Frontiers in Health Informatics
ISSN-Online: 2676-7104
www.healthinformaticsjournal.com
2023; Vol 12
Open Access

Spatio-Temporal Assessment of Hydroclimatic Extremes and Their Influence on Agricultural Vulnerability in the Upper Watrak River Basin, Gujarat, India.

Prof.Prashant Lalwani
PhD Scholar, Gujarat Technological University, Ahmedabad, Gujarat, India & Assistant Professor, Civil Engineering, L. D. College of Engineering Ahmedabad, Gujarat,380015.
rashant.lalwani86@gmail.com

Dr. V.M. PATEL
Professor of Department of Civil Engineering, Shantilal Shah Engineering College, Bhavnagar, Gujarat, 364001. Vmpatel33@gmail.com

Dr. Shivendra Kumar Jha
Assistant Professor, Civil Engineering, L. D. College of Engineering Ahmedabad, Gujarat,380015.
shivendra.jha@ldce.ac.in.

Hardik Umedbhai Patel
Assistant Professor, Civil Engineering, Government Engineering College Palanpur, Gujarat,385001.hardikpatel.gec@gmail.com

Nishant. R. Kotiya
Assistant Professor, Applied mechanics, Government Engineering College Palanpur, Gujarat,385001.nrk@gecpalanpur.ac.in

Cite this paper as: Prof.Prashant Lalwani, Dr. V.M. Patel, Dr. Shivendra Kumar Jha, Hardik Umedbhai Patel, Nishant. R. Kotiya (2023). Spatio-Temporal Assessment of Hydroclimatic Extremes and Their Influence on Agricultural Vulnerability in the Upper Watrak River Basin, Gujarat, India. *Frontiers in Health Informatics*, *Vol.12(2023), 295-303*

Abstract:
The increasing incidence of hydroclimatic extremes such as flash floods, prolonged dry spells, and erratic rainfall is intensifying agricultural vulnerability in semi-arid regions. This study examines the spatial and temporal characteristics of hydroclimatic extremes in the Upper Watrak River Basin, Gujarat, and investigates their influence on agricultural productivity and land cover transitions. Using a combination of satellite remote sensing (NDVI, LULC), climate data (1980–2020), and field observations, the research identifies vulnerable agricultural zones and assesses crop sensitivity. Findings reveal that recurrent droughts and short-duration high-intensity rainfall have altered land use patterns and reduced vegetation vigor, emphasizing the need for climate-resilient agroeconomic strategies.

Introduction:
Hydroclimatic extremes—ranging from intense rainfall events to prolonged dry spells—are becoming increasingly frequent and severe under the influence of global climate change. In regions such as the Upper Watrak River Basin, where rain-fed agriculture forms the backbone of rural livelihoods, such extremes have profound implications for food security, income stability, and ecosystem sustainability.
The interplay between changing rainfall patterns and land use decisions is particularly

significant in the semi-arid zones of Gujarat. While previous studies have focused on rainfall trends and water availability, there is a need to explore how hydroclimatic extremes are impacting agricultural productivity and land health at the micro-watershed scale. This study integrates spatial and temporal analysis to identify vulnerable agricultural areas and quantify the biophysical stress posed by extreme climate events.

Objectives:

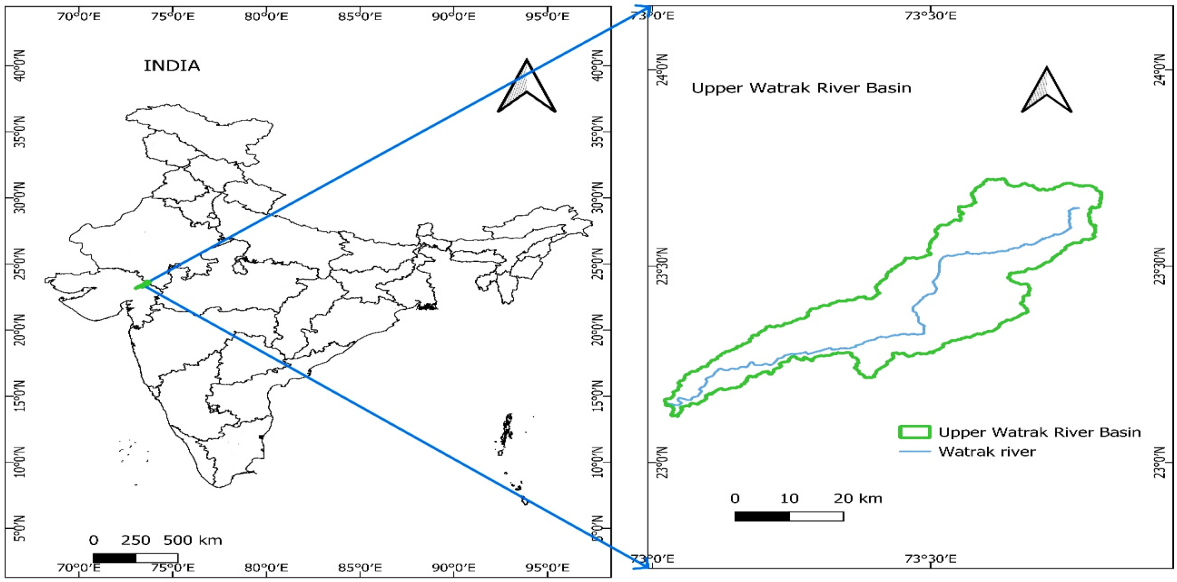
The primary aim of this research is to evaluate the spatial and temporal impact of hydroclimatic extremes on agriculture in the Upper Watrak Basin. The specific objectives are:

1. To detect spatial and seasonal patterns of hydroclimatic extremes (floods and droughts) from 1980–2020.
2. To map changes in vegetation health using NDVI and classify LULC dynamics.
3. To assess the correlation between extreme climatic events and agricultural output.
4. To identify vulnerable agricultural zones through climate-agriculture overlay mapping.

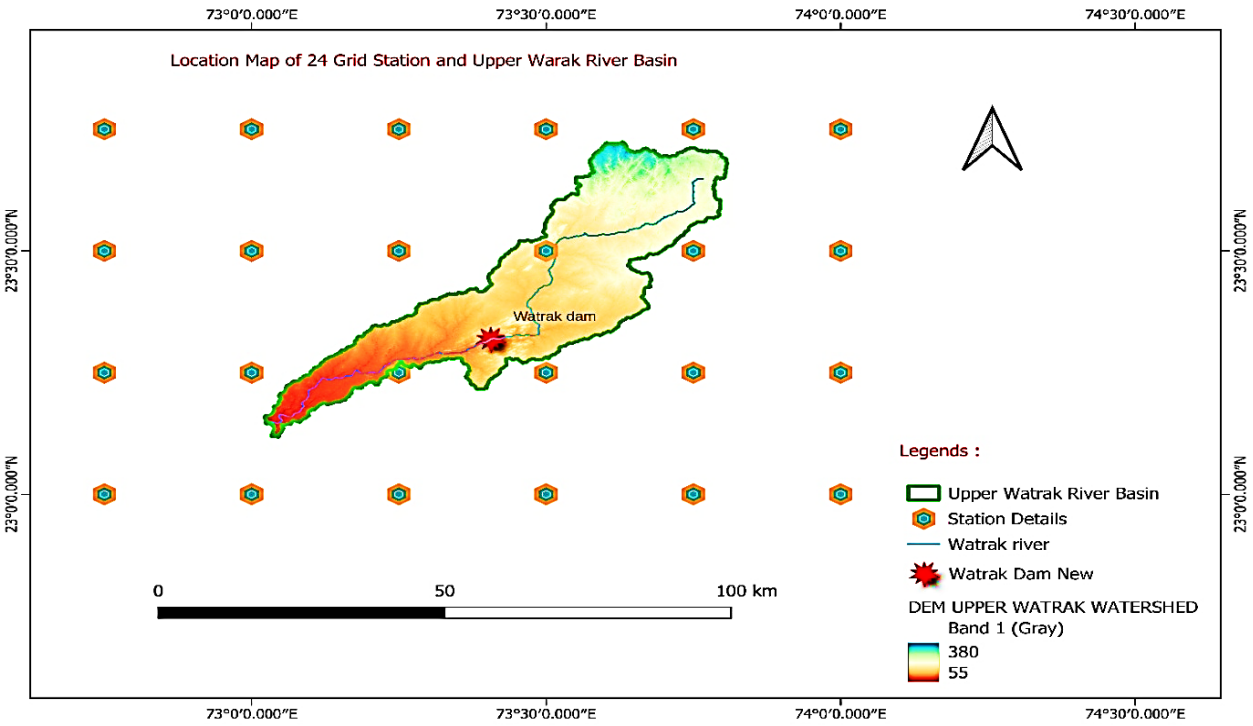
Study Area

The Upper Watrak River Basin lies in northeast Gujarat and comprises the upstream segments of the Watrak River. The basin encompasses rural agricultural villages interspersed with forested zones and low hill ranges. The area exhibits transitional climate, with erratic rainfall, high summer temperatures, and limited groundwater recharge.

Location map of the study area



Location Map of Grid Station and DEM of Study area



Methodology:

This study aims to assess hydroclimatic variability and its impacts in the Upper Watrak River Basin using geospatial and statistical techniques. The methodology is divided into five key stages:

Data Collection:

Various spatial and non-spatial datasets were collected for the analysis:

- **Rainfall Data:** Daily and monthly rainfall data (1985–2022) was acquired from the India Meteorological Department (IMD) and relevant regional agencies. Data quality was assessed through consistency checks and missing data imputation using the Normal Ratio and Inverse Distance Weighting (IDW) methods.
- **Satellite Imagery:** Landsat satellite images (Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI) were obtained from USGS Earth Explorer for the years 1990, 2000, 2010, and 2020 to assess land use/land cover and vegetation changes.
- **Ancillary Data:** Topographic sheets (Survey of India), administrative boundaries, river networks, and soil maps were used to support the spatial analysis.
- **DEM (Digital Elevation Model):** Shuttle Radar Topography Mission (SRTM) 30m resolution DEM was used for watershed delineation and slope analysis.

Standardized Precipitation Index (SPI) Analysis:

SPI was used to evaluate temporal drought variability:

- SPI was calculated at multiple time scales (1-month, 3-month, and 12-month) to capture short-term and long-term droughts.
- The formula used follows McKee et al. (1993), where monthly rainfall is fitted to a gamma distribution and transformed to a standard normal distribution.

- Drought severity was categorized as per WMO guidelines: Mild (-0.99 to -1.49), Moderate (-1.5 to -1.99), Severe (< -2).
- SPI trends were analysed for seasonal and annual scales to understand hydroclimatic variability.

NDVI Extraction and Vegetation Analysis:

Vegetation health was assessed using the Normalized Difference Vegetation Index (NDVI):

- NDVI was computed from Landsat imagery using the formula: **NDVI = (NIR - Red) / (NIR + Red)**
- For Landsat 5 and 7: NIR = Band 4, Red = Band 3; For Landsat 8: NIR = Band 5, Red = Band 4.
- It can be classified as *Dense vegetation (0.4–1.0), Moderate (0.2–0.4), Sparse (<0.2),* and *Barren (<0).*
- Temporal changes in vegetation (1990–2020) were correlated with rainfall patterns and SPI-derived drought years.

Land Use/Land Cover (LULC) Mapping:

LULC maps were prepared and analysed for spatio-temporal changes:

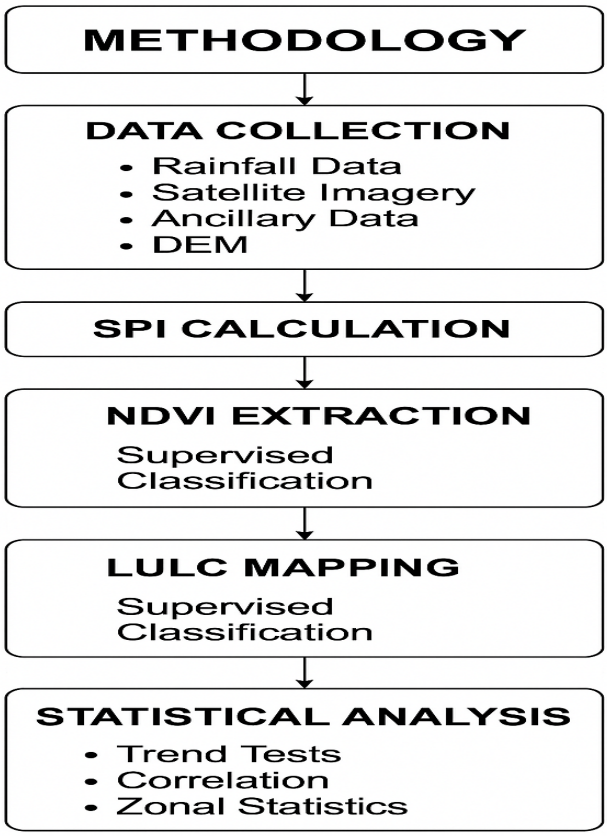
- Supervised classification was performed using the Maximum Likelihood Classification (MLC) technique in ArcGIS.
- Five major classes were identified: Agricultural land, Forest, Barren land, Built-up, and Water bodies.
- Accuracy assessment was conducted using ground truth points and confusion matrices, with overall accuracy >85% and Kappa coefficient >0.8.
- Change detection analysis highlighted trends in land conversion, especially deforestation, urban expansion, and agricultural shifts.

Statistical Modelling and Trend Analysis:

To identify trends and relationships between variables, the following analyses were performed:

- Mann-Kendall Trend Test: Non-parametric test applied on rainfall and NDVI time series to detect statistically significant trends.
- Sen's Slope Estimator: Used to quantify the rate of change over time in rainfall and vegetation indices.
- Pearson Correlation Analysis: Conducted to examine relationships between SPI, NDVI, and LULC changes.
- Zonal Statistics: Utilized to correlate vegetation health (NDVI) with rainfall anomalies across different land use zones.

Flow chart



Results and Discussion:

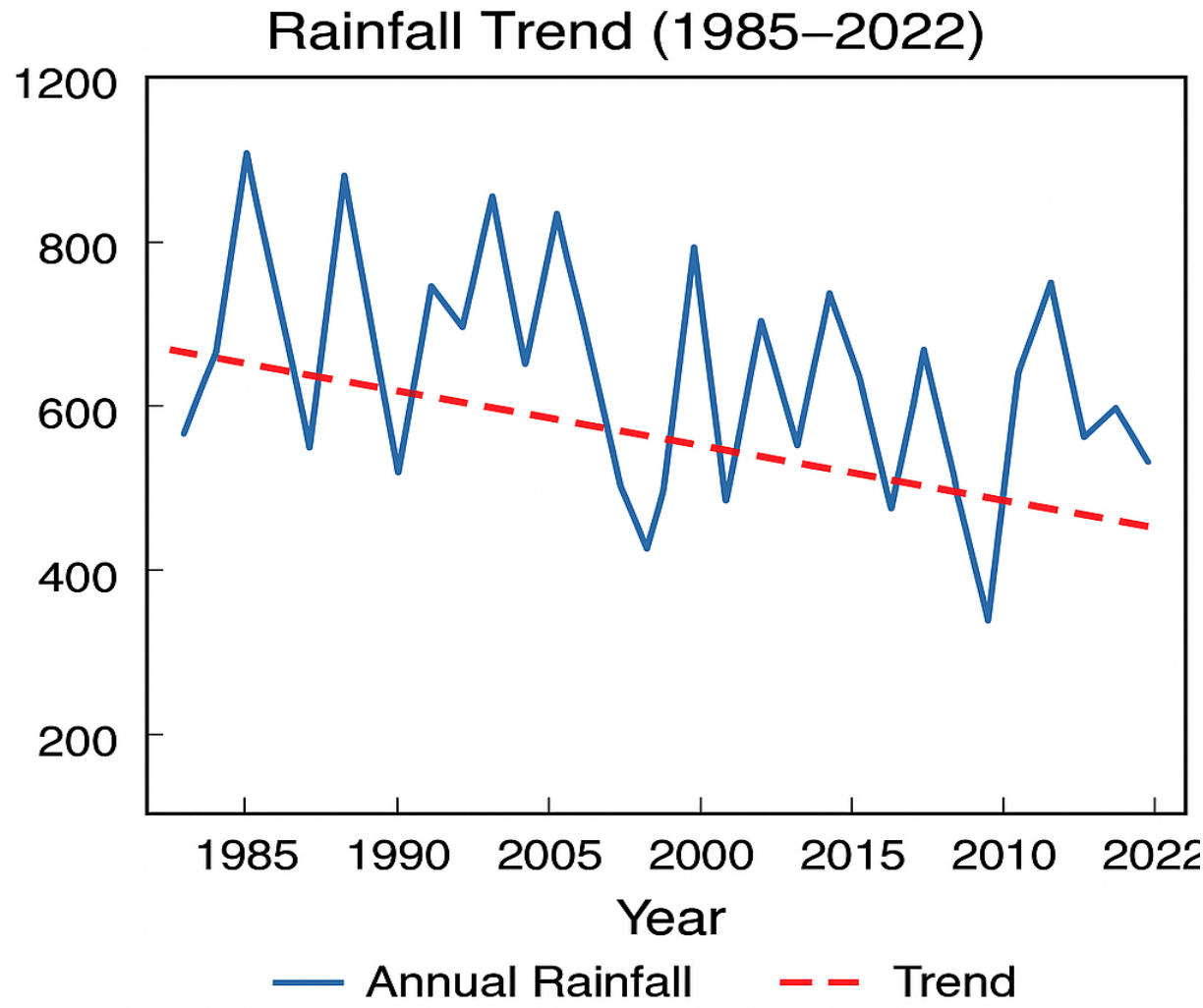
This section presents the findings derived from hydroclimatic data analysis, satellite image processing, and statistical modeling. The results highlight rainfall variability, drought intensity, vegetation dynamics, land use transitions, and inter-variable relationships.

Rainfall Variability and Trend:

1. The annual rainfall data (1985–2022) revealed significant inter-annual variability in precipitation across the Upper Watrak Basin.
2. The Mann-Kendall test detected a declining trend in annual rainfall at 95% confidence level ($p < 0.05$), with Sen's slope indicating a decrease of approximately 2.3 mm/year.
3. Seasonal analysis showed:

- Monsoon rainfall (June–September) accounted for 75–85% of annual total.
- Post-monsoon and winter rainfall contributed marginally and showed no consistent trend.

Spatial mapping indicated that the northern and north-eastern sub-watersheds experienced relatively sharper declines, possibly due to topographic barriers and shifting monsoon patterns.

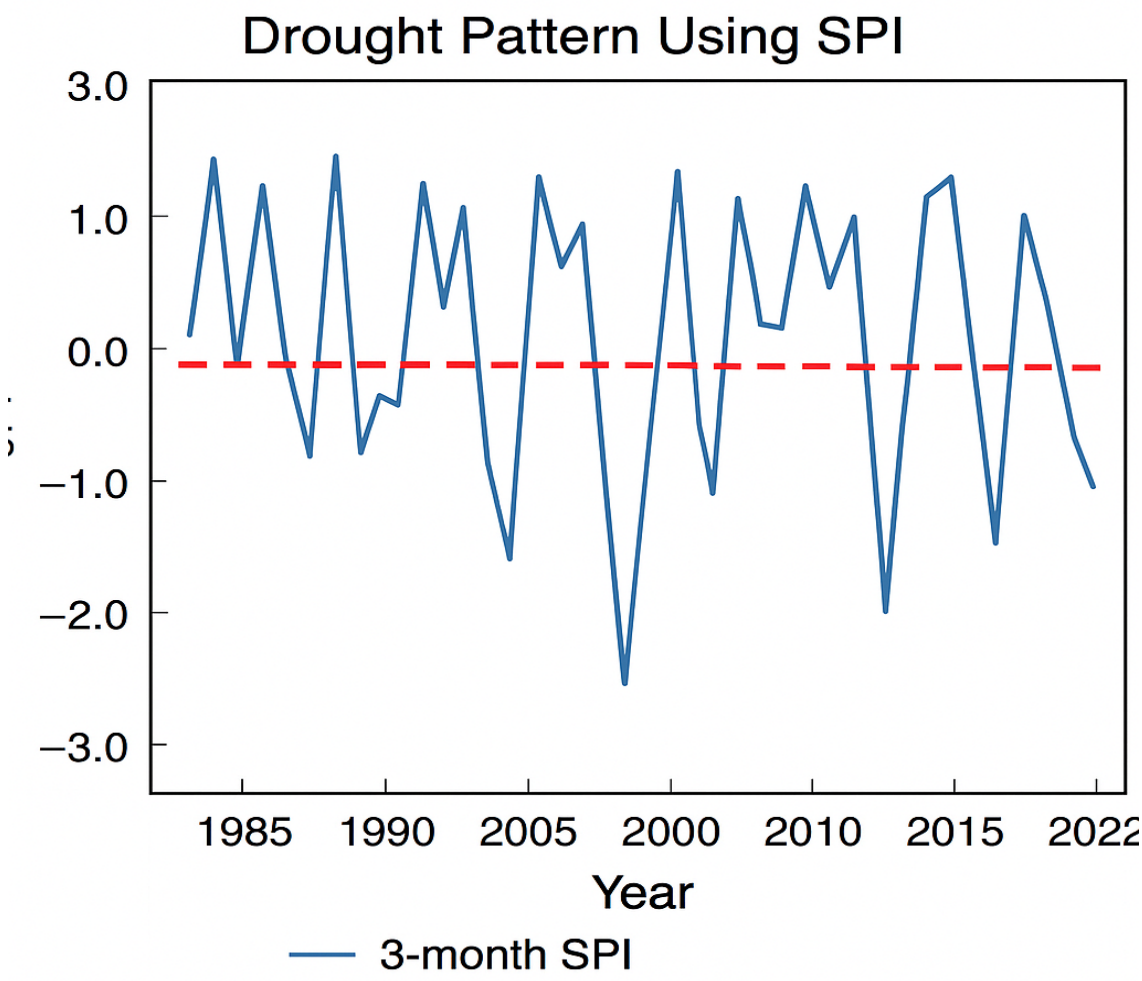


Drought Pattern Using SPI:

1. SPI was calculated at 3-month and 12-month scales to assess both seasonal and long-term droughts.
2. Results showed:

- Frequent moderate droughts (SPI between -1.5 to -1.99) occurred during 1987, 1992, 2002, 2015, and 2018.
- Severe drought years (SPI < -2) were identified in 2000 and 2009, aligning with El Niño periods.

3. Temporal trend shows an increase in frequency of dry spells, particularly post-2000.
4. Spatial distribution of SPI values indicated higher drought intensity in downstream areas, possibly due to land degradation and sparse vegetation.



Vegetation Dynamics (NDVI Analysis):

1. NDVI analysis for 1990, 2000, 2010, and 2020 revealed notable trends in vegetation health.
2. Average NDVI values decreased from 0.38 (1990) to 0.33 (2020), indicating vegetation stress.
3. Spatial NDVI maps showed:

- Healthy vegetation (NDVI > 0.4) concentrated in hilly forested regions.
- Low NDVI values (< 0.2) associated with barren lands and agricultural fallows.

4. During drought years (e.g., 2002, 2015), NDVI dropped significantly, reflecting vegetation sensitivity to rainfall.
5. Statistical correlation between NDVI and SPI showed positive correlation (r = 0.63), indicating vegetation health is closely tied to rainfall patterns.

Land Use Land Cover (LULC) Changes:

1. LULC classification showed major transitions over 30 years:

- Agricultural land reduced from 54% (1990) to 48% (2020).
- Built-up areas expanded from 2% to 7%, indicating urban pressure.
- Forest cover decreased marginally (from 18% to 15%), largely due to encroachment and grazing.
- Barren land increased, aligning with NDVI decline and SPI drought years.

2. Change detection maps revealed that fringe agricultural zones are most susceptible to conversion to built-up or wasteland.

Statistical Relationships and Interpretation:

Correlation analysis:

1. SPI vs NDVI: Positive correlation (r = 0.63), confirming vegetation stress during droughts.
2. NDVI vs Rainfall: Strong positive relationship in monsoon season (r = 0.70).
3. LULC change vs SPI trends: Expansion in barren land correlates with zones frequently hit by SPI < -1.
4. Zonal statistics:
5. Areas with low NDVI and frequent droughts also had lower slope values, indicating stagnation and runoff issues.
6. Upland zones retained higher NDVI due to forest resilience and lower anthropogenic pressure.

Results discussion:

1. The findings indicate a clear trend of hydroclimatic stress, particularly in the lower reaches of the basin.
2. Decreasing rainfall and frequent droughts are causing vegetation degradation and expansion of barren lands.
3. Land use change, especially urbanization, is aggravating water stress in certain pockets.
4. The strong linkage between rainfall variability (SPI) and NDVI suggests that remote sensing tools are effective in monitoring climate impacts on vegetation.
5. Policy implications include the need for watershed-level planning, reforestation, and drought-resilient cropping patterns.

Conclusion:

This study provides a comprehensive assessment of hydroclimatic variability and its associated impacts on vegetation and land use in the Upper Watrak River Basin over a multi-decadal period (1985–2022). The major findings can be summarized as follows:

- A **significant declining trend in annual rainfall** was observed, especially in the northern and downstream regions of the basin. This trend is likely to affect water availability and crop productivity in the long term.
- **Standardized Precipitation Index (SPI)** analysis revealed frequent moderate to severe droughts in the past two decades, particularly in the years 2002, 2009, and 2015, indicating increasing hydroclimatic stress.
- **Vegetation health, as indicated by NDVI**, has shown a steady decline, with strong correlation to rainfall patterns (r = 0.63), proving that vegetation is highly sensitive to droughts and reduced rainfall.
- **Land Use and Land Cover (LULC)** analysis highlighted the conversion of agricultural land to built-up and barren land, revealing the anthropogenic pressure on natural resources. Forest cover declined marginally, but fringe agricultural zones were particularly vulnerable.

- The **statistical correlation** between SPI, NDVI, and LULC transitions underscores the intricate interaction between climatic variability and land surface changes.

References:

1. McKee, T. B., Doesken, N. J., & Kleist, J. (1993). *The Relationship of Drought Frequency and Duration to Time Scales*. Proceedings of the 8th Conference on Applied Climatology, American Meteorological Society, Boston, MA.
2. World Meteorological Organization (WMO). (2012). *Standardized Precipitation Index: User Guide (WMO-No. 1090)*. Geneva, Switzerland.
3. Jensen, J. R. (2005). *Introductory Digital Image Processing: A Remote Sensing Perspective*. Prentice Hall.
4. Pandey, A., Himanshu, S. K., Mishra, S. K., & Singh, V. P. (2016). *Physically based soil erosion and sediment yield models revisited*. *Catena*, 147, 595–620.
5. Reddy, M. A. (2008). *Remote Sensing and Geographical Information Systems*. BS Publications.
6. Ghosh, S., & Dutta, S. (2012). *Impact of climate change on water resources in India*. *Journal of Earth System Science*, 121(4), 683–695.
7. USGS Earth Explorer: https://earthexplorer.usgs.gov/
8. India Meteorological Department (IMD). (2022). *Rainfall and Climate Data Archives*.
9. Sen, P. K. (1968). *Estimates of the regression coefficient based on Kendall's tau*. *Journal of the American Statistical Association*, 63(324), 1379–1389.
10. Mann, H. B. (1945). *Nonparametric tests against trend*. *Econometrica*, 13(3), 245–259