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Reaserch Article

Onset, cessation, and seasonality of rainfall during monsoon in Gujarat state of India

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Abstract

Rainfall onset, cessation and its temporal rainfall distribution is very important for monsoon based crop production. Climatic timeseries data of 26 stations of Gujarat state were chosen for the study. Year wise agroclimatic onset, cessation, length, and seasonality of rainy season were determined. Long term average over the timeseries were considered as climatic normals to characterize rainfall pattern to support kharif crop production. Onset starts in South Gujarat from 8th June and it cover the entire state by 6th July at Kutch, with large variation. Cessation of rainy season ranges from 6th September to 21st September in Gujarat. Length of active rainy season prevails from 66 days (at Bhachau) to 96 days (at Ubharat) with state mean of 81 days. Most part of the state has seasonal rainfall regime with dry periods. Rainfall seasonality monsoon season in Gujarat has not changed significantly during recent past.

Keywords: Onset, Cessation, Seasonality, Length of rainy season, Kharif season

Introduction

Although global warming causes extreme weather conditions in all regions of the world (regions where monsoons are effective, the Middle East, etc.), it can also differentiate the effects of natural events, which are more effective due to their own characteristics (Ülker at al., 2018; Uzun and Ustaoğlu, 2022). The precise onset, cessation, and the amount and the distribution of rainfall required to agriculturists to ensure better harvest (Ojo and Ilunga, 2018).

Monsoon onset and withdrawal in India is determined by IMD using meso scale meteorological condition and rainfall. Effective rainy season onset considering growing season is also referred as agroclimatic onset. Rainfall based crop season is known as *kharif season* in India. Most kharif crops' suitability and sowing time depends on location specific start, end and length of rainy period with sufficient amount of rainfall to sustain crop growth. So, for agricultural planning, agroclimatic approach is more suitable to determine onset, cessation, and length of rainy season. It can be useful for farmers' sowing strategy (Marteau et al., 2011). The onset of Indian summer monsoon (ISM) represents one of the most dramatic transitions in the regional circulation pattern. According to Goswami and Gouda (2007) the onset marks the beginning of the main rainy season for India; advance and accurate forecast of the day of the onset of monsoon (Patel and Shete, 2014).

The agroclimatic approach defines the onset as the optimal date that ensures sufficient soil moisture during sowing and early growing period to avoid crop failure after sowing (Walter, 1967; Sivakumar, 1988). While first occurrence of a long dry spell after a specified date can be used as definition for end of rainy season (Stern et al., 1981; Ati et al., 2002). Researchers have formulated different criteria to determine the onset and cessation time for rainy or wet period (Amekudzi, et al., 2015; Odekunle, 2004; Sivakumar, 1988; Ashok Raj,1979; Subash et al., 2011; Panchal et al., 2021). The difference of end and onset can be taken as length of rainy season or length of active rain period for kharif. In general, rainfall seasonality characterizes the temporal distribution of rainfall over the year on monthly basis. The index can be used as indicator of temporal distribution of rainfall during monsoon by replacing weeks in place of months. In the study length of season and seasonality are used to determine assured period of *kharif season* to support agriculture.

In Gujarat state (Figure 1), seasonal rainfall during monsoon varies from 200 mm (in Kutch) to 2000 mm (in South Gujarat). The state has 98.8 lakh ha net sown area (SCR, 2017) and large part of it is under rainfed condition. Out of 8 agroclimatic zones of the state, five are arid to semi-arid and three are dry subhumid (Annon., 2015). About 80-90% of groundnut, 60% of sorghum and cotton, 90% of pearlmillet and more than 50% of pulses are produced in areas with uncertain and erratic rainfall. Thus, the rainfall quantum and temporal distribution during monsoon is very important for *kharif season* of the state. The present study is aimed to characterize rainfall onset, cessation, active rainy period, and temporal rainfall distribution in Gujarat to support agriculture during *kharif season* (Das et al., 2016).

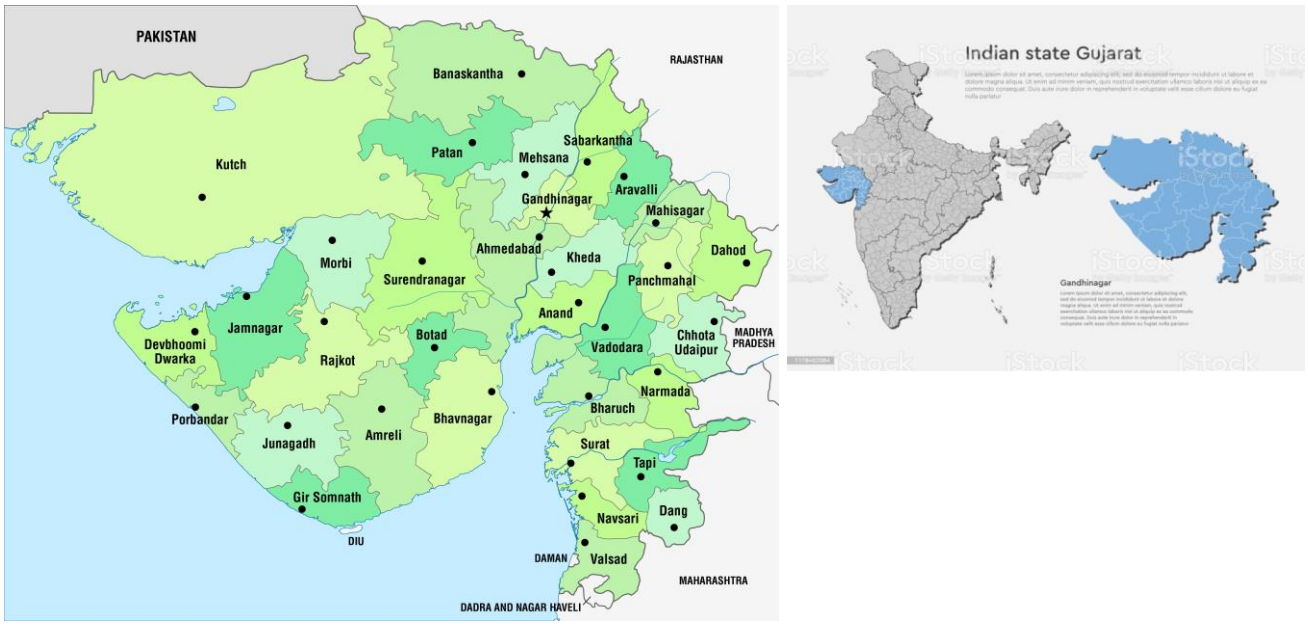

Fig. 1. Gujarat state

Materials and Methods

Considering quality and length of available time series data 26 stations of Gujarat state were chosen for the study (Table 1). The agroclimatic onset and cessation criteria used in the study are based on concept by Sivakumar, 1988 and work of Marteau et al., 2009. The agroclimatic onset is determined by defining onset date as the first wet day of the 3 days' spell receiving at least 20 mm after 1st June and not followed by 10-day dry spell (<2.5 mm day-1). Cessation date of rainy season at a station is taken as the date after 1 September which followed by a 15-day dry spell. Year wise onset and cessation dates were determined over the time series of each station. This approach is also adopted in the study for Karnataka state recently (Huggi et al., 2020).

Table 1. Stations of Gujarat and data time series used in the study

Sr. No.	Station	Time series (Years)	Missing/ Removed (Years)
1	Anand	1958-2018	
2	Amreli	1992-2018	
3	Arnej	1989-2015	2016
4	Bhachau	1991-2016	1998-2004,2006-2013, 2016 to 2018
5	Bharuch	1990-2017	2004,2018
6	Dabhoi	1989-2017	2000,2001,2015,2018
7	Derol	1988-2018	1991,2011,
8	Dhandhuka	2001-2016	2005,2007,2008,2018
9	Dharmaj	1996-2016	2005,2007,2008,2017,2018
10	Gandevi	1987-2016	1992,2007-2008,2017-2018
11	Godhra	1989-2018	
12	Jamnagar	1992-2017	2004,2018
13	Khandha	1994-2017	2007,2011-2014
14	Khedbrahma	1992-2008	2004, (2009 to 2018)
15	Ladol	1999-2016	2004,2008-2011,2017,2018
16	Mahuva	1987-2017	2004,2010-2014, 2018
17	Mangrol	1993-2017	1995,1998,2004,2018
18	Navsari	1980-2017	2018
19	Nawagam	1979-2018	1983-1992
20	Pariya	1987-2018	1995-1998,2003-2006
21	Radhanpur	1992-2011	1999, (2012 to 2018)
22	Rajkot	1989-2015	1991, 2013, 2016 to 2018
23	SK Nagar	1982-2018	1987
24	Tanchha	1994-2011	2004,2008,2012-2018
25	Ubharat	1996-2007	
26	Vijapur	1991-2003	1992,1993

The length of rainy season is the period where rainwater will be available to support the kharif crop. Onset, cessation, and length of the rainy season can be useful for planning or decisions on crop sowing, crop suitability, irrigation, water harvesting and rabi sowing.
Walsh and Lawler (1981) developed a Seasonality Index (SI) to estimate seasonality of a place. The index is the sum of the absolute deviations of mean monthly rainfall from the overall monthly mean, divided by the mean annual rainfall.

$$SI = \frac{1}{\bar{R}} \sum_{n=1}^{12} \left| \overline{x_n} - \frac{\bar{R}}{12} \right|$$

Where, $\overline{x_n}$ is mean monthly rainfall of month n and $\bar{R}$ is mean annual rainfall.

The index characterizes the distribution of rainfall throughout the year. Kumar et al., 2014 have studied decadal seasonality of stations of Gujarat. However, monsoon is the main rainfall giving period in India and temporal distribution of rain during the monsoon is also very important for kharif production. So, the index was modified to present temporal distribution of rainfall during monsoon by considering monsoon weeks instead of months. Meteorological standard weeks of June to September period were considered (23 MSW to 39 MSW) in a year as period of monsoon.

$$SI_m = \frac{1}{\bar{R}} \sum_{w=23}^{w=39} \left| \overline{x_w} - \frac{\bar{R}}{17} \right|$$

Climatic data of geographically distributed 28 stations were used to determine monsoon rainfall seasonality of different parts of Gujarat state. The index was calculated using long period mean weekly rainfall as well as individual year weekly data. Zero value of SIm indicates rainfall is equally distributed to all weeks while 1.88 is when total rainfall is one week only. The changes through time in seasonality were explored by trend analysis of monsoon seasonality index of individual year. The station wise mean index values were spatially interpolated for the Gujarat state to depict spatial pattern of seasonality on thematic map.

Results and Discussion

Year wise date of agroclimatic onset was determined for all stations and mean over the time series considered as onset date. Onset date variation over timeseries for Anand station is depicted in Figure 3(a). Meteorological normal onset of monsoon considering IMD criteria for Gujarat state is between 15 June to 5 July (Pai et al., 2020, Figure 2).

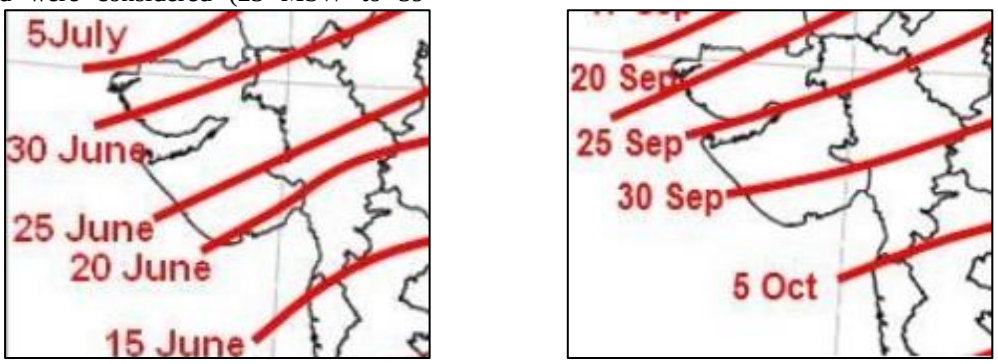

Fig. 2. Normal onset and withdrawal of monsoon in Gujarat (source; Pai *et al.*, 2020)

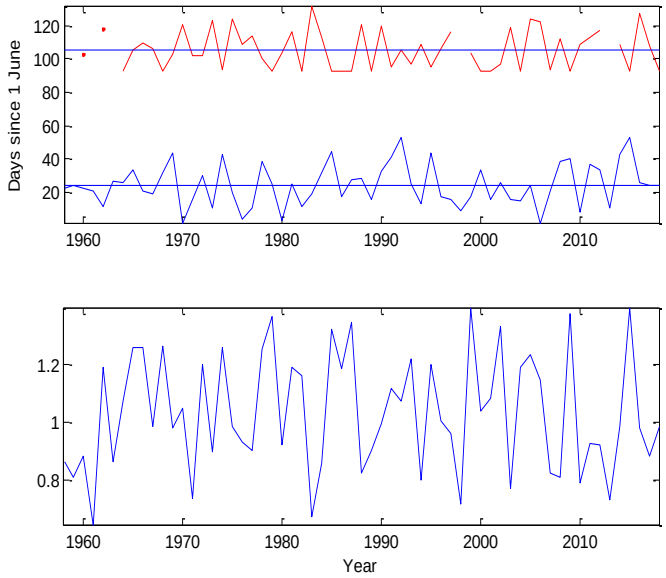

Fig.3. Variation in (a) onset (line) and cessation of rainy season (line with breaks) and (b) rainfall seasonality during 1958 to 2018 at Anand. Horizontal line is mean day.

Table 2. Onset, cessation, and length of rainy season at different stations of Gujarat.

Sr. No.	Station	Onset Days since 1st June	Date	Cessation Days since 1st June	Date	Length of rainy season (Days)
1	Amreli	24	24-June	109	17-September	85
2	Anand	25	25-June	106	14-September	81
3	Arnej	22	23-June	108	16-September	85
4	Bhachau	36	6-July	105	13-September	69
5	Bharuch	24	25-June	111	19-September	87
6	Dabhoi	27	27-June	109	17-September	82
7	Derol	23	24-June	105	14-September	82
8	Dhandhuka	24	25-June	107	16-September	83
9	Dharmaj	28	28-June	106	14-September	78
10	Gandevi	14	15-June	111	19-September	96
11	Godhara	27	28-June	107	15-September	80
12	Jamnagar	27	27-June	97	6-September	71
13	Khandha	19	20-June	103	11-September	84
14	Khedbrahma	19	20-June	104	12-September	85
15	Ladol	30	30-June	100	8-September	70
16	Mahuva	24	24-June	102	10-September	78
17	Mangrol	19	20-June	102	11-September	83
18	Navsari	17	18-June	108	16-September	91
19	Nawagam	24	24-June	103	12-September	79
20	Pariya	11	12-June	101	9-September	89
21	Radhanpur	35	5-July	97	6-September	62
22	Rajkot	18	19-June	104	12-September	86
23	S K nagar	35	5-July	101	9-September	66
24	Tanchha	23	24-June	104	12-September	80
25	Ubharat	16	17-June	112	21-September	96
26	Vijapur	25	26-June	102	10-September	76
	State	24	24-June	105	13-September	81

While the dates of agroclimatic onset at different stations is given in Table 2 and their spatial interpolation over the state as depicted in Figure 4. IMD has recently revised dates of onset of monsoon by emphasizing occurrence of rainfall with other meteorological approaches. In the revised determination IMD used grided data. The data having spatial resolution of 1° (about 110 km), which is also relatively coarser representation than the number of stations used in the study.

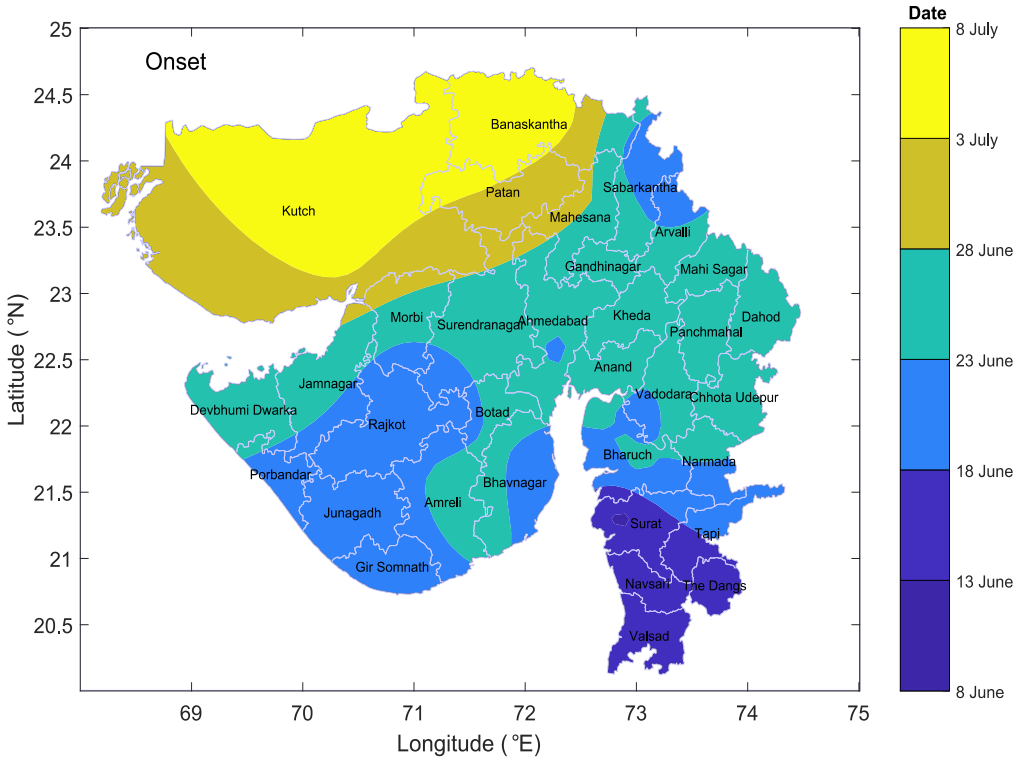

Fig. 4. Normal agroclimatic onset time (date) of rainy season in Gujarat

Time of effective first rainfall receipt for sowing of kharif crops shows large variation at all the stations. The onset time variation at Anand during last 61 years is given in Figure 3. The mean day of agroclimatic onset at Anand is 25th June (given as horizontal line in Figure 3). This date indicates that the normal starting of *kharif season* is only a few days after normal onset of monsoon and can be considered for crop planning. Similarly, station wise agroclimatic onset as days since 1 June and date of onset are given in Table 2. In the state onset ranges from June 12 (at Pariya) to July 06 (at Bhachau). Thematic map by spatial interpolation depicts onset range of 8 June to 8 July. The mean date of all the stations can be considered as onset date for the state which is June 24 (176th day of year). Figure 4 depicts spatial pattern of agroclimatic onset over different parts of Gujarat state.

The onset date suggests the starting of *kharif season* in systematic progression from South Gujarat to Kutch and North Gujarat. In the state, station wise end date of rainy season ranges from 6th September (at Radhanpur and Jamnagar) to 21st September (at Ubhrat; Figure 4). Spatially interpolated range for the state is 2nd September to 20th September. While the monsoon withdrawal according to meteorological (IMD) criteria is for the state is during 20th September to 5th October (Figure 2). In agroclimatic approach, 13th September can be considered as cessation date of rainy season for Gujarat state (Table 2; Figure 5). Length of rainy season at different stations prevail from 66 days (at Bhachau) to 96 days (at Ubharat) with mean period of 81 days (Table 2; Figure 6).

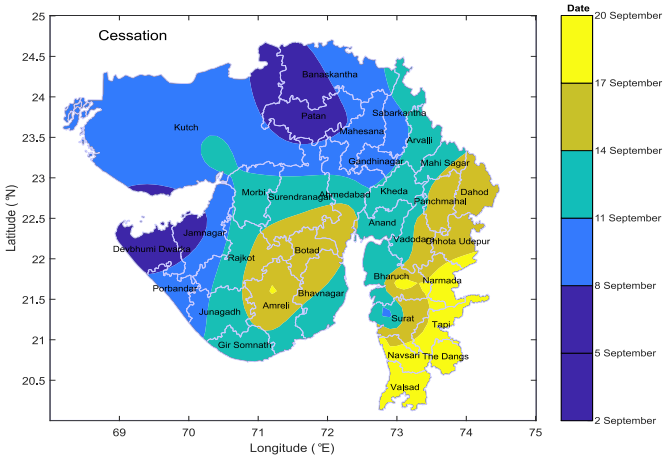

Fig. 5. Normal cessation time (date) of rainy season in Gujarat

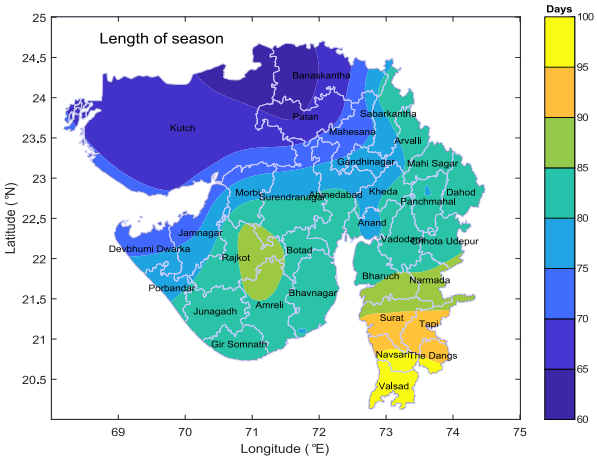

Fig. 6. Length of active rainy period in Gujarat"

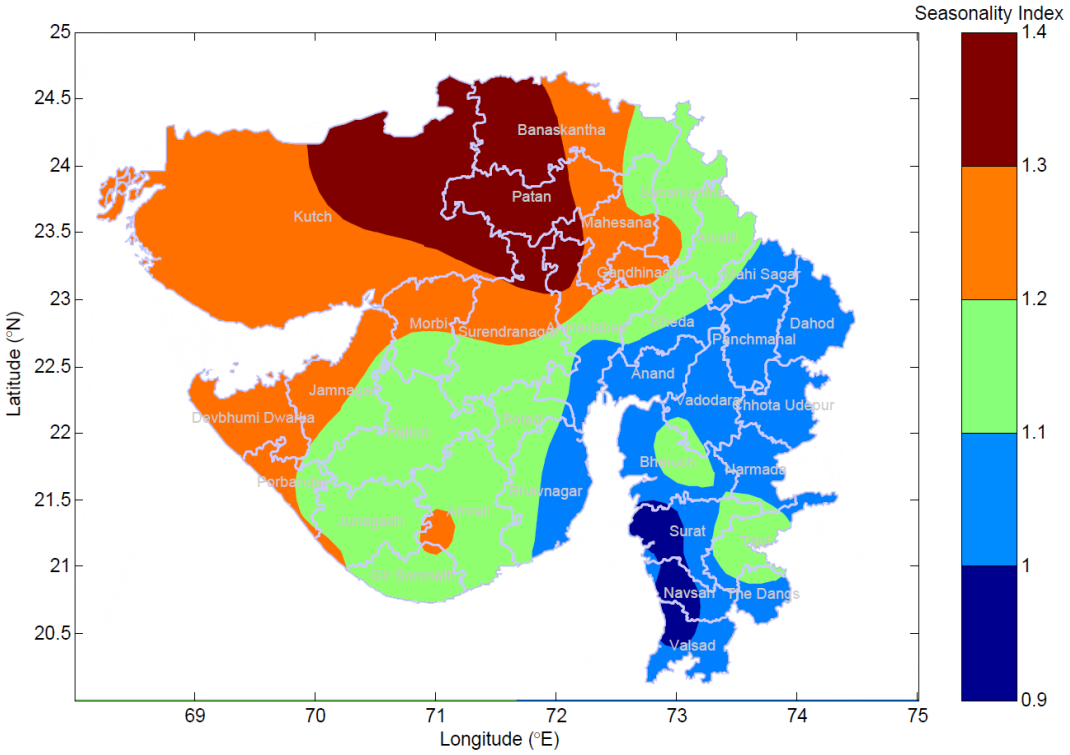

Fig. 7. Seasonality index ($\bar{SI}_{mi}$) map of Gujarat state.

Decadal comparison in seasonality of monsoon in Gujarat has been studied by Kumar et al.,2014 using district monthly rainfall data. They reported that most districts of Gujarat had high seasonality during recent decade (2002 - 2011). Rainfall seasonality pattern during monsoon season over Gujarat state is depicted in Figure 7. Only western part of South Gujarat has most equable rainfall distribution compared to other parts of the state. While most part of the state falls under the category of seasonal rainfall regime with dry periods (index 1-1.3). Northern central part covering parts of Kutch, Banaskantha, Patan, Surendranagar and Ahmedabad districts falls under the rainfall regime distributed to less than eight weeks (index 1.3-1.4). In general, gradual changes in temporal wet period distribution has pattern from southeast part to northwestern parts of the state. This distribution follows rainfall quantum and rainy days pattern up to some extent. The change in precipitation pattern is one of the major concerns under climate change. Changes in rainfall seasonality during monsoon over the years can be accessed by determining trend in individual year seasonality. Trend pattern at Anand station is given in Figure 3 (b) showing year to year variation in the range of seasonal rainfall regime with short dry period to long dry periods. Trend of rainfall seasonality of different stations are given in Table. 3 and Figure 8).

Table 3. Mean seasonality indices of monsoon computed from (a) averaging individual year data (b) mean weekly data

Sr. No.	Station	$\overline{SI}_m$	$\overline{SI}_{mi}$	Trend in $\overline{SI}_{mi}$	$\frac{\overline{SI}_m}{\overline{SI}_{mi}}$
1	Anand	0.36	1.03	0.000	0.35
2	Arnej	0.28	1.05	-0.011	0.26
3	Bhachau	0.57	1.29	-0.020	0.44
4	Bharuch	1.14	1.15	-0.001	0.99
5	Dabhoi	0.36	1.00	-0.002	0.37
6	Derol	0.41	1.03	0.000	0.40
7	Dhari	0.37	1.22	0.014	0.30
8	Dharmaj	0.35	1.02	0.000	0.34
9	Gandevi	0.42	0.94	0.009	0.45
10	Godhra	0.44	1.05	-0.005	0.42
11	Jamnagar	0.42	1.25	-0.004	0.33
12	Khandha	0.36	1.12	0.027*	0.32
13	Sanand	0.52	1.16	0.013	0.45
14	Viramgam	0.55	1.34	-0.007	0.41
15	Vyara	0.56	1.15	0.041*	0.49
16	Khedbrahma	0.48	1.10	0.002	0.43
17	Ladol	0.60	1.15	-0.020	0.52
18	Mangrol	0.53	1.21	-0.010	0.43
19	Navsari	0.38	0.98	-0.004	0.38
20	Nawagam	0.35	1.15	-0.007	0.31
21	Pariya	0.33	0.90	-0.004	0.37
22	Radhanpur	0.57	1.36	-0.008	0.42
23	Rajkot	0.29	1.10	0.003	0.26
24	Sagrividi	0.40	1.12	-0.006	0.36
25	SK Nagar	0.47	1.26	-0.006	0.38
26	Tanchha	0.41	1.12	-0.006	0.36
27	Ubharat	0.50	1.06	-0.017	0.47
28	Vijapur	0.69	1.33	0.014	0.52

** Statistically significant*

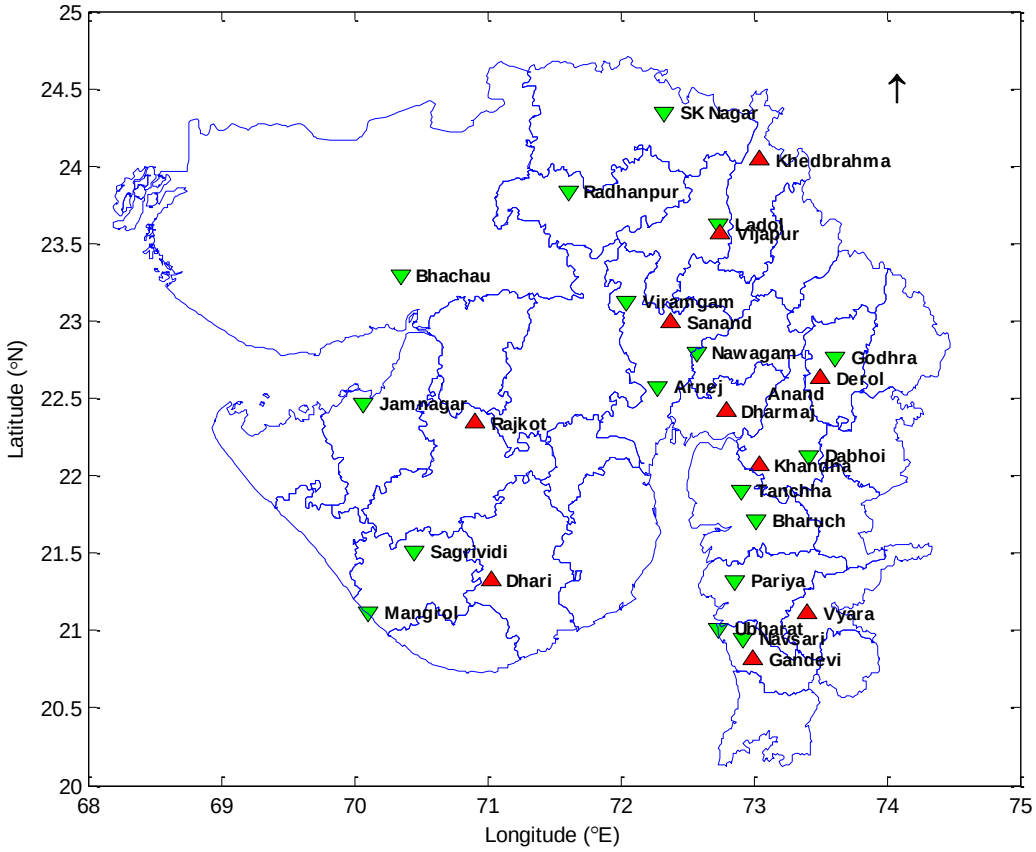

Fig. 8. Trends in rainfall seasonality of monsoon over Gujarat state. Inverted triangles represent decreasing trend and triangles are increasing trend

There is mixed pattern of trends for seasonality. Most stations in the state have non-significant seasonality trend except Khandha and Vyara. Similar trend patterns in monthly rainfall-based seasonality are also reported for Gujarat (Kumar *et al*., 2014) and India (Rai and Dimri, 2019). If mean rainfall regime occurred every year, SIm would equal to SImi and timing of rainfall peaks and troughs would be same each year (Walsh and Lawler, 1981). So, degree of rainfall regime variation can be assessed by ratio of seasonal index calculated using long period mean weekly rainfall to the average or individual years' seasonal index values ($\frac{\bar{SI}_m}{\bar{SI}_{mi}}$).

High ratio indicates the weeks of maximum rainfall occurs in a small spread of time and the range of index values for individual years is low, then replicability of the mean rainfall regime is high. The ratio values of almost stations of Gujarat are 0.52 or lower showing high variability in seasonality, except Bharuch. So, there is relatively lack of reliability in timing and quantum of rainfall in the state.

Conclusions

Agroclimatic onset for *kharif season* is in progression from Southeast to Northwest of the state with time and vice versa in cessation. South Gujarat has early onset from 8th June and it cover the entire state with at last onset in Kutch at 6th July with large variation. Station wise end date of rainy season ranges from 6th September to 21st September in Gujarat. In general, 13th September can be considered as cessation date of rainy season for Gujarat state. Length of rainy season at different stations prevail from 66 days (at Bhachau) to 96 days (at Ubharat) with mean period of 81 days. In Gujarat state, monsoon rainfall seasonality follows spatial pattern of seasonal rainfall amount. Most part of the state has seasonal rainfall regime with dry periods. Rainfall seasonality monsoon season in Gujarat has not changed significantly during recent past.

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