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Rainfall Variability and Crop Planning of Dahod: A Case study from Tribal District in Gujarat, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

India is an agrarian economy mostly depends on monsoon for its crop success. The onset and cessation of monsoon along with unpredictability in weather conditions, reflects the statistics in foodgrain production in this region. Planning of crop requires details on period of dry and wet spell of an area. The present study takes into account Markov chain model for rainfall probability analysis. The mean annual rainfall of Dahod district is 1073 mm with 59 rainy days. Only 41% shows rainfall above normal. 95% of annual rainfall is contributed by South-west monsoon whereas only 4% was contributed by North-east monsoon followed by 0.9% and 0.2% in summer and winter season. Analyzed data (1998-2019) reveals that monsoon start effectively from 25th SMW and cease on 40th SMW. The average monsoon period is of 16 weeks, *i.e.,* 112 days. Initial, conditional and consecutive probability of dry and wet week indicates a shift in weather pattern around 20th SMW, transition of dry to wet weeks. More than 75% of wet probability can be observed from 27th to

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35th SMW. Onwards 40th SMW, likelihood of P(D/D) keeps increasing up to 52 SMW. P(W/W) probability more than 75% can be observed from 27th to 32nd SMW. The district's priority lies in poultry farming and vegetable cultivation along with sustaining soybean and chickpea. The cropping pattern of majority of district falls in maize-maize, maize-chickpea, maize-wheat-green gram, soybean-wheat-green gram and pigeon pea- groundnut, respectively. The area frequently experiences extended dry spells between monsoon. To address these challenges, crop diversification and efficient irrigation practices are prioritized.

Keywords: Crop planning; markov chain model; onset and cessation of monsoon; rainfall; wet and dry spells.

1. INTRODUCTION

Crop success depends on weather parameters of specific locations. Radiation is the defining factor, while, water availability is the limiting factor and pest and disease is the reducing one [1]. Food production from dryland and rainfed agriculture is always uncertain due to large temporal and spatial variation in rainfall. The success of rainfed agriculture largely depends on onset and withdrawal of monsoon. Planning of crops requires details on distribution pattern of rainfall, onset and withdrawal period of monsoon and period of dry and wet spell of an area. Markov Chain Probability model helps to study the occurrence of dry and wet spell [2,3]. Furthermore, the insights on weekly, monthly and seasonal pattern of rainfall and their probabilities on wet and dry spells are helpful in planning of crops throughout the year.

Dahod, a tribal district in the heartland of Gujarat, India stretches across an area of 20°30' to 23°30' in north while 73°15' to 74°30 in the East, sharing its boundaries with States Rajasthan and Madhya Pradesh. The predominant crops grown in the area are maize, soybean, paddy, pigeon pea, chickpea, wheat, and green gram. It covers around 70% of rainfed area. The main challenge of the district lies in erratic and uneven distribution of rainfall along with hilly terrains in the regions. Only one third of farmers of the district cultivates during summer season. Optimization of resources and adoption of efficient farm practices are the key to help them prosper in upcoming eras of water crisis.

In order to stabilize the crop production at certain level, it is essential to plan agriculture on scientific basis in terms of making best use of rainfall pattern of that area. This necessitates studying the sequences of dry and wet spells of an area so that necessary steps can be taken to prepare contingency crop planning of rainfed areas [4]. Crop planning is often the overlooked yet critical part of farming. When weather unpredictability leads to crop failure, contingency crops comes into role. Similarly, in face of changing weather and water dynamics, strategic crop planning gains immense importance [5-7]. Crop cultivation further depends on length of growing period, determined by available soil moisture fulfilling the crop evapotranspiration needs, ensuring productivity. In dryland agriculture, the length of growing period of less than 5 weeks, guarantee crop failure [8-9]. 14 weeks of length of growing period allows single crop whereas more than 20 weeks supports cultivation of long duration crops and double cropping [10]. Additionally, we have managed to seek out, potential crop planning for the entire district taking into account the onset and cessation of monsoon rainfall.

2. MATERIALS AND METHODS

Daily rainfall data was extracted from GIOVANNI NASA site for period of 1998 to 2019 for co-ordinates ranging from 20.3863 - 23.5030 to 73.2530 – 74.5030 grid based for present study. Monthly, seasonally and weekly values have been computed from daily data values. The wet and dry spell analysis was carried out using Markov Chain Probability model with a limit of 20 mm rainfall in one standard meteorological week. More than 20 mm of rainfall was considered as wet week whereas less than 20 mm was considered as dry week [2].

The wet and dry week probabilities were further categorized into initial and conditional probability. The initial probability refers to occurring of an event independently, whereas conditional refers to occurring of an event in relation to another [11]. The different notations used in analysis are defined below.

2.1 Initial Probability

- P(D) = F(D)/N
- P(W) = F(W)/N

Where,

P(D) and P(W) are probabilities of dry and wet weeks
N is number of years
F(D) and F(W) represents frequency/number of dry and wet weeks

2.2 Conditional Probability

- P(DD) = F(DD)/F(D)
- P(WW) = F(WW)/F(W)
- P(WD) = 1-P(DD)
- P(DW) = 1-P(WW)

Where,

P(DD) is probability (conditional) of a dry week preceded by a dry week
P(WW) is probability (conditional) of a wet week preceded by a wet week
P(WD) is probability (conditional) of a wet week preceded by a dry week
P(DW) is probability (conditional) of a dry week preceded by a wet week
F(DD) is frequency/number of dry weeks preceded by dry weeks
F(WW) is frequency/number of wet weeks preceded by wet weeks

Onset and withdrawal of monsoon was computed from weekly rainfall data by forward and backward accumulation [12]. 75 mm of cumulative rainfall was chosen for onset of monsoon and 20 mm of rainfall was chosen for cessation of monsoon rainfall. Also probabilities of dry and wet spells of consecutive weeks are calculated. The monthly mean, standard deviation, coefficient of variation and seasonal contribution to annual rainfall were calculated and illustrated in result discussion section for same period of study year.

3. RESULT AND DISCUSSION

3.1 Rainfall Characteristics

The trend line for annual rainfall is depicted in Fig. 1 and rainy days in Fig. 2. The mean annual rainfall of Dahod district for a period 1998-2019 was 1073 mm, with 59 rainy days. The yearly rainfall varies from 1527 mm in 2006 to 662 mm in 2002 showing high variability between the years. Only 41 % shows rainfall above the mean annual rainfall. The standard deviation and co-efficient of variance were 248 and 23 respectively. The magnitude of rainfall of study period showed increase of 6.42 mm/year.

The number of rainy days (1998-2019) ranges from 41 to 86. The average number of rainy days seems to fluctuate but generally falls within the range of 50 to 70. Year 2006 stands out with a notably high rainfall of 1527 mm with 67 rainy days. Whereas year 2019 also records a high rainfall of 1426 mm but with a higher number of rainy days (86) as observed in Fig. 2.

A distribution of seasonal rainfall is crucial for planning of rainfed agriculture instead of annual so the season wise rainfall was summed as amount and illustrated it in pie diagram (Fig. 3). 95% of annual rainfall was contributed by South West monsoon whereas only 4% was contributed by North East monsoon followed by 0.9% and 0.2% in summer and winter seasons. Also statistical parameters like mean, standard deviation and coefficient of variance is calculated and tabulated (Table 1).

Table 1. Season wise standard statistical parameters

Season	Mean	SD	CV
Winter	2.37	4.69	1.98
Summer	10.30	12.59	1.22
Southwest monsoon	1015.07	250.76	0.25
Northeast monsoon	44.97	39.75	0.88

Furthermore, the highest mean monthly rainfall of 376 mm was received during July followed by 278, 210 and 152 mm in month of August, September and June, respectively. Whereas the lowest mean monthly rainfall was observed in January followed by December and February.

3.2 Onset and Withdrawal of Rainy season

The data on onset and withdrawal of monsoon and its variability in Dahod district is illustrated in Table 2. Weekly rainfall data of 22 years from 1998 to 2019 reflected that monsoon starts effectively from 25th standard meteorological week *i.e.,* 18th June to 24th June and cease on 40th standard meteorological week *i.e.,* 1st October to 7th October. The average period of

monsoon is of 16 weeks, which is around 112 days. As per the chosen set of data, the range for onset of monsoon was from 22nd standard meteorological week to 28th standard meteorological week and cessation of monsoon falls between 36th standard meteorological week to 47th standard meteorological week. Amongst the years, 25th SMW repeated the most for onset of monsoon while 41st SMW for withdrawal of the same.

3.3 Dry and Wet Spell Probability

The Markov Chain Probability method had been used by many researchers to determine dry and wet spells, onset and cessation of rainfall events as to manage farm operations related to agriculture. The Markov Chain probability level was used to compute initial, conditional and consecutive probabilities of wet and dry spell based on data set of 22 years (1998-2019). Table 3 illustrates the calculated values for initial, conditional and consecutive probability of rainfall for Dahod district for all 52 standard meteorological week at 20 mm limit.

At the start (SMW 1), there's a 0% chance of encountering wet conditions (P(W) = 0) and a 100% chance of facing dry conditions (P(D) = 1). These initial probabilities remain constant for the first 20 weeks, indicating consistently dry conditions. As the weeks progress, the conditional probabilities reflect the likelihood of transitioning from dry to wet in the subsequent weeks. The transition probabilities for consecutive wet-to-wet (P(W/W)) or dry-to-dry (P(D/D)) remain at 0%, suggesting no successive wet or dry periods, initially.

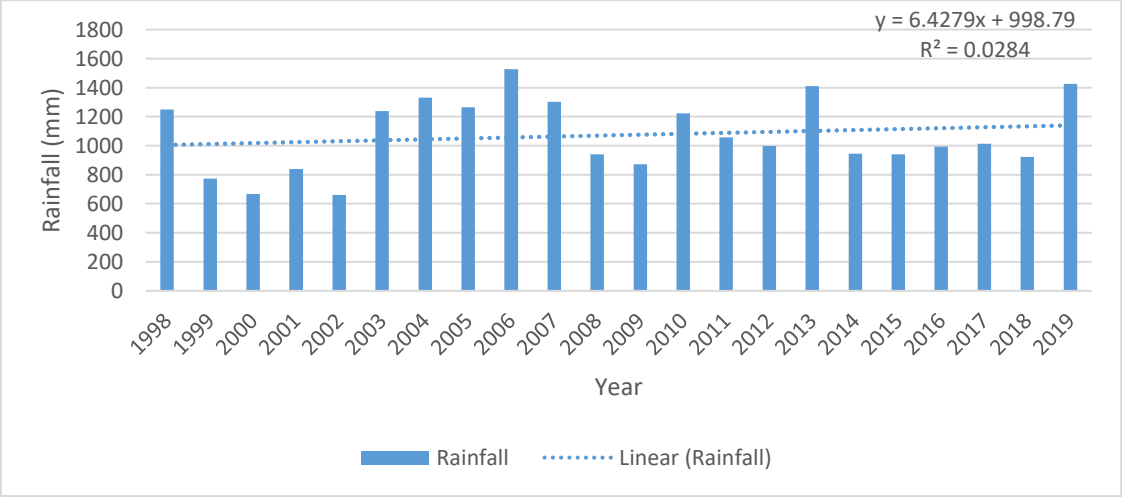

Fig. 1. The annual and long term mean rainfall (1998-2019)

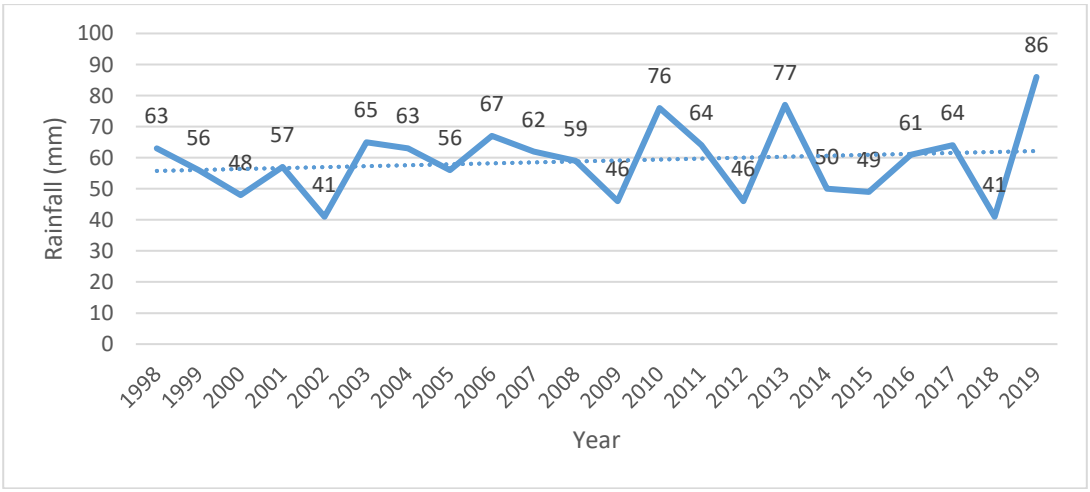

Fig. 2. Rainy days (1998-2019)

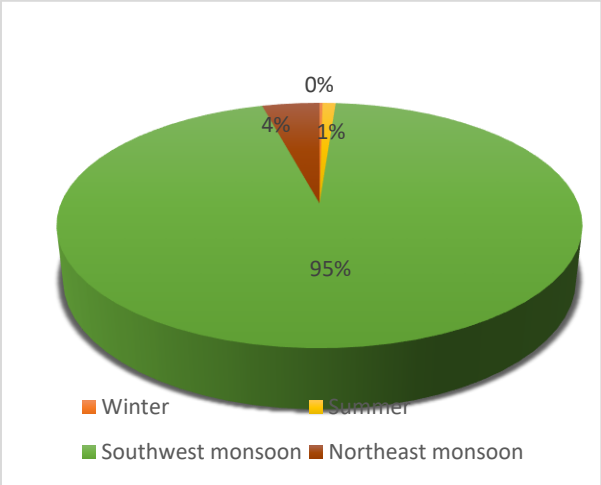

Fig. 3. Season wise rainfall (1998-2019)

Around Week 20, the probabilities start changing, indicating a shift in weather patterns. The probabilities of transitioning from a dry week to another dry week (P(D/D)) decrease from 100% to lower values, suggesting a decreasing trend in consecutive dry periods. Conversely, probabilities of transitioning from dry to wet (P(D/W)) or wet to dry (P(W/D)) start increasing, signifying an increasing likelihood of alternating wet and dry periods. For instance, by Week 27, there's a high probability of transitioning from dry to wet conditions (P(D/W) = 72.73) and a decreasing probability of consecutive dry periods (P(D/D) = 13.64).

As per data depicted in Table 3, the initial probability of wet week P(W) exceeding 75% can be observed from 27th SMW to 34th SMW. Onwards 40th SMW the chances of week getting dry P(D) increases *i.e.,* more than 60%, indicating chances of dry spell afterwards. P(W) exceeding 80% could be expected in 27th, 30th and 31st SMW, respectively.

In case of conditional probability, the probability of wet week preceded by wet week P(W/W) exceeding 80% can be observed in 27th, 28th, 31st and 32nd SMW in *Kharif* season, whereas probability of wet week preceded by dry week P(W/D) exceeding 80% can be observed in 29th and 30th SMW. The probability of dry week preceded by dry week P(D/D) exceeding 80% can be observed from 1st to 22nd SMW. SWM 35 and 36 recorded P(D/D) exceeding 70%. As the week progress, onwards 40th SMW the likelihood of week getting dry P(D/D) keeps on increasing. These changing transition probabilities continue to fluctuate, indicating varying patterns of wet and dry conditions as the weeks progress (Table 3).

Likewise the third column showcases the likelihood of experiencing two three consecutive dry and wet spells. As week progresses, the consecutive dry probabilities gradually decreases over time, indicating a higher chance of encountering wet spells. Overall, it reveals the changing patterns of consecutive dry and wet spells over the 51-week period, indicating the increasing probability of wet spells and decreasing probability of dry spells as the observation progresses as Dahod is dependent on monsoon for its agriculture produce.

Table 2. Onset and withdrawal of monsoon

Particulars	Standard Meteorological Week	Date
Onset of monsoon	25	18th -24th June
Early onset	23	4th-10th June
Delayed Onset	26	25th June -1st July
Withdrawal of monsoon	40	1st-7th Oct
Early Withdrawal	39	24th-30th Sept
Late Withdrawal	44	29th Oct-4th Nov

Table 3. Probability of rainfall in Dahod

Initial, conditional and consecutive probabilities of Precipitation
Station: Dahod
Year: 1998-2019
Limit 20 mm

SMW	Probability									
	Initial		Conditional				Consecutive			
	P(W)	P(D)	P(W/W)	P(D/W)	P(D/D)	P(W/D)	2D	3D	2W	3W
1	0	100	0	0	100	0	100	100	0	0
2	0	100	0	0	100	0	100	100	0	0
3	0	100	0	0	100	0	100	100	0	0
4	0	100	0	0	100	0	100	100	0	0
5	0	100	0	0	100	0	100	100	0	0
6	0	100	0	0	100	0	100	100	0	0
7	0	100	0	0	100	0	100	100	0	0
8	0	100	0	0	100	0	100	100	0	0
9	0	100	0	0	100	0	100	100	0	0
10	0	100	0	0	100	0	100	100	0	0
11	0	100	0	0	100	0	100	100	0	0
12	0	100	0	0	100	0	100	100	0	0
13	0	100	0	0	100	0	100	100	0	0
14	0	100	0	0	100	0	100	100	0	0
15	0	100	0	0	100	0	100	100	0	0
16	0	100	0	0	100	0	100	100	0	0
17	0	100	0	0	100	0	100	100	0	0
18	0	100	0	0	100	0	100	95.45	0	0
19	0	100	0	0	100	0	95.45	95.45	0	0
20	4.55	95.45	0	0	95.45	4.55	95.45	82.44	0	0
21	0	100	0	100	100	0	86.36	59.09	0	0
22	13.64	86.36	0	0	86.36	13.64	59.09	25.32	9.09	6.82
23	36.36	63.64	66.67	33.33	68.42	31.58	27.27	13.64	27.27	15.58
24	63.64	36.36	75	25	42.86	57.14	18.18	7.27	36.36	27.27
25	54.55	45.45	57.14	42.86	50	50	18.18	5.19	40.91	38.18
26	68.18	31.82	75	25	40	60	9.09	6.06	63.64	53.59
27	86.36	13.64	93.33	6.67	28.57	71.43	9.09	0	72.73	47.06
28	77.27	22.73	84.21	15.79	66.67	33.33	0	0	50	37.5
29	72.73	27.27	64.71	35.29	0	100	0	0	54.55	48.48
30	81.82	18.18	75	25	0	100	9.09	4.55	72.73	60.61
31	81.82	18.18	88.89	11.11	50	50	9.09	5.45	68.18	32.09
32	77.27	22.73	83.33	16.67	50	50	13.64	3.41	36.36	25.45
33	45.45	54.55	47.06	52.94	60	40	13.64	11.36	31.82	21.88
34	72.73	27.27	70	30	25	75	22.73	15.91	50	37.5
35	54.55	45.45	68.75	31.25	83.33	16.67	31.82	12.73	40.91	23.86
36	54.55	45.45	75	25	70	30	18.18	10.1	31.82	24.48
37	59.09	40.91	58.33	41.67	40	60	22.73	14.2	45.45	19.48
38	63.64	36.36	76.92	23.08	55.56	44.44	22.73	15.73	27.27	12.12
39	40.91	59.09	42.86	57.14	62.5	37.5	40.91	35.06	18.18	6.82
40	36.36	63.64	44.44	55.56	69.23	30.77	54.55	51.34	13.64	0
41	22.73	77.27	37.5	62.5	85.71	14.29	72.73	69.26	0	0
42	4.55	95.45	0	100	94.12	5.88	90.91	90.91	0	0
43	4.55	95.45	0	100	95.24	4.76	95.45	86.36	4.55	0
44	4.55	95.45	100	0	100	0	86.36	86.36	0	0
45	9.09	90.91	0	100	90.48	9.52	90.91	90.91	4.55	0

SMW	Probability									
	Initial		Conditional				Consecutive			
	P(W)	P(D)	P(W/W)	P(D/W)	P(D/D)	P(W/D)	2D	3D	2W	3W
46	4.55	95.45	50	50	100	0	95.45	95.45	0	0
47	0	100	0	100	100	0	100	100	0	0
48	0	100	0	0	100	0	100	100	0	0
49	0	100	0	0	100	0	100	100	0	0
50	0	100	0	0	100	0	100	100	0	0
51	0	100	0	0	100	0	100	0	0	0
52	0	100	0	0	100	0				

3.4 Crop Planning

Based on the analysis, recommendations can be made for the region that could help in increase crop production for better use of resources under rainfed condition. About 95% of annual rainfall falls in south west monsoon which coincides with the *kharif* season. Rainfall prior to onset of monsoon can be utilized in land preparation practices. The earliest start of rainy season has occurred at 22nd SMW while the delayed start was observed on 28th SMW for the studied data set. The major obstacles affecting progress and productivity of district are depleting soil fertility, lack of irrigation facility, inadequate resources, migration and lack of training and marketing awareness. The whole district is composed of hilly terrain with undulating land where rainfed farming is most prevailing. Maize is the staple food of the district, while soybean comes the second cultivated crop in *Kharif* season.

The predominant cropping system in the district involves maize, paddy, and pulses like green gram and black gram, cultivated predominantly under irrigated conditions. Various crop combinations such as maize-maize, maize-chickpea, maize-wheat-green gram, paddy-wheat, soybean-wheat-green gram, and pigeon pea-groundnut contribute to a diverse cropping system, resulting in a cropping intensity of 134% of the district.

The primary focus lies in promotion of poultry farming and vegetable cultivation in the region along with sustaining soybean and gram is the top most priority for the district due to recurrent vulnerability to drought conditions and erratic rainfall. The area frequently experiences extended dry spells between monsoons. To address these challenges, agricultural diversification and efficient irrigation practices are prioritized. Moreover, the establishment of rainwater harvesting systems and storage structures aims to manage and utilize monsoon rainfall effectively in the future.

4. CONCLUSION

The mean annual rainfall of Dahod district for a period of 1998-2019 was 1073 mm, with 59 rainy days. Only 41 % shows rainfall above the mean annual rainfall. 95% of annual rainfall was contributed by south west monsoon whereas only 4% was contributed by northeast monsoon followed by 0.9% and 0.2% in summer and winter seasons.

Threshold limit of 20 mm of rainfall per week at more than 50% of initial probability during the rainy season is adequate for crop activities like land preparation and the conditional probability of occurrence of rainfall at 20mm per week above 50% is the right week for sowing/planting [13]. The initial probability indicates that more than 75% of wet probability can be seen onwards 27th SMW upto 34th SMW. Onwards 39th SMW, the chances of wet getting dry increases. More than 80% likelihood of week getting wet could be expected in 27th, 30th and 31st SMW. Conditional probability P(W/W) exceeding 80% can be expected in 27th, 28th, 31st and 32nd SMW in *Kharif* season whereas P(W/D) exceeding 80% in 29th and 30th SMW. SMW 35 and 36 records P(D/D) more than 70%. Onwards 40th SMW likelihood of P(D/D) keeps increasing upto 52nd SMW.

The district experiences a semi-arid climate mainly depending on monsoon season for the choice of crops. Majorly, maize and soybean crop is grown in *Kharif* season followed by cultivation of wheat, chickpea and vegetables in *rabi* as crops benefits from post monsoon moisture and cooler temperature. Overall crop planning in Dahod involves a mix of traditional and modern agricultural techniques along with adaptation strategies tailored to regions specific

condition to ensure a successful and sustainable agriculture output.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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