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Drought Frequency and Severity in the Tahsils of Ahilyanagar (Ahmadnagar)) District: A Four-Decade Statistical Analysis

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Abstract: ***This study presents a comprehensive analysis of drought frequency and severity across 14 Tahsils of Ahilyanagar (Ahmadnagar) District, Maharashtra, over a 44-year period (1981-2024). Using IMD's standardized deficit classification criteria, we identified and characterized 25 severe drought events and 107 moderate drought events across the district. Parner Tahsil emerged as the most drought-vulnerable with 5 severe drought occurrences (11.4% frequency), while Sangamner, Kopargaon, and Rahata experienced no severe droughts despite lower average rainfall. The study reveals distinct spatial patterns in drought vulnerability, with southern and central Tahsils experiencing higher severe drought frequency compared to northern Tahsils. Temporal analysis indicates drought clustering in specific years (1985-86, 2003, 2012, 2017-19), suggesting systematic rainfall failures during these periods. The research provides critical insights for drought preparedness, water resource management, and agricultural adaptation strategies in this semi-arid region.***

Keywords: Drought severity, rainfall deficit, spatial vulnerability, temporal patterns, Ahilyanagar (Ahmadnagar) District

1. Introduction

Drought represents one of the most disturbing natural hazards affecting agricultural productivity, water security, and socio-economic stability in semi-arid regions. Unlike other natural disasters, droughts develop gradually and can persist for multiple seasons or years, causing cumulative damage to ecosystems, agriculture, and human livelihoods. The study of drought frequency and severity is essential for developing effective mitigation strategies and building climate resilience in vulnerable regions.

Ahilyanagar (Ahmadnagar) District, located in the rain shadow region of the Western Ghats in Maharashtra, India, experiences significant rainfall variability and recurrent drought conditions. With an average annual rainfall of 520.1 mm (1981-2024), the district falls under the semi-arid climatic classification, where agriculture is predominantly rain-fed and highly susceptible to moisture stress. The district comprises 14 Tahsils with varying topographical and climatic characteristics, resulting in spatial heterogeneity in drought vulnerability.

Previous studies have documented drought occurrences in Maharashtra, but comprehensive Tahsil-level characterization of drought frequency and severity in Ahilyanagar (Ahmadnagar) District remains limited. This research addresses this gap by analyzing 44 years of rainfall data (1981-2024) to systematically characterize drought patterns across all 14 Tahsils, identify high-vulnerability zones, and examine temporal clustering of drought events.

Objectives

The objectives of this study are:

1) To quantify the frequency and severity of drought events across all Tahsils of Ahilyanagar (Ahmadnagar) District.
2) To identify spatial patterns and high-vulnerability zones for drought occurrence.
3) To analyze temporal clustering and consecutive drought years
4) To assess the relationship between average rainfall and drought vulnerability
5) To provide evidence-based recommendations for drought mitigation and agricultural adaptation

Study Area

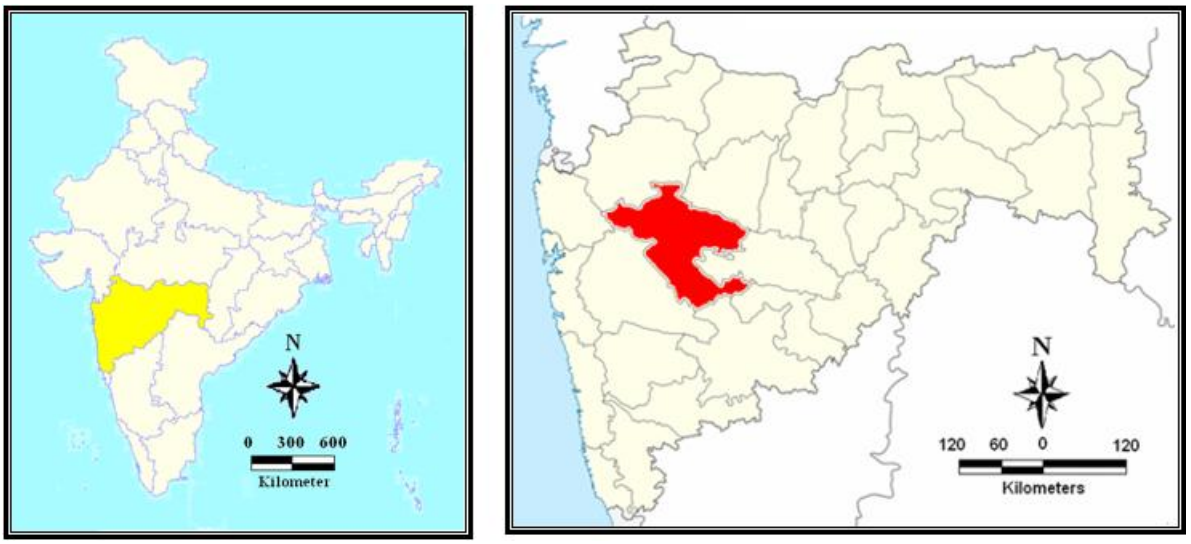
Ahilyanagar (Ahmadnagar) district is located in the western part of Maharashtra, India, positioned between 18°22' to 19°59' North latitude and 73°32' to 75°37' East longitude. The district covers an area of 17,047.67 sq.km (5.54% of the State) with a population of approximately 4.5 million and comprises 14 administrative Tahsils: Akole, Sangamner, Shrirampur, Kopargaon, Rahuri, Newasa, Shevgaon, Pathardi, Parner, Shrigonda, Karjat, Jamkhed, Nagar, and Rahata.

The district exhibits diverse topographical features, ranging from hilly terrain in the western parts (foothills of Western Ghats) to relatively flat plains in the eastern regions. This topographic diversity creates distinct microclimatic zones within the district. The western Tahsils (Akole, Sangamner) receive comparatively higher rainfall due to their proximity to the Western Ghats, while eastern Tahsils (Pathardi, Jamkhed, Karjat) experience lower and more erratic rainfall due to their location in the rainshadow zone.

The district experiences a semi-arid tropical climate characterized by hot summers, mild winters, and a distinct monsoon season from June to September. The soils are predominantly medium to deep black cotton soils, suitable for crops like sugarcane, cotton, jowar, bajra, and pulses.

Agriculture is the primary livelihood for approximately 70% of the district's population, with major crops including

jowar, bajra, wheat, sugarcane, and various pulses. The predominance of rain-fed agriculture makes the district highly vulnerable to drought conditions, with significant implications for food security and rural livelihoods.



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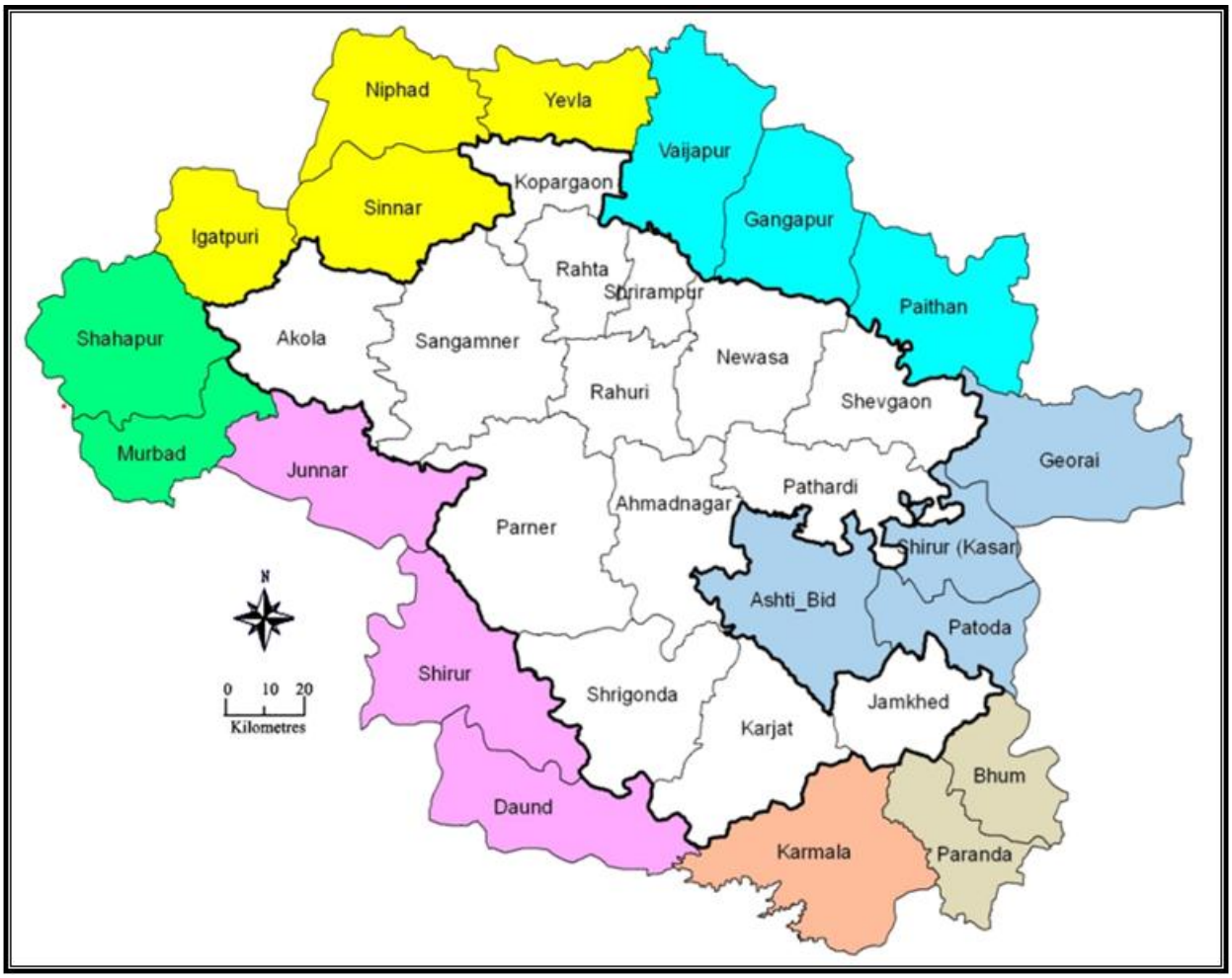


Ahilyanagar (Ahmadnagar)

Map 1: Location of Study Area: Ahmadnagar District

2. Database and Methodology

Data Collection

The present research work is entirely based on secondary data. Rainfall data for the period 1981-2024 (44 years) was obtained for all 14 Tahsils of Ahilyanagar (Ahmadnagar) District from the https://ahilyanagar.maharashtra.gov.in/en/ and https://maharain.maharashtra.gov.in. The dataset includes annual rainfall measurements and average number of rainy days. For 13 Tahsils, complete 44-year records (1981-2024) were available, while Rahata Tahsil has records from 2000-2024 (25 years).

Drought Classification Methodology

Drought events were classified based on percentage deviation from the long-term mean annual rainfall for each Tahsil, following the methodology used by the India Meteorological Department (IMD) and adopted by various state governments:

Classification Categories:

- **Severe Drought:** Rainfall deficit ≤ -51% from mean
- **Moderate Drought:** Rainfall deficit between -26% to -50% from mean
- **Normal:** Rainfall deviation between -25% to +25% from mean
- **Excess Rainfall:** Rainfall surplus ≥ +26% from mean

The deficit percentage was calculated using the formula:
Deficit (%) = [(Actual Rainfall - Mean Rainfall) / Mean Rainfall] × 100

Analytical Methods

The following analytical approaches were employed:

1) **Frequency Analysis:** Calculation of severe and moderate drought occurrences for each Tahsil over the study period
2) **Severity Assessment:** Identification of extreme deficit years and their magnitude
3) **Temporal Analysis:** Examination of drought clustering, consecutive drought years, and decadal patterns
4) **Spatial Analysis:** Mapping of drought vulnerability zones based on frequency and severity metrics
5) **Correlation Analysis:** Assessment of relationships between mean rainfall, variability, and drought frequency
6) **Comparative Assessment:** Inter-Tahsil comparison of drought characteristics

3. Results and Discussion

District-Level Drought Overview

Over the 44-year study period, Ahilyanagar (Ahmadnagar) District experienced significant drought stress with varying intensity across different Tahsils. At the district level, the most severe drought year was 2003, when rainfall dropped to 303 mm, representing a 41.7% deficit from the long-term average of 520.1 mm. This district-wide event affected all Tahsils simultaneously, causing widespread agricultural failure and water scarcity.

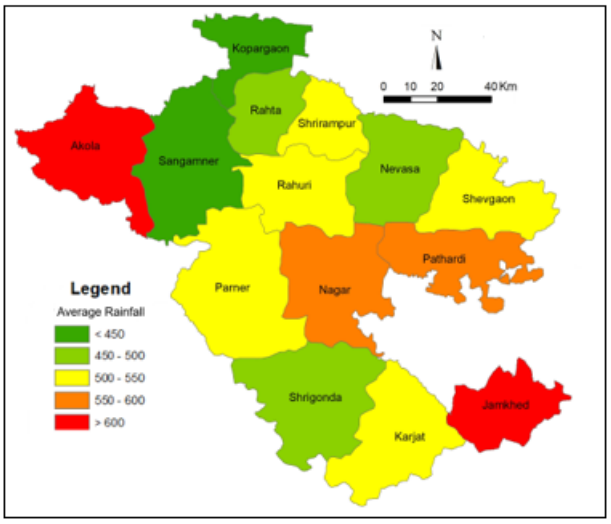
Analysis of all 14 Tahsils revealed a total of 25 severe drought events and 107 moderate drought events over the study period. This translates to an average of 1.8 severe droughts and 7.7 moderate droughts per Tahsil over 44 years, indicating that each Tahsil experiences a severe drought approximately once every 24 years and a moderate drought every 14 years on average.

Tahsil-wise Drought Frequency Analysis

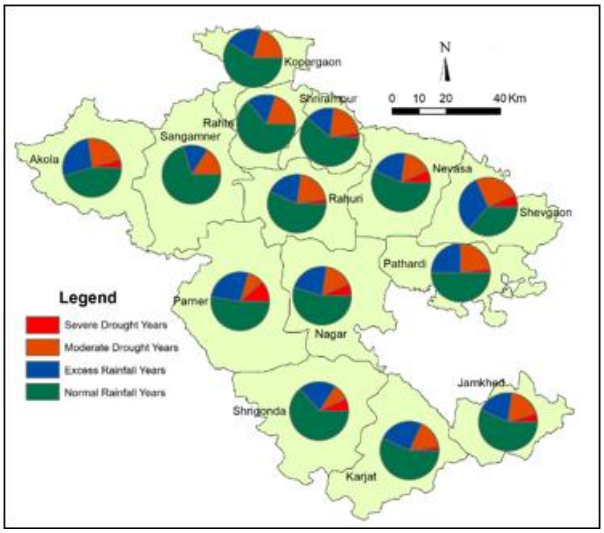
Table 1 presents the comprehensive drought frequency statistics for all 14 Tahsils, revealing striking differences in drought vulnerability across the district.

Table 1: Drought Frequency and Classification Statistics by Tahsil (1981-2024)

Tahsil	Mean Rainfall (mm)	Study Period (Years)	Severe Drought Count	Moderate Drought Count	Total Drought Years	Combined Drought Frequency (%)	Excess Rainfall Years	Normal Years
1. Akole	599.8	44	2	10	12	27.3	12	20
2. Jamkhed	653.5	44	2	8	10	22.7	9	25
3. Karjat	530.3	44	1	7	8	18.2	11	25
4. Kopargaon	441.1	44	0	9	9	20.5	9	26
5. Nagar	588.3	44	3	7	10	22.7	10	24
6. Newasa	467.8	44	3	7	10	22.7	9	25
7. Parner	513.3	44	5	4	9	20.5	12	23
8. Pathardi	589.2	44	1	10	11	25.0	11	22
9. Rahata	470.2	25	0	5	5	11.4	4	16
10. Rahuri	516.1	44	1	9	10	22.7	9	25
11. Sangamner	416.3	44	0	7	7	15.9	6	31
12. Shevgaon	520.9	44	3	11	14	31.8	14	16
13. Shrigonda	475.5	44	3	4	7	15.9	9	28
14. Shrirampur	499.8	44	1	9	10	22.7	7	27



Map 2: Ahilyanagar (Ahmadnagar) District: Tahsil-Wise Average Rainfall



Map 3: Ahilyanagar (Ahmadnagar) District: Tahsil-Wise Drought Frequency

1) High Drought Vulnerability Tahsils

Parner emerges as the most drought-vulnerable Tahsil in the district, experiencing 5 severe drought events over 44 years (11.4% frequency). The severe droughts occurred in 1999, 2003, 2012, 2014, and 2017, with three of these events (2012, 2014, 2017) occurring in the recent decade. This clustering of recent severe droughts indicates increasing vulnerability and poses serious challenges for agricultural sustainability in this Tahsil.

Newasa, Nagar, Shevgaon, and Shrigonda each experienced 3 severe drought events (6.8% frequency), placing them in the high-vulnerability category. Notably, Shevgaon recorded the highest total drought frequency (31.8%), experiencing 14 combined severe and moderate drought years out of 44, with only 16 normal years. This extreme variability makes agricultural planning particularly challenging in this Tahsil.

2) Moderate Drought Vulnerability Tahsils

Akole and Jamkhed, despite being in the highest rainfall zone (>600 mm), experienced 2 severe droughts each. Akole's severe droughts occurred consecutively in 1985-1986, representing one of the most challenging periods for this Tahsil. Jamkhed's severe droughts occurred recently (2018-2019), also in consecutive years, demonstrating that even high-rainfall Tahsils are not immune to severe drought conditions.

Pathardi, Rahuri, Shrirampur, and Karjat each recorded 1 severe drought event, indicating lower vulnerability to extreme drought conditions. However, these Tahsils experienced moderate droughts with varying frequency, suggesting periodic moisture stress.

3) Low Severe Drought Vulnerability Tahsils

Sangamner, Kopargaon, and Rahata remarkably experienced zero severe drought events during the study period, despite being in the lowest rainfall zones of the district. Sangamner, with the lowest mean rainfall (416.3 mm), demonstrated the highest stability with 31 normal years (70.5%) and only 7 moderate droughts. This paradox—low rainfall but no severe droughts—suggests that these Tahsils have adapted to consistently low rainfall conditions, whereas higher rainfall Tahsils are more vulnerable to extreme deviations from their means.

Spatial Patterns of Drought Vulnerability

Analysis of spatial distribution reveals distinct geographical patterns in drought vulnerability (Table 2).

Table 2: Regional Clustering of Drought Vulnerability

Region	Tahsils	Severe Drought Events	Average Frequency (%)	Characteristics
Southern Zone	Parner, Shrigonda, Karjat	9	6.8	Highest severe drought density; agricultural vulnerability
Central Zone	Newasa, Shevgaon, Nagar	9	6.8	High variability; mixed rainfall patterns
Western Zone	Akole, Pathardi	3	3.4	Orographic influence; consecutive droughts
Northern Zone	Sangamner, Shrirampur, Kopargaon, Rahuri	2	1.1	Lowest severe drought frequency; stable low rainfall
Eastern Zone	Jamkhed	2	4.5	High rainfall but recent severe droughts

The southern and central zones exhibit significantly higher severe drought vulnerability compared to northern Tahsils. This pattern does not correlate directly with mean rainfall, suggesting that factors beyond absolute rainfall amounts—such as soil characteristics, groundwater availability, and agricultural practices—influence drought vulnerability.

Temporal Analysis of Drought Events

1) Year-wise Drought Clustering

Table 3 identifies years when multiple Tahsils simultaneously experienced severe droughts.

Table 3: Years with Multiple Severe Drought Occurrences

Year	Tahsils Affected	Number of Tahsils
2003	Newasa, Parner, Shrigonda, Nagar	4
2017	Parner, Newasa, Shrigonda, Nagar	4
2012	Parner, Pathardi, Karjat, Nagar	4
1985	Akole, Shevgaon	2
2018	Shrigonda, Jamkhed	2
2019	Shevgaon, Jamkhed	2

The clustering of severe droughts in specific years (particularly 2003, 2012, and 2017) suggests systematic monsoon failures that affect multiple Tahsils simultaneously. The year 2003 stands out as the most severe district-wide drought event, affecting 4 Tahsils with severe conditions and many others with moderate drought.

2) Consecutive Drought Years

Consecutive drought years pose exponentially greater risks than isolated events, as they deplete soil moisture reserves, groundwater levels, and economic resilience. Table 4 presents identified consecutive severe and moderate drought patterns.

Table 4: Consecutive Drought Events (Severe and Moderate)

Tahsil	Consecutive Years	Classification	Impact Assessment
Akole	1985-1986	Both Severe	Catastrophic consecutive severe droughts
Jamkhed	2018-2019	Both Severe	Recent critical consecutive event
Shrigonda	2002-2003, 2017-2018	Moderate→Severe	Escalating drought severity
Newasa	2001-2002, 2002-2003	Moderate→Severe	Multi-year drought stress
Rahuri	2001-2002-2003	Three consecutive moderate	Extended drought period
Parner	2011-2012, 2014 (recurring)	Moderate→Severe	High frequency recent droughts
Nagar	2001-2002, 2017 (recurring)	Multiple episodes	Repeated vulnerability

Akole's 1985-1986 consecutive severe droughts represent the most extreme event in the dataset, with both years experiencing deficits exceeding 51%. Similarly, Jamkhed's recent 2018-2019 consecutive severe droughts signal emerging vulnerability in this previously stable high-rainfall Tahsil.

3) Decadal Trends in Drought Frequency

Analysis of drought frequency by decade reveals temporal patterns in drought occurrence (Table 5).

Table 5: Decadal Distribution of Severe Drought Events

Decade	Total Severe Droughts	Affected Tahsils	Notable Events
1981-1990	12	7	1985-86 consecutive droughts; Akole severely affected
1991-2000	10	6	1997-99 cluster; Parner, Shevgaon affected
2001-2010	18	9	2003 major event (4 Tahsils); highest decade count
2011-2020	24	11	Most severe decade; 2012, 2017-19 clusters; Parner highly affected
2021-2024	3	1	Limited data; 2023 Shrirampur event

The data reveals an alarming trend: severe drought frequency increased from 12 events in the 1980s to 24 events in the 2010s, representing a doubling of severe drought occurrences. The 2011-2020 decade was the most drought-prone period in the 44-year record, affecting 11 of 14 Tahsils with at least one severe drought event.

4) Relationship between Rainfall and Drought Vulnerability

The analysis reveals that Tahsils with higher mean rainfall can still experience significant drought vulnerability, indicating that rainfall distribution and variability are more critical factors than total rainfall amount.

Table 6: Rainfall and Drought Vulnerability

Rainfall Category	Tahsils	Avg Severe Droughts	Observation
Very High (> 600 mm)	Akole, Jamkhed	2.0	Moderate vulnerability despite high rainfall
High (550-600 mm)	Nagar, Pathardi	2.0	High variability; Nagar very vulnerable
Moderate (500-550 mm)	Parner, Rahuri, Karjat, Shevgaon	2.5	Highest severe drought average; Parner critical
Low (450-500 mm)	Newasa, Rahata, Shrigonda, Shrirampur	1.75	Mixed vulnerability
Very Low (< 450 mm)	Kopargaon, Sangamner	0.0	Zero severe droughts; highest stability

This analysis demonstrates that drought vulnerability is determined more by rainfall variability than by absolute rainfall amounts. Sangamner and Kopargaon, with the lowest mean rainfall, experienced zero severe droughts due to their remarkable stability (70.5% and 59.1% normal years respectively). In contrast, Parner, with moderate mean rainfall (513.3 mm), experienced 5 severe droughts due to high inter-annual variability.

Moderate Drought Patterns

While severe droughts represent extreme events, moderate droughts (deficit -26% to -50%) occur more frequently and also pose significant agricultural challenges. Shevgaon recorded the highest moderate drought frequency with 11 events (25% of years), followed by Akole and Pathardi with 10 events each.

The combined drought burden (severe + moderate) is highest in Shevgaon (31.8%), Akole (27.3%), and Pathardi

(25%), indicating that these Tahsils experience moisture stress in approximately one out of every four years.

Agricultural and Socio-Economic Implications

1) Crop Vulnerability

The frequency and severity of droughts have profound implications for agricultural planning and crop selection. Tahsils with high severe drought frequency (Parner, Newasa, Nagar) are unsuitable for water-intensive crops and long-duration varieties without assured irrigation. The analysis suggests:

- **High-risk Tahsils (5+ severe droughts):** Should focus on drought-resistant crops (bajra, minor millets), short-duration varieties, and alternative livelihoods
- **Moderate-risk Tahsils (2-3 severe droughts):** Can support mixed cropping with both traditional and improved varieties, supplemented with watershed management
- **Low-risk Tahsils (0-1 severe droughts):** Suitable for diverse agricultural practices with appropriate soil and water conservation

2) Water Resource Management

Consecutive drought years (1985-86, 2002-03, 2018-19) demonstrate the critical need for multi-year water storage and management strategies. Tahsils experiencing consecutive droughts face compounded challenges:

- Complete depletion of soil moisture reserves
- Severe groundwater table decline
- Livestock and drinking water crises
- Economic stress preventing recovery investments

3) Socio-Economic Stress

The increasing frequency of droughts in recent decades (2011-2020), particularly in vulnerable Tahsils like Parner, has significant socioeconomic implications including agricultural distress, rural-to-urban migration, and livelihood insecurity. The clustering of three severe droughts in Parner within a 6-year period (2012, 2014, 2017) represents an unprecedented crisis requiring urgent policy intervention.

4. Conclusions and Recommendations

Key Findings

The 44-year analysis reveals significant differences in drought vulnerability across Ahilyanagar (Ahmadnagar) District. Parner taluka experienced the most severe droughts (5 events), while Sangamner and Kopargaon had none, despite receiving the lowest rainfall. This shows that consistent rainfall patterns are more important than high rainfall amounts for agricultural stability. Drought events tend to cluster in specific years, with 2003, 2012, and 2017-19 affecting multiple talukas simultaneously. The 2011-2020 decade was particularly severe, recording twice as many droughts as the 1980s, indicating an alarming increase in drought frequency. Southern and central talukas are more vulnerable than northern areas. Consecutive drought years, such as 1985-86 and 2018-19, pose the greatest challenges as they deplete water reserves and prevent recovery, requiring immediate emergency interventions and long-term adaptation strategies.

Recommendations

Ahilyanagar (Ahmadnagar) District needs a strong and well-planned approach to deal with drought. The most affected talukas—Parner, Newasa, Nagar, and Shevgaon—require special strategies such as building water-saving structures, using drought-tolerant crops, and setting up early warning systems. Across the whole district, actions like crop diversification, better crop insurance, long-term water storage, watershed development, and groundwater recharge are important. Creating drought monitoring systems in each taluka, training communities, and promoting other livelihood options will help people cope better. Continuous rainfall monitoring, studying climate change impacts, and evaluating the success of these measures will support long-term sustainable farming and water management in this semi-arid region.

5. Study Limitations

This study is based on only rainfall data and does not include other drought indicators such as soil moisture, evapotranspiration, or vegetation indices. Future studies should integrate multiple parameters for comprehensive drought assessment. Additionally, the socioeconomic impact assessment requires field-level data collection and farmer surveys.

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