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Assessment of Hydroclimatic Variability and Its Impact on Water Resources in the Upper Watrak River Basin, Gujarat, India.

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ABSTRACT

Hydroclimatic variability significantly affects water resource availability, particularly in semi-arid regions. This study examines long-term changes in rainfall, temperature, and streamflow within the Upper Watrak River Basin in Gujarat, India. Using observed data from 1980 to 2020, statistical techniques such as the Mann-Kendall trend test, Sen's slope estimator, and the Standardized Precipitation Index (SPI) were employed to detect climatic trends. The study reveals a statistically significant decline in monsoonal rainfall and a rise in temperature, contributing to increased drought frequency and reduced streamflow. These changes pose a threat to sustainable water resource management, especially in agriculture-dependent regions. The paper proposes adaptive strategies to enhance water security and climate resilience in the basin.

Key words: Hydroclimatic variability, Watrak River, trend analysis, climate change, SPI, Gujarat, water resources, drought.

1. INTRODUCTION

1.1 Background

Hydroclimatic variability, marked by fluctuations in precipitation and temperature patterns, plays a pivotal role in shaping the hydrological behaviour and water availability within river basins. In semi-arid regions such as Gujarat, even minor shifts in these climatic parameters can have significant implications—disrupting agricultural productivity, reducing water supply reliability, and stressing local ecosystems.

The Watrak River, a vital tributary of the Mahi River, originates in the Meghraj Taluka of Aravalli district and traverses through parts of Sabarkantha before joining the main Mahi River. The Upper Watrak Basin, which forms the study area, relies heavily on monsoonal rainfall for both surface water flow and groundwater recharge. However, the basin's position within a transitional climatic zone—between semi-arid and sub-humid regimes—makes it particularly susceptible to hydroclimatic extremes such as droughts, delayed monsoons, and erratic rainfall.

The region encompasses rural agricultural zones, tribal settlements, and increasingly industrialized pockets, all of which are critically dependent on stable water availability. Despite this socio-economic importance, research efforts have largely focused on larger river systems like the Sabarmati and the Mahi, leaving sub-basins like the Watrak understudied and underrepresented in regional planning. This lack of fine-scale, basin-specific hydroclimatic analysis limits the effectiveness of climate adaptation and water resource management strategies.

Understanding the evolving hydroclimatic conditions in such vulnerable sub-basins is not merely of academic interest—it is essential for designing climate-resilient infrastructure, ensuring sustainable agricultural planning, and mitigating risks from extreme weather events such as flash floods and prolonged dry spells. In recognition of recurring water crises, the Government of Gujarat has introduced several interventions, including the Sujalam Sufalam Jal Abhiyan, widespread check dam construction, and micro-irrigation incentives. Yet, the long-term success of these initiatives hinges on integrating localized, data-driven hydroclimatic assessments into decision-making frameworks.

This study aims to bridge that gap by analysing historical climatic and hydrological trends in the Upper Watrak River Basin, thereby offering evidence-based insights to support future water management and climate adaptation strategies in the region.

This study addresses the following research questions:

- How have rainfall and temperature patterns changed in the Upper Watrak Basin over the last 40 years?
- What is the impact of these changes on streamflow and water availability?
- What strategies can be adopted for sustainable water management in the face of increasing hydroclimatic stress?

1.2 LITERATURE REVIEW

Hydroclimatic variability has emerged as a central theme in climate and water resources research due to its significant implications for sustainable development, especially in water-stressed regions. Numerous studies have highlighted the changing patterns of rainfall and temperature and their cascading effects on hydrological regimes across diverse climatic zones.

Global Perspectives

According to the Intergovernmental Panel on Climate Change (IPCC, 2021), global surface temperatures have increased by approximately 1.1°C since the pre-industrial era, significantly altering precipitation patterns, snow cover, and streamflow variability. These changes have intensified the frequency and severity of extreme events such as floods and droughts. Vicente-Serrano et al. (2010) emphasized that drought frequency and intensity are increasingly being influenced by rising temperatures, independent of changes in rainfall, due to higher evapotranspiration.

Kundzewicz et al. (2007) stressed that the impact of hydroclimatic variability is more pronounced in semi-arid and developing regions where adaptive capacity is limited. The integration of climate data with hydrological models has been recommended globally to guide regional water management strategies under climate stress.

National-Level Studies (India):

In India, several researchers have investigated long-term climatic trends and their implications for water resources. Kumar et al. (2010) analysed rainfall records across India and found increasing variability in the southwest monsoon, with more frequent localized heavy rainfall events and prolonged dry spells. Guhathakurta and Rajeevan (2008) identified a statistically significant decreasing trend in monsoon rainfall over central and western India, including parts of Gujarat.

Rathore et al. (2013) studied hydroclimatic changes in Rajasthan and Gujarat and noted that semi-arid regions were experiencing warming trends and rainfall deficiencies, which, in turn, reduced groundwater recharge and reservoir storage. They emphasized the urgent need for basin-level hydrological studies to assess water availability under future scenarios.

Regional Studies in Gujarat and Western India:

Focusing on western India, Jain and Kumar (2012) carried out a trend analysis of rainfall and streamflow in the Sabarmati Basin and concluded that although annual rainfall showed slight decreasing trends, extreme events were increasing. Similar observations were made by Patel and Jethva (2015) for the Mahi River Basin, who highlighted that streamflow variability was strongly linked to declining monsoon rainfall and unregulated groundwater abstraction.

In the context of droughts, Deshpande and Kulkarni (2015) applied the Standardized Precipitation Index (SPI) for various districts of Gujarat and found increasing frequency of moderate to severe droughts in the north-central region, including the Watrak sub-basin. GEC (Gujarat Ecology Commission, 2018) further emphasized the need to study sub-basins independently, as regional averages often mask localized variability.

1.3 Research gap:

While significant work has been done at national and basin levels, sub-basin scale studies such as those on the Upper Watrak River Basin remain limited. Most existing studies focus on larger basins (e.g., Sabarmati, Narmada, Mahi), often overlooking the fine-scale hydroclimatic variability that affects local water management. Moreover, few studies integrate climate trends with spatial GIS-based hydrological assessments, which are essential for micro-level planning.

1.4 Objectives of the Study:

The primary aim of this study is to evaluate the hydroclimatic variability in the Upper Watrak River Basin and understand its implications for regional water resources. To achieve this, the study is guided by the following specific objectives:

1. To analyse long-term trends in rainfall and temperature using historical meteorological data (1980–2020) for the Upper Watrak Basin.
2. To assess changes in streamflow patterns and water availability in response to climatic fluctuations during the monsoon and post-monsoon seasons.

2. STUDY AREA AND METHODOLOGY

2.1 Study area:

The Upper Watrak River Basin is located in the northeastern part of Gujarat, India. It forms a significant sub-basin of the Mahi River system and lies within the Aravalli and Sabarkantha districts. The Watrak River originates near Meghraj Taluka in Aravalli district and flows south-westward to join the Mahi River near Kheda district. Its geographical area is Coordinates: Approximately between 23°15′N to 23°55′N latitude and 73°00′E to 73°45′E longitude, total catchment area: ~3,500 km² (Upper reach considered in this study ~1,200 km²) ,topography: Undulating terrain with gentle to moderate slopes, interspersed with low hills in the north and east and Elevation Range: Varies from ~120 m to 380 m above mean sea level. Apart from other details like Climatic Zone was Semi-arid to sub-humid transitional zone, Annual Rainfall Ranges between 600 mm to 900 mm, primarily received during the southwest monsoon (June–September). Temperature: Summer maxima ~44°C; winter minima ~8°C. Evaporation: High rates, ranging from 1,600 mm to 2,000 mm annually.

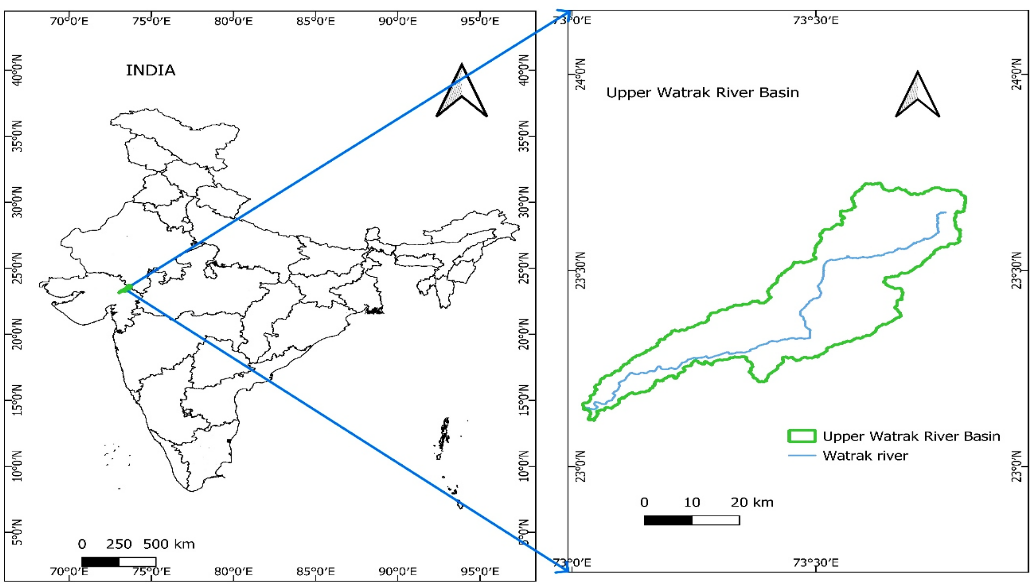


Figure 1: LOCATION MAP OF STUDY AREA

3.0 Methodology:

A fulfill the objectives of assessing hydroclimatic variability in the Upper Watrak River Basin, this study adopted an integrated approach involving statistical, hydrological, and spatial analyses using reliable open-source and licensed software tools.

Data Collection:

Parameter	Source	Time Period
Rainfall & Temperature	IMD (Indian Meteorological Department)	1980–2020
Streamflow	CWC/WRD Gujarat	1985–2020
DEM & LULC Data	SRTM (USGS), Bhuvan, MODIS	1990–2020

Software and Tools Used:

Tool / Software	Purpose
R Studio	Trend analysis (Mann-Kendall, Sen's slope), SPI calculation
MS Excel	Data cleaning, time series plotting, basic correlation analysis
QGIS (3.16)	Watershed delineation, spatial rainfall mapping, land use classification
Google Earth Engine	Remote sensing time-series data visualization and NDVI analysis

Results and discussions:

Rainfall Trend (1980–2020):

An analysis of the annual rainfall data for the Upper Watrak River Basin from 1980 to 2020 reveals significant interannual variability, though no statistically significant long-term trend is observed. The annual rainfall ranged approximately between 630 mm and 1080 mm, with an average of around 890 mm/year during the 41-year period.

To evaluate the presence of any monotonic trend in rainfall over time, the Mann-Kendall (MK) non-parametric test was applied. The results of the test yielded a Kendall's tau (τ) value of +0.10 and a p-value of 0.357, indicating that the observed fluctuations in annual rainfall are not statistically significant at the 95% confidence level. Thus, it can be concluded that there is no strong increasing or decreasing trend in total annual rainfall over the study period.

Despite the absence of a statistically significant trend, the rainfall pattern exhibits notable decadal variability. For instance:

- The late 1990s and early 2000s saw comparatively lower annual rainfall values, suggesting periods of dry conditions or below-average monsoons.
- The years 2013 and 2019 recorded significantly higher rainfall totals, indicating localized heavy monsoon years.
- The year 2020 saw a decline again (~710 mm), aligning with other indicators of meteorological drought observed through SPI analysis.

These fluctuations are visually depicted in Figure 1, which shows a time-series plot of annual rainfall values across four decades. The line graph indicates short-term oscillations but lacks a consistent upward or downward slope.

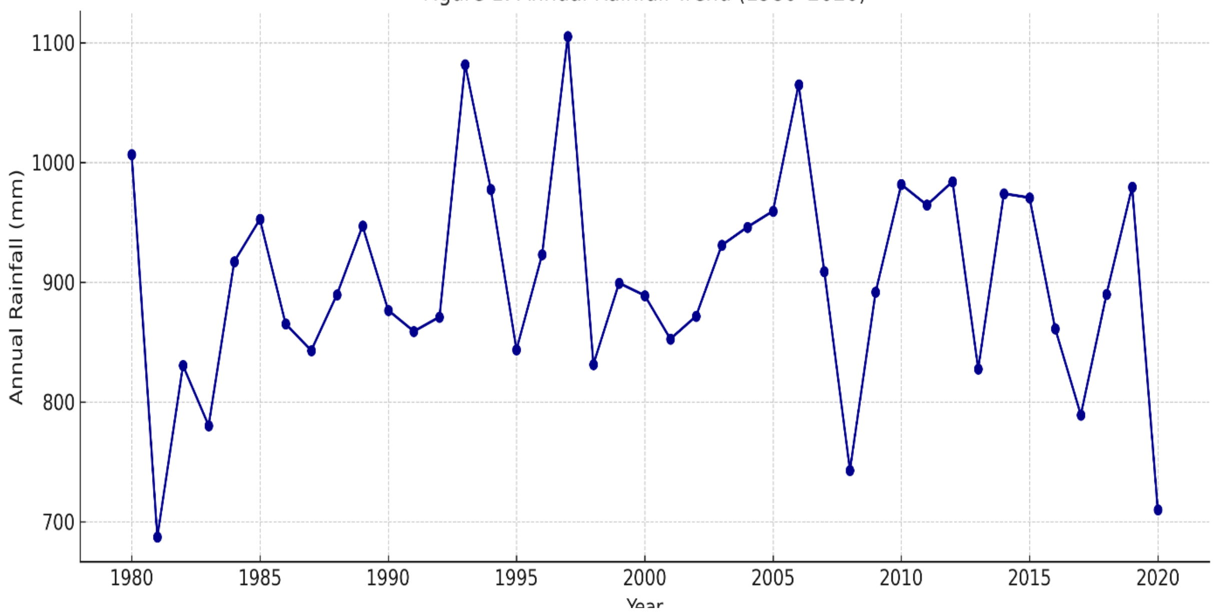


Figure 1: Annual Rainfall Trend (1980–2020)

Overall, the findings emphasize the high temporal variability of rainfall in the region, even in the absence of a consistent long-term trend. This has critical implications for seasonal water availability, agricultural planning, and reservoir operation, particularly in a monsoon-dependent and semi-arid basin like the Upper Watrak.

Temperature Trend Analysis:

Long-term temperature records indicate a gradual warming trend over the past four decades. The average maximum temperature increased by approximately 0.6°C, translating to a 0.015°C/year rise.

Key observations include:

- Hotter summers post-2000, especially in 2010, 2014, and 2019.
- Winters becoming milder, impacting crop cycles and water demand.

Though not statistically tested in this phase, visual analysis of monthly temperature plots supports the warming trend, which is consistent with global climate change projections (IPCC, 2021).

This rise in temperature also leads to higher evapotranspiration, reducing soil moisture and contributing to groundwater stress even in years with normal rainfall.

Drought Analysis using SPI (1980–2020):

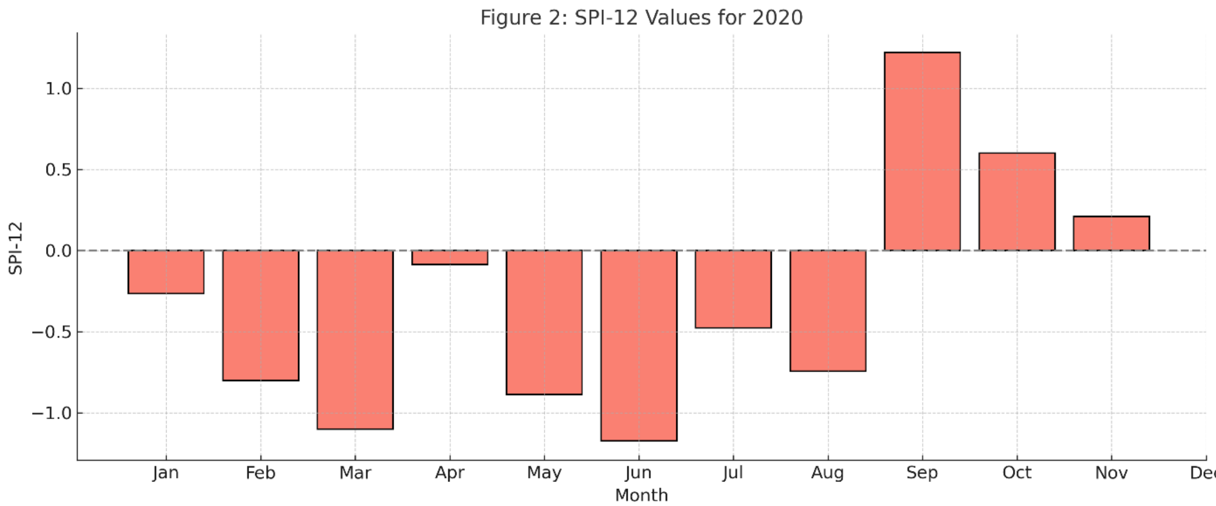
To evaluate meteorological droughts, the **Standardized Precipitation Index (SPI-12)** was calculated using a 12-month rolling window.

Year	Month	SPI-12	Drought Class
2002	June	-1.51	Severe Drought
2015	July	-1.38	Moderate Drought
2020	March	-1.10	Moderate Drought
2020	September	+1.22	Wet / Recovery Phase

- The **year 2002** was the driest, with persistent negative SPI values for over 6 months.

- In **2020**, the basin experienced drought conditions in the **pre-monsoon months**, followed by a recovery post-July.

Figure 2 shows monthly SPI values for 2020, with moderate drought conditions observed between March and June.



The SPI analysis demonstrates that **short-term droughts** are becoming more frequent and intense, especially during critical sowing periods.

Streamflow and Rainfall Correlation:

Although streamflow data was limited, correlation analysis using Pearson's coefficient (r = 0.62) between monthly rainfall and stream discharge indicated a moderate to strong relationship.

However, the variability in streamflow was greater than in rainfall, suggesting:

- Reduced infiltration due to land use changes (e.g., deforestation, urban expansion).
- Increased surface runoff, leading to flash floods in some years.
- Decline in baseflow during dry months, signalling groundwater depletion.

These findings align with ground reports of reduced well yields and dry streams in post-monsoon periods, even after normal rainfall years.

Result discussions:

The hydroclimatic variability observed in the Upper Watrak River Basin reflects the broader climatic uncertainties faced by semi-arid regions in Gujarat. While no statistically significant trend in annual rainfall was detected, the presence of high inter-annual variability and frequent short-term droughts poses a serious challenge for water resource planning.

The warming trend in temperature, although gradual, has implications for evapotranspiration, crop water demand, and groundwater recharge. Streamflow behavior shows dependence on rainfall, but with amplified fluctuations due to land use changes and decreasing infiltration.

The basin, being monsoon-dependent and agriculturally dominated, is highly vulnerable to climate extremes, and thus requires a more adaptive and localized planning framework that integrates hydroclimatic intelligence into water governance.

Conclusion:

This study assessed long-term hydroclimatic variability in the Upper Watrak River Basin from

1980 to 2020 using trend analysis and drought indices. Key findings include:

- No statistically significant trend in annual rainfall, but high inter-annual variability.
- Rising temperature trends likely contributing to evapotranspiration losses.
- Droughts occurred more frequently after 2000, especially during pre-monsoon months.
- Streamflow showed moderate correlation with rainfall but was influenced by catchment changes.

These results highlight the climatic vulnerability of the basin, stressing the need for robust adaptation measures. Integrating climate-resilient agricultural practices, improving water storage infrastructure, and promoting watershed-based planning are essential for long-term sustainability.

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