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Original Article

Spatial Assessment of Drought Vulnerability in Eastern Sangli District, Maharashtra: A Geographical Analysis

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Abstract:

Drought is a major climatic hazard in the semi-arid region of Maharashtra, particularly in areas with low and highly variable rainfall. Eastern Sangli is one such drought-prone region, where rainfall uncertainty affects agriculture, water resources and rural livelihoods. This study assesses drought vulnerability in Atpadi, Jat and Kavathe Mahankal talukas using rainfall characteristics and the Standardized Precipitation Index (SPI), without applying GIS techniques. Annual rainfall data for 1992–2021 were analysed using mean rainfall, standard deviation, coefficient of variation, drought frequency and drought severity. Atpadi recorded the lowest mean annual rainfall (427.7 mm) and the highest rainfall variability (47.4%). Jat received higher average rainfall (615.6 mm) but experienced the highest frequency of SPI-based drought conditions. Kavathe Mahankal recorded 504.1 mm of mean annual rainfall with a coefficient of variation of 38.8%. SPI values of −1.00 or below occurred in five years at Atpadi, six years at Jat and one year at Kavathe Mahankal. The most severe drought was observed in 2018, with SPI values of −1.94 at Atpadi and −2.12 at Jat. The findings show that drought vulnerability is influenced not only by rainfall amount but also by its variability, frequency and severity. The study suggests location-specific water conservation, improved groundwater management, crop diversification and drought-resilient agricultural practices for Eastern Sangli.

Keywords: Drought Vulnerability, Rainfall Variability, SPI, Eastern Sangli, Maharashtra.

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Introduction:

Drought is a recurrent climatic hazard that affects agriculture, water resources, livestock and rural livelihoods. Unlike sudden disasters, drought develops gradually through prolonged rainfall deficiency and may continue for months or longer. Its impact is particularly serious in semi-arid agricultural regions where farming and water availability depend largely on seasonal rainfall. Therefore, understanding rainfall variability and drought recurrence is important for effective resource management and agricultural planning.

Drought is commonly classified into meteorological, agricultural, hydrological and socio-economic types. Among these, meteorological drought is directly associated with rainfall deficiency and provides an important basis for assessing the climatic dimensions of drought. The occurrence and severity of drought are influenced by rainfall amount and variability, as well as by physiography, soils, drainage, land use, irrigation and human activities. In semi-arid regions, high rainfall variability can create drought conditions even where average annual rainfall is not extremely low.

Maharashtra experiences considerable spatial variation in rainfall, mainly because of the Western Ghats, monsoon circulation and regional physiography. The western parts generally receive higher rainfall, while several areas of the interior plateau fall within the rain-shadow zone. Consequently, drought is a recurring problem in many parts of the state, particularly in regions dependent on rain-fed agriculture.

Sangli District provides a clear example of this rainfall contrast. Rainfall generally decreases from the western part of the district towards the east. The western talukas, including Shirala and Walwa, receive relatively high rainfall, whereas the eastern region is comparatively dry and falls within the rain-shadow area. The district administration identifies Atpadi, Jat and Kavathe Mahankal among the permanently drought-affected talukas. These three talukas therefore provide an appropriate geographical setting for examining variations in rainfall and drought occurrence.

The selected talukas show considerable differences in their long-term rainfall characteristics. Atpadi has the lowest mean annual rainfall (427.7 mm) and the highest coefficient of variation (47.4%), indicating low and unstable rainfall conditions. Jat receives a higher mean annual rainfall of 615.6 mm, but drought occurrence remains significant. Kavathe Mahankal records an intermediate mean annual rainfall of 504.1 mm with a coefficient of variation of 38.8%. These differences suggest that annual rainfall totals alone cannot adequately explain drought vulnerability.

The Standardized Precipitation Index (SPI) is widely used to identify and compare meteorological drought conditions. It converts rainfall anomalies into standardized values, allowing both dry and wet conditions to be examined over a common scale. Negative SPI values indicate rainfall deficiency, with increasingly negative values representing greater drought intensity. A 12-month SPI is particularly useful for analysing accumulated precipitation deficits and longer-term drought conditions.

Several studies have examined rainfall variability and drought in Sangli District using rainfall indices and SPI. However, a focused comparative assessment of the eastern drought-prone talukas using a consistent long-term dataset remains useful. Treating the district as a single climatic unit may hide important differences between individual talukas. The present study therefore concentrates on Atpadi, Jat and Kavathe Mahankal and compares their rainfall characteristics, drought frequency and drought severity.

The study uses a 30-year period from 1992 to 2021 and adopts a statistical approach without GIS techniques. Annual rainfall characteristics and 12-month SPI values are analysed using mean rainfall, standard deviation, coefficient of variation, drought frequency and drought severity. Rainfall and SPI data published by the Department of Agricultural Meteorology, College of Agriculture, Pune, under Mahatma Phule Krishi Vidyapeeth, form the principal basis of the analysis.

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The study assumes that drought vulnerability is influenced not only by the amount of rainfall but also by its variability, frequency and severity. Thus, a taluka receiving relatively higher rainfall may still experience considerable drought risk when rainfall is highly variable or when severe drought events occur.

The geographical significance of this study lies in its comparative assessment of rainfall and drought behaviour in three drought-prone talukas of Eastern Sangli. The findings are expected to provide useful evidence for location-specific water conservation, agricultural planning, crop diversification and drought adaptation strategies in the semi-arid region of Maharashtra.

Study Area:

The study focuses on the eastern drought-prone part of Sangli District in Maharashtra, particularly Atpadi, Jat and Kavathe Mahankal talukas. These talukas were selected because of their relatively dry climatic conditions and their identification as permanently drought-affected areas by the Sangli District Administration.

Sangli District covers approximately 8,572 km² and is located in southern Maharashtra. It is bordered by Satara and Solapur districts in the north and northeast, Vijayapura district of Karnataka in the east, Belagavi and Kolhapur districts in the south, and Ratnagiri district in the west. The district shows a marked east-west contrast in rainfall and climatic conditions. The western region, influenced by the Sahyadri ranges, receives comparatively high rainfall, whereas the eastern region lies in the rain-shadow zone and has a semi-arid climate.

According to the Groundwater Surveys and Development Agency (GSDA), the western talukas such as Shirala and Walwa receive substantially higher rainfall, while much of eastern Sangli receives around 500–600 mm annually and falls within the Drought Prone Area Programme (DPAP). The eastern region is characterized by dry conditions, seasonal streams, scrub vegetation and considerable dependence on monsoon rainfall. The Man and Bor river systems provide drainage to parts of this region and are associated with the Bhima River system.

1. Atpadi: Atpadi is located in the eastern part of Sangli District and represents one of the driest areas of the district. The taluka experiences low and variable rainfall, resulting in a high dependence on seasonal precipitation. The rainfall analysis used in this study records a mean annual rainfall of 427.7 mm, indicating its relatively dry climatic conditions.

2. Jat: Jat is situated in the easternmost part of Sangli District along the Maharashtra–Karnataka border. It has a predominantly semi-arid climate and is characterized by dry agricultural conditions. Although its average rainfall is higher than that of Atpadi, rainfall remains variable and drought is a recurring concern. Jat is officially recognized as a permanently drought-affected taluka.

3. Kavathe Mahankal: Kavathe Mahankal lies in the eastern part of Sangli District and has climatic conditions intermediate between Atpadi and Jat. The taluka receives relatively low and variable rainfall and is also identified as a permanently drought-affected area. Its semi-arid environment and dependence on seasonal rainfall make it suitable for comparative drought analysis.

The three talukas therefore provide a useful geographical basis for comparing rainfall variability and drought behaviour within the eastern drought-prone region of Sangli District.

Objectives:

The present study has the following objectives:

1. To examine the rainfall characteristics and variability of Atpadi, Jat and Kavathe Mahankal talukas of Eastern Sangli District.

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2. To assess the frequency and severity of meteorological drought during 1992–2021 using the 12-month Standardized Precipitation Index (SPI).
3. To comparatively evaluate drought vulnerability in the three eastern talukas and suggest appropriate measures for drought mitigation and agricultural adaptation.

Data Sources and Methodology:

1. Data Sources:

The study is based mainly on secondary climatic and geographical data. Rainfall and 12-month Standardized Precipitation Index (SPI) data for the selected talukas were obtained from published studies using records associated with the Department of Agricultural Meteorology, College of Agriculture, Pune, Mahatma Phule Krishi Vidyapeeth, along with official rainfall sources.

Information on the geographical setting, drought-prone status and groundwater conditions of the study area was collected from the Sangli District Administration, Government of Maharashtra, Groundwater Surveys and Development Agency (GSDA), Central Ground Water Board (CGWB), and relevant published studies.

2. Study Period:

The analysis covers a 30-year period from **1992 to 2021**. This period was selected because comparable annual rainfall and 12-month SPI data are available for Atpadi, Jat and Kavathe Mahankal.

3. Method of Analysis:

Annual rainfall data were analysed using mean annual rainfall, standard deviation and coefficient of variation (CV) to assess the amount and variability of precipitation. The coefficient of variation was calculated as: **CV = (Standard Deviation / Mean Rainfall) × 100**

The 12-month SPI was used to identify and classify meteorological drought conditions. SPI values of **−1.00 or below** were considered indicative of drought conditions. Drought frequency was determined by counting the number of years with SPI ≤ −1.00, while drought severity was assessed from the magnitude of the negative SPI values.

The analysis was carried out using statistical and comparative methods. The results were compared among Atpadi, Jat and Kavathe Mahankal to identify differences in rainfall variability, drought frequency and drought severity.

Rainfall Characteristics:

Rainfall is the most important climatic determinant of drought in Eastern Sangli. The rainfall characteristics of the three selected talukas reveal substantial differences in both rainfall amount and variability.

Table 1. Rainfall Characteristics of the Study Area

Taluka	Mean annual rainfall (mm)	Standard deviation (mm)	CV (%)
Atpadi	427.7	202.8	**47.4**
Jat	615.6	214.7	**34.9**
Kavathe Mahankal	504.1	195.6	**38.8**

The results show that **Atpadi has the lowest mean annual rainfall** among the three study units. Its mean annual rainfall of 427.7 mm is approximately 30% lower than that of Jat. However, the most important feature of Atpadi's rainfall is its high variability. Its coefficient of variation of 47.4% is the highest among the three talukas. Jat has the highest mean annual rainfall at 615.6 mm and the

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lowest CV among the three, at 34.9%. Nevertheless, its drought record demonstrates that relatively higher rainfall does not eliminate drought risk. Kavathe Mahankal occupies an intermediate position with mean rainfall of 504.1 mm and CV of 38.8%.

30-Year SPI Analysis:

The 12-month SPI values for 1992–2021 provide a detailed picture of the temporal occurrence of dry and wet conditions in Eastern Sangli.

Table 2. Annual 12-Month SPI, 1992–2021

Year	Atpadi	Jat	Kavathe Mahankal	Year	Atpadi	Jat	Kavathe Mahankal
1992	−1.43	−1.17	−0.67	2007	0.97	0.32	0.48
1993	−0.03	0.51	0.47	2008	0.10	1.00	0.33
1994	−1.28	−1.36	0.38	2009	1.34	0.92	0.64
1995	0.30	0.81	0.83	2010	1.18	0.92	0.53
1996	0.18	1.02	0.11	2011	0.02	−0.32	−0.44
1997	−0.73	0.36	−0.48	2012	−0.70	−1.78	−0.90
1998	1.22	0.72	1.49	2013	0.20	−0.76	−0.36
1999	0.59	0.47	0.56	2014	0.25	−0.18	0.49
2000	−0.15	0.47	1.09	2015	0.31	−1.30	−0.14
2001	−0.82	0.38	0.87	2016	−0.15	−0.83	0.72
2002	−0.77	−1.36	−0.10	2017	0.27	−0.37	0.51
2003	−1.29	−0.58	−0.76	2018	**−1.94**	**−2.12**	**−1.05**
2004	−0.19	0.69	0.25	2019	1.08	0.40	1.88
2005	−1.62	−0.33	−0.57	2020	2.58	1.46	1.94
2006	−0.83	0.30	0.78	2021	1.66	1.20	1.67

1. General SPI Pattern:

The SPI series reveals substantial interannual variation. Atpadi experienced negative SPI values during several years, with particularly pronounced drought conditions in 1992, 1994, 2003, 2005 and 2018. Jat experienced drought conditions in 1992, 1994, 2002, 2012, 2015 and 2018. Kavathe Mahankal experienced relatively fewer SPI-defined drought years, with 2018 being its principal drought event during the selected period.

2. The 2018 Drought:

The year 2018 is the most significant drought year in the 30-year series. The simultaneous occurrence of drought conditions in all three talukas indicates a widespread regional drought episode. Jat experienced the most severe condition, with SPI falling below −2.00. Atpadi also experienced severe drought, while Kavathe Mahankal experienced moderate drought.

3. Wet Conditions After 2018:

The SPI record also shows a strong transition from drought to wet conditions after 2018. In 2019, all three talukas recorded positive SPI values. In 2020, Atpadi recorded an exceptionally high SPI of **2.58**, while Kavathe Mahankal recorded **1.94** and Jat **1.46**. In 2021, all three talukas again recorded positive SPI values. This sequence demonstrates the high interannual variability of rainfall in the region.

Drought Frequency:

Drought frequency is one of the most important indicators of drought vulnerability. A drought year is considered when SPI ≤ −1.00.

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Table 3. Drought Frequency During 1992–2021

Taluka	Drought years	Total years	Drought frequency (%)
Atpadi	5	30	**16.67**
Jat	6	30	**20.00**
Kavathe Mahankal	1	30	**3.33**

The results show that **Jat has the highest drought frequency**, with drought occurring in 20% of the years during the study period. Atpadi ranks second with 16.67%, whereas Kavathe Mahankal records only 3.33%.

Drought Severity:

Drought severity is assessed using the number of moderate, severe and extreme drought events.

Table 4. Drought Severity During 1992–2021

Taluka	Moderate drought (−1.00 to −1.49)	Severe drought (−1.50 to −1.99)	Extreme drought (≤−2.00)	Total
Atpadi	3	2	0	**5**
Jat	4	1	1	**6**
Kavathe Mahankal	1	0	0	**1**

Atpadi: Atpadi experienced five drought years. The most severe event was in 2018, when SPI reached −1.94. Another severe event occurred in 2005, when SPI reached −1.62. Thus, 40% of the drought years in Atpadi were severe.

Jat: Jat recorded six drought years. The most severe event occurred in 2018, with SPI of −2.12, classified as extreme drought. The 2012 drought, with SPI −1.78, was severe. Thus, Jat experienced both severe and extreme drought conditions.

Kavathe Mahankal: Kavathe Mahankal recorded only one drought year under the selected SPI threshold, namely 2018, with SPI −1.05. Although the taluka is officially drought-prone, the selected 30-year SPI record indicates fewer meteorological drought events than Atpadi and Jat.

Statistical Results:

The annual SPI values were statistically summarized to provide a comparative assessment.

Table 5. Statistical Characteristics of 12-Month SPI

Statistic	Atpadi	Jat	Kavathe Mahankal
Mean SPI	0.011	−0.017	0.352
Standard deviation	1.046	0.959	0.798
Minimum SPI	−1.94	**−2.12**	−1.05
Maximum SPI	**2.58**	1.46	1.94
Drought years	5	**6**	1
Drought frequency	16.67%	**20.00%**	3.33%
Severe drought years	2	1	0
Extreme drought years	0	1	0

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1. Mean SPI:

The mean SPI values are close to zero for Atpadi and Jat, indicating that the long-term series does not show a strong overall dry or wet bias. Atpadi has a mean SPI of approximately 0.011, while Jat has −0.017. Kavathe Mahankal has a comparatively positive mean SPI of approximately 0.352. The near-zero mean values of Atpadi and Jat should not be interpreted as an absence of drought risk. The mean conceals substantial interannual variability and extreme events.

2. SPI Variability:

Atpadi records the highest SPI standard deviation at approximately 1.046, followed by Jat at 0.959 and Kavathe Mahankal at 0.798. This result is consistent with the rainfall CV analysis and reinforces the conclusion that Atpadi experiences considerable climatic instability.

3. Minimum SPI:

Jat has the lowest SPI value at −2.12. Atpadi's minimum is −1.94, while Kavathe Mahankal records −1.05. Therefore, Jat experienced the most severe single drought event during the study period.

Discussion:

The findings demonstrate that Eastern Sangli is a drought-sensitive geographical region, but the intensity of drought vulnerability varies considerably among the selected talukas.

The first important observation is the low rainfall environment. GSDA identifies the eastern portion of Sangli as a rain-shadow region and reports rainfall generally in the range of 500–600 mm within the DPAP area. It also identifies Atpadi and Jat among the driest parts of the district.

The second important observation is rainfall variability. Atpadi has a coefficient of variation of 47.4%, indicating substantial uncertainty in annual rainfall. High variability is particularly problematic for rain-fed agriculture because farmers depend not merely on the total annual rainfall but on its timing and distribution.

The third observation is that higher mean rainfall does not necessarily eliminate drought risk. Jat records the highest mean annual rainfall among the three selected talukas, at 615.6 mm, but has the highest drought frequency in the 30-year SPI record.

The fourth observation concerns the 2018 drought. The occurrence of negative SPI values across all three talukas during 2018 demonstrates the regional character of drought. The event was most severe in Jat, followed by Atpadi and Kavathe Mahankal.

The fifth observation is the rapid transition from drought to wet conditions. The very high positive SPI values recorded during 2019–2021 indicate that Eastern Sangli does not experience a continuous state of dryness. Instead, the region exhibits considerable climatic fluctuation between deficient and excessive rainfall years.

This pattern has major implications for water management. Drought management cannot focus exclusively on emergency water supply during dry years. It must also emphasize storage and groundwater recharge during wet years.

Drought Vulnerability Assessment:

The drought vulnerability assessment is based on the combined interpretation of rainfall characteristics and SPI statistics.

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Table 6. Comparative Drought Vulnerability Assessment

Indicator	Atpadi	Jat	Kavathe Mahankal
Mean rainfall	**Very low**	Relatively high	Low
Rainfall variability	**Very high**	High	High
Drought frequency	High	**Very high**	Very low
Severe drought	High	Moderate	Low
Extreme drought	None	**Present**	None
Minimum SPI	−1.94	**−2.12**	−1.05
SPI variability	**Highest**	High	Moderate
Overall climatic vulnerability	**High**	**Very High**	**Moderate**

Based on the combined evidence, the three talukas may be comparatively classified as follows:

1. Very High Vulnerability: Jat is assessed as having **very high climatic drought vulnerability** because it records Six drought years, 20% drought frequency, One extreme drought event, The lowest SPI value of −2.12, Severe drought in 2012, Official permanent drought-prone status.

Although its mean rainfall is relatively higher than Atpadi, the frequency and severity of drought events are important vulnerability indicators.

2. High Vulnerability: Atpadi is assessed as having **high climatic drought vulnerability**. The principal reasons are Lowest mean annual rainfall, Highest rainfall CV, Five drought years, Two severe drought events, SPI minimum of −1.94.

Atpadi therefore represents a classic low-rainfall/high-variability drought environment.

3. Moderate Vulnerability: Kavathe Mahankal is classified as having **moderate climatic vulnerability relative to the other two study units**. It has Low mean rainfall, High rainfall variability, only one SPI-defined drought year during the study period, No severe or extreme drought event.

However, this does not mean that Kavathe Mahankal is free from drought risk. Its official drought-prone status and relatively low rainfall indicate continuing structural vulnerability.

Finding:

Drought vulnerability in Eastern Sangli is not directly proportional to mean annual rainfall. Jat has the highest average rainfall but the highest drought frequency and the most severe drought event. Atpadi has the lowest rainfall and the highest rainfall variability. Kavathe Mahankal has relatively fewer SPI-defined drought years.

Therefore, drought vulnerability is better understood through a combination of climatic indicators rather than a single rainfall measure.

Recommendations:

Based on the findings of the study, several measures can be adopted to reduce drought vulnerability in Eastern Sangli. These measures should be planned according to the rainfall conditions and local resource availability of each taluka.

- Rainwater harvesting should be promoted at household, farm and village levels. Farm ponds, check dams, percolation tanks and other small storage structures can help conserve runoff and improve water availability during dry periods.

- Groundwater recharge should be given priority, particularly in Atpadi and Jat. Recharge structures should be planned and maintained according to local geological and hydrogeological conditions. Groundwater management information provided by the Central Ground Water Board (CGWB) can support scientific planning and sustainable groundwater use.
- Farmers in drought-prone areas should be encouraged to adopt drought-tolerant crops and varieties. Cereal and pulse-based cropping systems can be promoted in areas where irrigation facilities are limited and rainfall is uncertain.
- Crop diversification can reduce the risks associated with dependence on a single crop. Farmers should be encouraged to combine suitable cereals, pulses, oilseeds, fodder crops and other locally appropriate crops according to rainfall and water availability.
- Drip and sprinkler irrigation systems should be promoted wherever feasible. These methods can improve water-use efficiency and reduce unnecessary water losses, particularly in areas facing recurring water shortages.
- SPI-based drought monitoring can be incorporated into a local drought early-warning system. Regular monitoring of SPI values can help identify developing rainfall deficits and support timely decisions related to agriculture, water management and drought preparedness.
- In highly drought-prone areas, dependence on rain-fed agriculture should be reduced by promoting alternative sources of income. Livestock, dairy farming, horticulture, agro-processing, rural employment and other non-farm activities can provide additional livelihood opportunities during periods of agricultural stress.
- A uniform drought-management strategy may not be equally effective across Eastern Sangli because rainfall characteristics and drought behaviour differ among the talukas. In Jat, greater emphasis should be placed on drought early warning, water budgeting and crop diversification. Atpadi requires greater attention to rainwater harvesting, groundwater recharge and drought-resistant agriculture. In Kavathe Mahankal, preventive water conservation, groundwater management and agricultural diversification should receive greater priority.

Overall, drought management in Eastern Sangli should follow a **taluka-specific and locally appropriate approach** that combines water conservation, efficient agricultural practices, drought monitoring and livelihood diversification.

Conclusion:

The study assessed drought vulnerability in Eastern Sangli using rainfall characteristics and 12-month SPI values for the period 1992–2021. Atpadi, Jat and Kavathe Mahankal were selected as representative drought-prone talukas of the eastern dry zone.

The rainfall analysis shows clear differences among the three talukas. Atpadi recorded the lowest mean annual rainfall (427.7 mm) and highest rainfall variability (47.4%), while Jat received the highest mean rainfall (615.6 mm). Kavathe Mahankal recorded 504.1 mm of mean annual rainfall with comparatively moderate variability. These results confirm that Eastern Sangli is not climatically uniform.

SPI analysis indicates that drought conditions (SPI ≤ -1.00) occurred in five years at

Atpadi, six years at Jat and one year at Kavathe Mahankal. The most severe drought was recorded in Jat in 2018, with an SPI of −2.12, followed by Atpadi (−1.94). The findings show that higher average rainfall does not necessarily mean lower drought vulnerability.

Overall, Jat showed the highest climatic drought vulnerability, followed by Atpadi, while Kavathe Mahankal experienced comparatively fewer drought events during the study period. The study confirms that drought assessment should consider rainfall amount, variability, frequency and severity rather than mean rainfall alone.

Effective drought management in Eastern Sangli therefore requires taluka-specific measures, including rainwater harvesting, groundwater recharge, crop diversification, micro-irrigation, drought-resistant crops, water budgeting and SPI-based early warning.

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