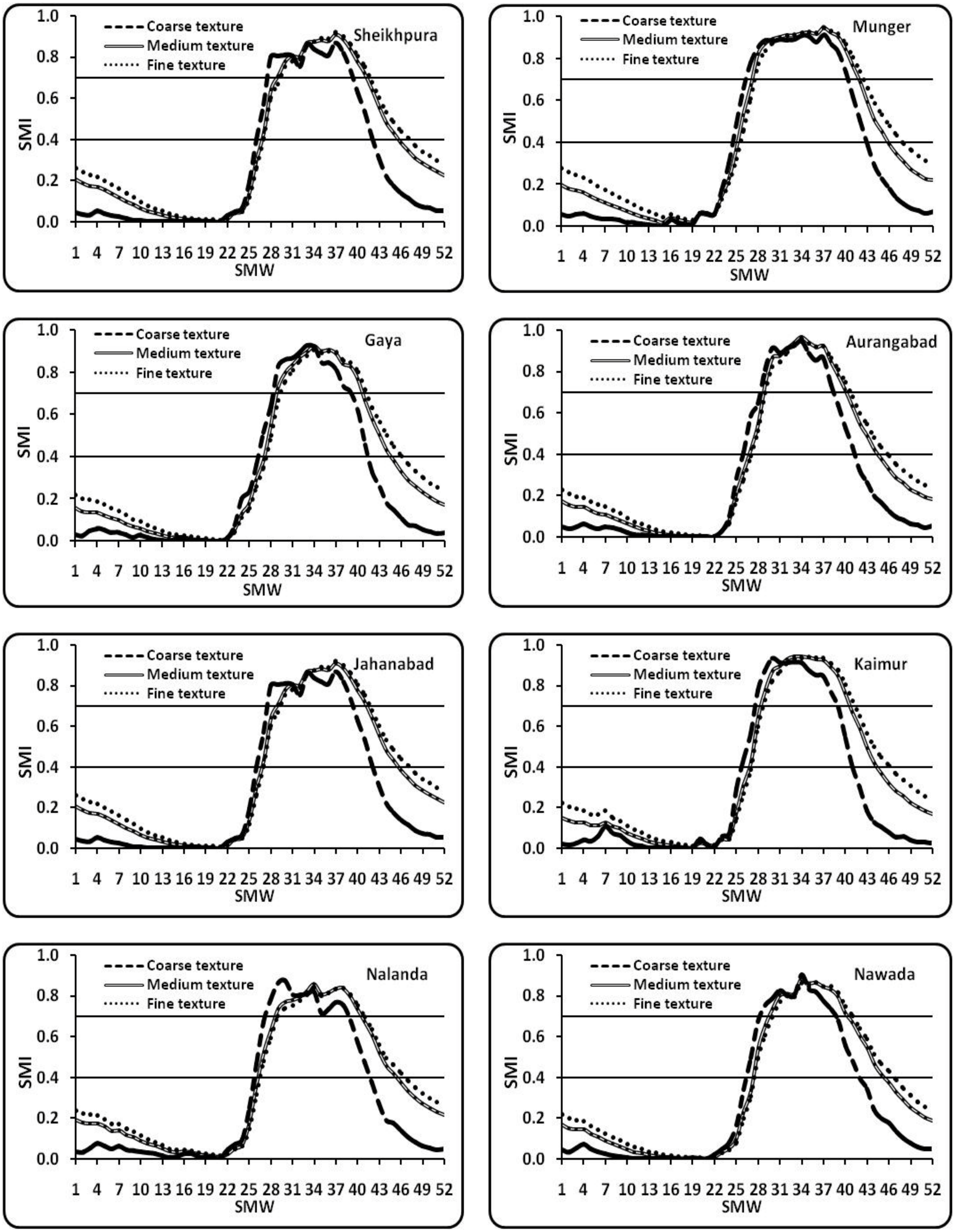

Fig. 6. Variation in weekly soil moisture index (SMI) in Zone I1IA (Sheikhpura and Munger districts) and Zone IIIB (Gaya, Aurangabad, Jahanabad, Kaimur, Nalanda and Nawada districts)

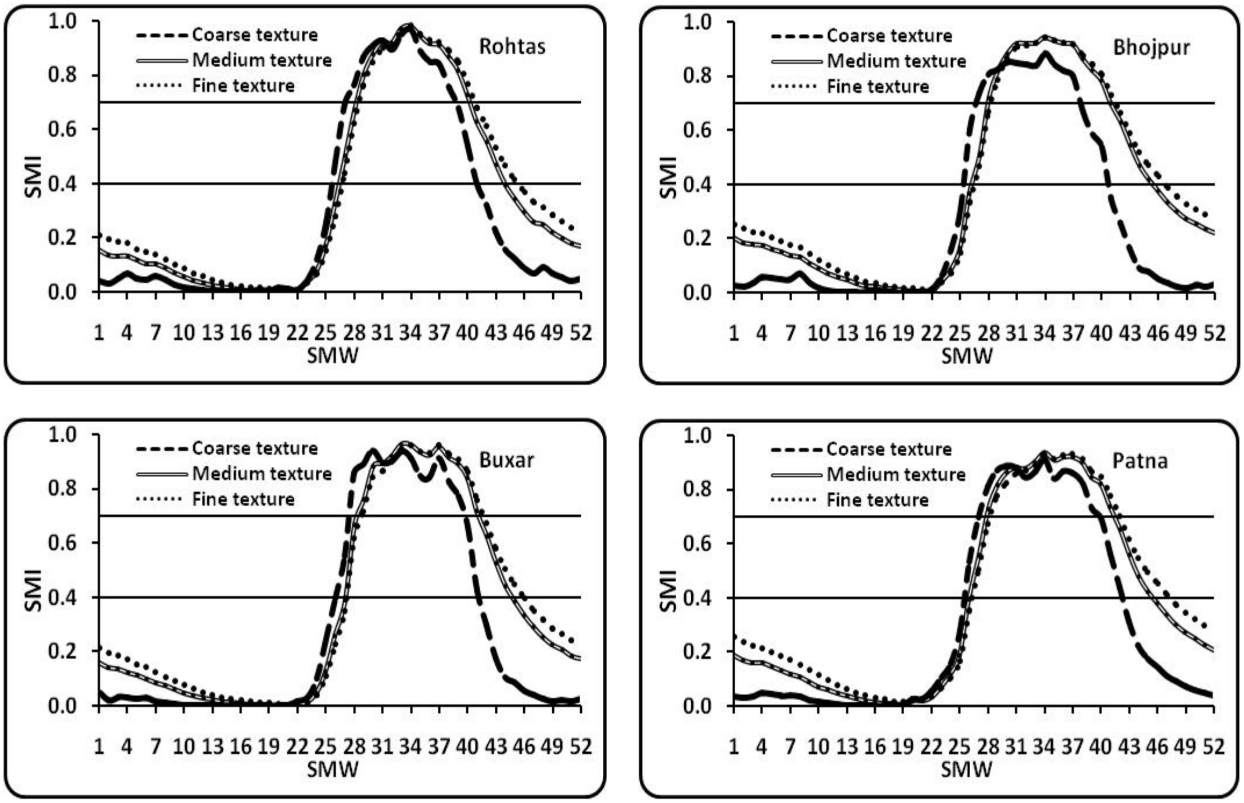

Fig. 7. Variation in weekly soil moisture index (SMI) in Zone IIIB (Rohtas, Bhojpur, Buxar and Patna districts)

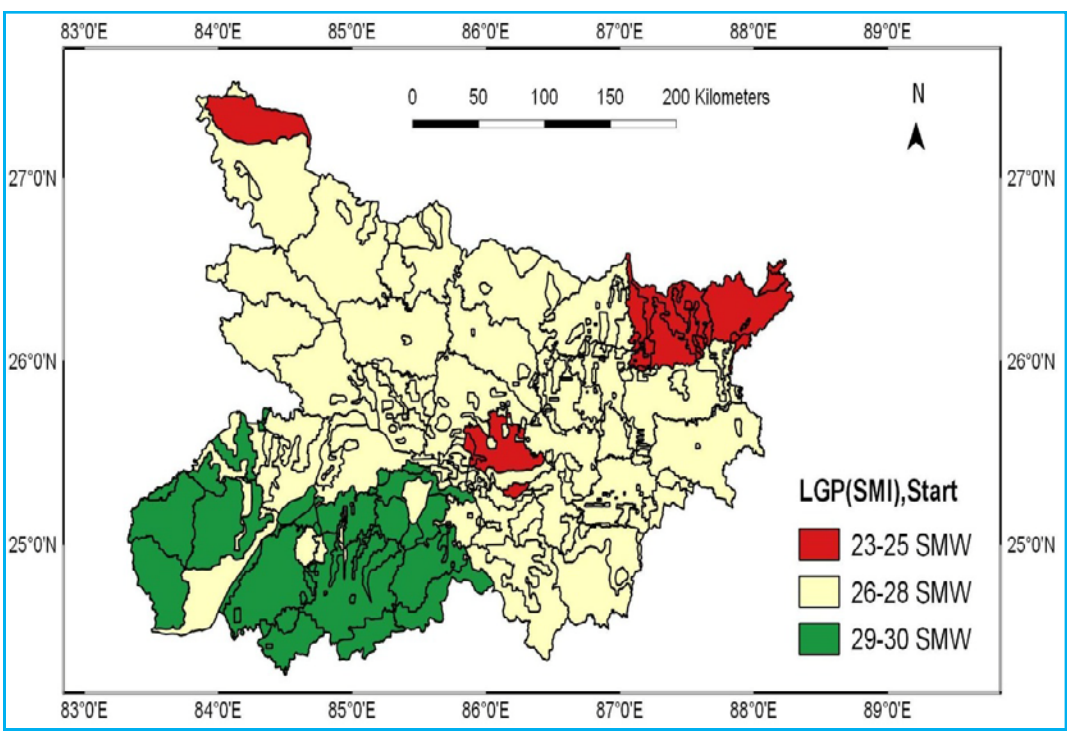

Fig. 8. Spatial variability in onset of LGP based on soil moisture index in Bihar

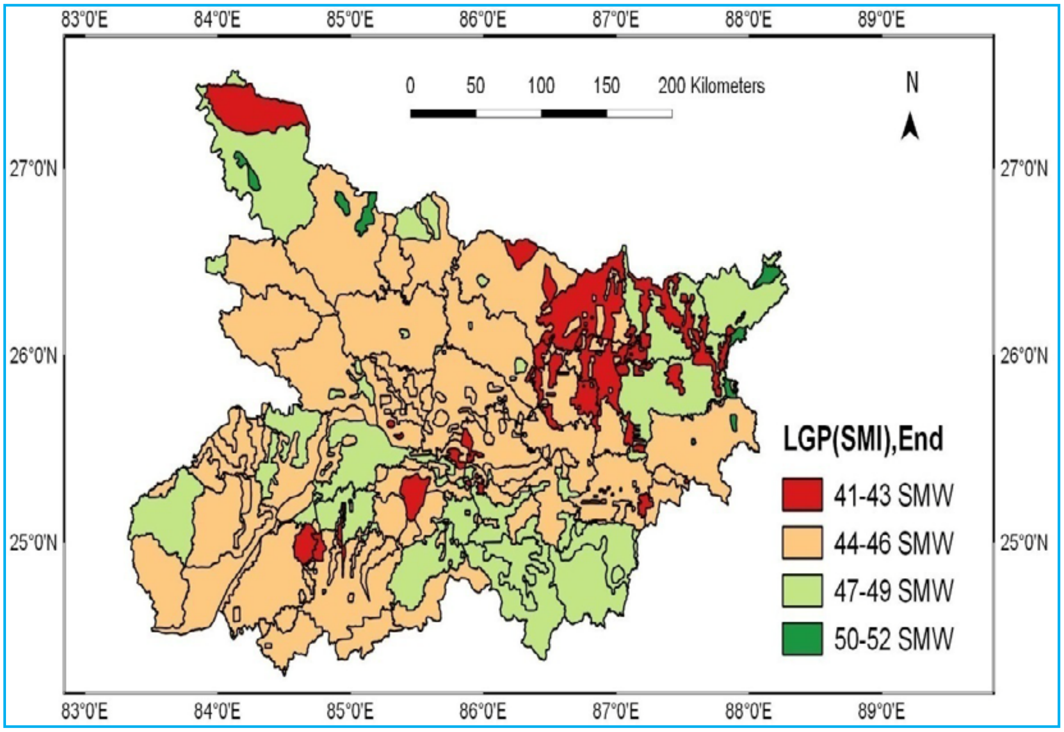

Fig. 9. Spatial variability in cessation of LGP based on soil moisture index in Bihar

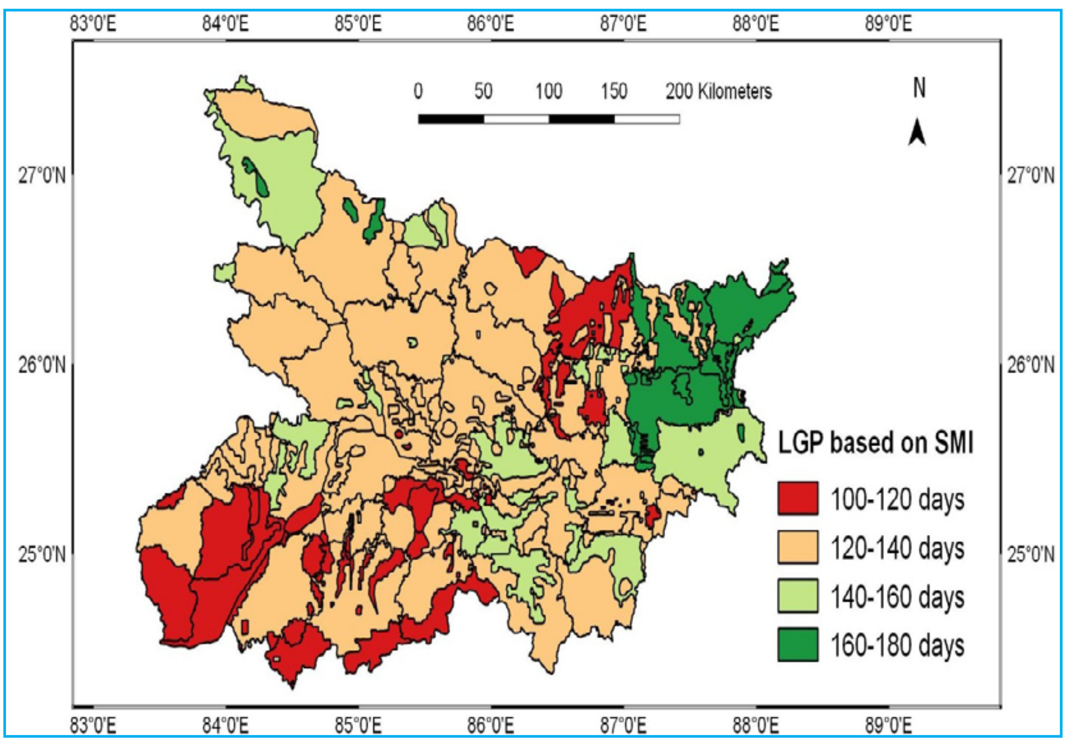

Fig. 10. Spatial variability in duration of LGP based on soil moisture index in Bihar

started during 24-26 SMW in the districts under Zone I, irrespective soil textural classes. In Zone II, it started during 21-25 SMW in coarse textured, during 22-26 SMW in medium textured and during 23-26 SMW in fine textured soils. Considering all soils, SMI being equivalent to 0.4 started during 25-28 SMW across various districts under Zone IIIA and Zone IIIB, with relatively later start being observed for the districts under Zone IIIB. The cessation of such moisture level (SMI < 0.4) differed widely among three soils, irrespective of the districts, which extended up to 41 to 43 SMW in coarse textured soil, 44 to 48 SMW in medium textured soil and 45 to 3 SMW in fine textured soil over different districts. The duration of such period was 17-20, 20-24 and 21-32 in coarse, medium and fine textured soils, respectively, in the districts under Zone I, with West Champaran district recording the highest duration. In the districts under Zone II, coarse, medium and fine textured soils recorded durations of 18-23, 19-27 and 21-28 weeks, respectively, with Kishanganj showing the highest duration of drought free growing period (SMI $\geq$ 0.4). On the other hand, there was little variation in the duration within the same soil texture across the districts under Zone IIIA and Zone IIIB. Such durations were 18-19, 20-22 and 22-25 weeks in Zone IIIA and 16-17, 18-21 and 19-21 weeks in Zone IIIB for coarse, medium and fine textured soils, respectively. Spatial variation in onset of LGP revealed that majority of the areas of the state recorded onset of LGP during 26-28 SMW (Fig. 8). Extreme northeast part of the state and pocketed areas in central Bihar exhibited onset during 23-25 SMW. On the other hand, late onset of LGP could be observed across many areas of south-west Bihar. Considering cessation of LGP across entire Bihar, it started early in 41 SMW and ceased as later as 50 SMW (Fig. 9). The majority of early cessation of LGP was associated with northeastern part, while late cessation comprised of the area located in extreme north-east, south Bihar and extreme north-west part falling within east and west Champaran and Sheohar and Sitamarhi districts. Northern strip of West Champaran district also showed early cessation, probably due to dominance of coarse textured soil. However, vast majority of areas in Bihar exhibited LGP cessation during 44-46 SMW. Appraisal of actual onset and cessation of LGP in a region would help undertake effective agronomic measures for successful crop production. Based on actual identification of onset dates of LGP, crops can be fitted appropriately in the cropping sequence to harness maximum agricultural potential for attaining higher yield. Moreover, sowing of crops in improper sowing window and late sowing would shorten growing period and increase the infestation of pests, diseases and weeds (Sattar *et al*., 2018a; Vaksmann *et al*., 1996); leading to lower productivity.

There existed large spatial variation in the length of growing period in Bihar. GIS map (Fig. 10) showed that LGP varied from as low as 100 days to as high as 180 days across the state. The entire range of variation in LGP has been categorized into four groups, *viz*., (*i*) 110-120 days, (*ii*) 120-140 days and (*iii*) 140-160 days. The lowest LGP, *i.e*., in the group of 100-120 days was observed mostly in several patches in south Bihar and in some pockets of north-east Bihar. On the other hand, the highest values of LGP could be observed across Kishanganj, Purnia, Araria and Katihar districts. Major areas of the state exhibited LGP in the range of 120-140 days. Araya (2005) 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 (Sattar *et al*., 2018b) and thereby realization of potential yield of an area for rainfed crop production could be achieved.

3.3. *Variation in potential moisture and LGP*

Soil moisture in the root zone on spatial scale would be a reliable guide in effective and sustainable crop production program in rainfed region (Sattar and Khan, 2016). Considering the potential soil moisture level of SMI $\geq$ 0.7, it was observed that the onset and termination of such moisture level were comparatively earlier in coarse textured soil due to lower values of water holding capacity of this soil. As compared to moisture at SMI $\geq$ 0.4, the onset of such level of moisture (SMI $\geq$ 0.7) was delayed by 1-3 weeks, irrespective of soil textures across the districts under different agroclimatic zones of the state. On the other hand, when compared with lower moisture level (SMI $\geq$ 0.4), the cessation of potential moisture level (SMI $\geq$ 0.7) was advanced by from as low as of 2 weeks in coarse textured soil and to as high as of 11 weeks in fine textured soil. The duration in weeks with potential moisture for rainfed crops (SMI $\geq$ 0.7) varied from 13 to 16, 14 to 17 and 15 to 17 weeks in coarse, medium and fine textured soils, respectively, over various districts under Zone I. A large variability in the duration of such moisture level was observed within the same soil texture and across the districts under Zone II. The coarse, medium and medium textured soils registered durations of 13-19, 14-20 and 15-20 weeks with SMI $\geq$ 0.7. The districts under Zone IIIA and Zone IIIB showed SMI $\geq$ 0.7 for 11-15, 11-16 and 12-16 weeks in coarse, medium and fine textured soils, respectively, with lower values being observed across Agroclimatic Zone IIIB. Determination of SMI based LGP helped identify spatial status of soil moisture regime across the state and provided an idea to undertake strategic measures in vulnerable region of the state for slicing climatic risks. Similar study to evaluate agricultural drought using soil moisture index was conducted in Delhi region (Victor and Sastry, 1984). Dey (2008) also worked out the duration of drought free growing period and potential moisture for the Gangetic plains of West Bengal. Carrao *et al.* (2016) made elaborate study on SMI for agricultural drought assessment using remote sensing data and classified soil moisture anomalies.

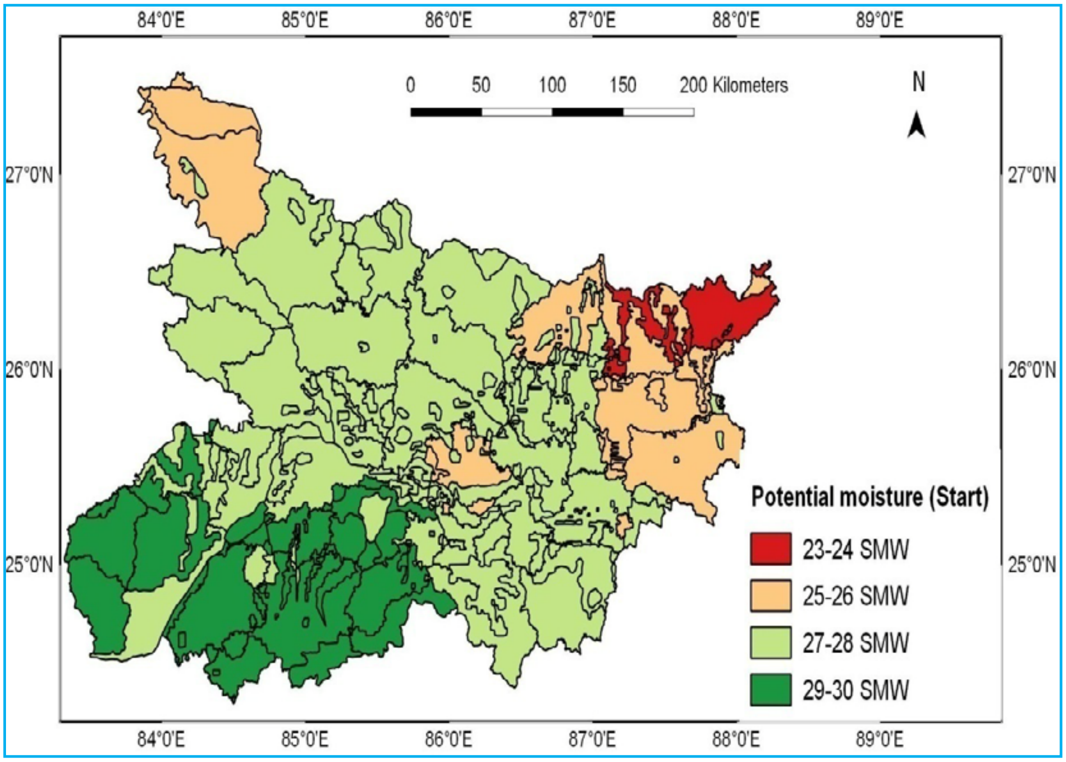

Fig. 11. Spatial variability in start of potential soil moisture districts in Bihar

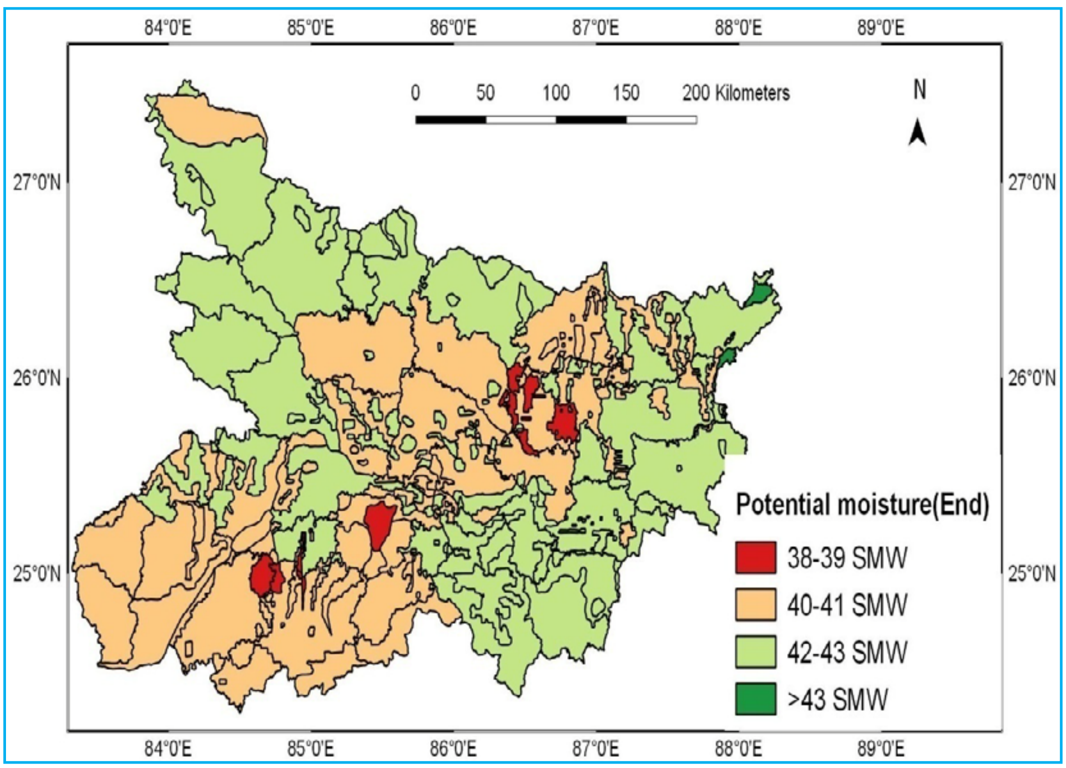

Fig. 12. Spatial variability in cessation of potential soil moisture districts in Bihar

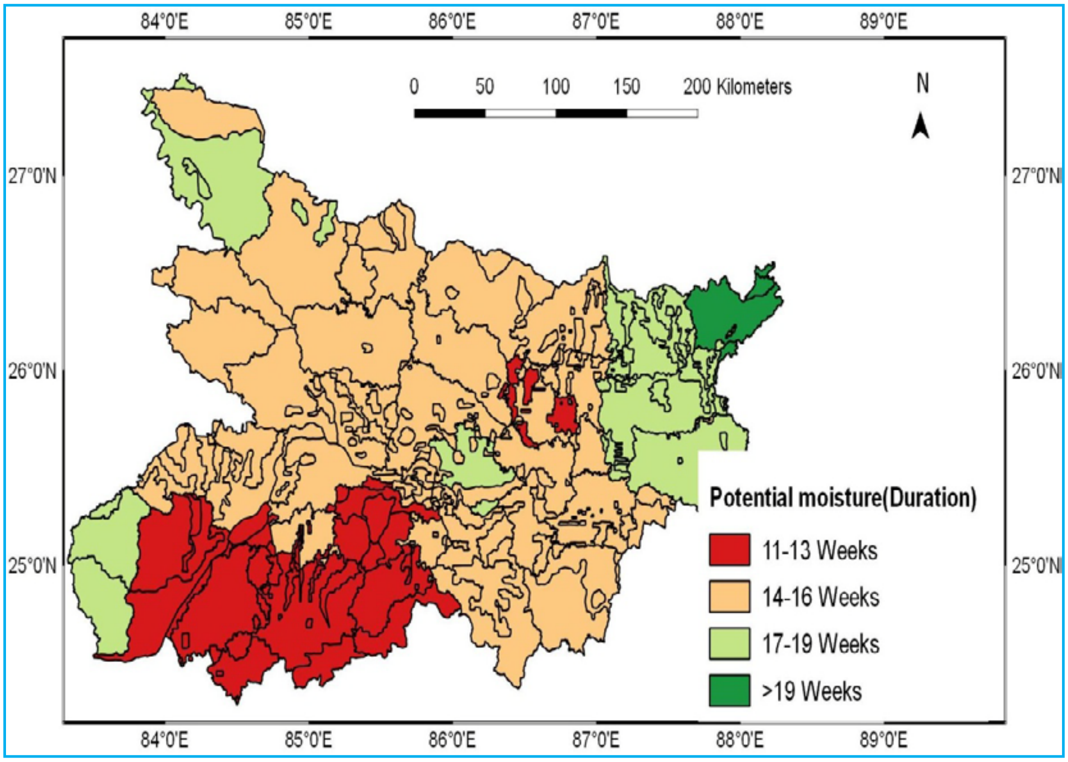

Fig. 13. Spatial variability in length of potential soil moisture districts in Bihar

Spatial variations in onset, cessation and duration of potential moisture are presented in Figs. 11-13. Early commencement of potential moisture during 23-24 SMW was found to prevail in north-eastern parts, while late start during 29-30 SMW of such moisture was found across the vast areas of south Bihar (Fig. 11). However, majority of the areas in the state exhibited commencement of potential moisture during 27-28 SMW. While considering, the cessation of potential moisture, it was observed that vast majority of the geographical area of the state showed cessation during 40-43 SMW (Fig. 12). The duration of potential moisture varied from 11-13 weeks to greater than 19 weeks in the state. Most of the areas of the state showed duration of potential moisture in the range of 14-16 weeks (Fig. 13). Identification and demarcation of potential moisture across the state would facilitate efficient planning of rainfed crops in the areas, where provision of irrigation is less developed and farmers find it hard to irrigate their crops under dry spell condition. Availability of potential moisture, which accounts for most of the water need of crops, will help selection of suitable crops based on their water requirements.

4. Conclusions

The information on drought free growing period, length of growing period and availability of potential moisture presented through GIS maps appropriately depicted the constraints and agroclimatic potential of different areas of the state, which could be utilized as important inputs for enhancing crop production under changing climatic condition. It is, therefore, essential that agricultural planning needs to be drawn up based on the agroclimatic potential of the area. The significant findings are listed as below:

(*i*) The districts of Zone II showed higher agroclimatic potential considering the status of water availability. On the other hand, the districts of Zone IIIB were most vulnerable ones. When individual districts are considered, West Champaran district in Zone I and Kishanganj district in Zone II recorded the highest crop production potential under rainfed condition, whereas Arwal, Nawada, Gaya, Bhojpur, Buxar and Aurangabad districts situated in Zone IIIB exhibited the lowest potential.

(*ii*) Large variations in LGP were found across the state. Accordingly, selection of crops and their varieties could be made by matching with the length of growing period for realization of potential yield of an area.

(*iii*) Earliest start of potential moisture during 23-24 SMW was found to prevail across north-eastern part of the state, while late cessation of such moisture was found during 29-30 SMW in south Bihar. Most of the areas of the state showed duration of potential moisture in the range of 14-16 weeks.

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