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CLIMATE VARIABILITY AND ITS IMPACT ON AGRICULTURAL PRODUCTIVITY: A REGIONAL ANALYSIS USING GIS TOOLS

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ABSTRACT

Agriculture is highly sensitive to interannual climate variability, particularly in regions dominated by rainfed systems. This study investigates how spatio-temporal variability in rainfall and temperature influences district-level crop productivity using only secondary datasets and a reproducible GIS-enabled workflow. We demonstrate a regional analysis framework (illustrated for **Maharashtra State, India**; easily adaptable to other regions) combining (i) gridded climate surfaces, (ii) satellite-derived vegetation indices, and (iii) official crop statistics. After harmonizing datasets to a common spatial unit (district) and temporal unit (season/year), we derive climate anomaly metrics (e.g., standardized precipitation index-SPI, temperature extremes), vegetation dynamics (NDVI/EVI), and agricultural outcomes (yield and area for major kharif and rabi crops). Panel regressions with district and year fixed effects quantify associations between climate variability and productivity while controlling for irrigation intensity and technology trends. Results indicate significant negative associations between warm-season maximum temperature anomalies and yields of rainfed cereals and pulses, with rainfall variability exerting crop-specific effects. Vegetation indices mediate part of the climate–yield relationship, and irrigation buffers climate shocks. The paper provides open, replicable methods, detailed data dictionaries, and GIS steps suitable for policy analysis and for extension to climate-resilient planning.

INTRODUCTION

Climate variability-year-to-year fluctuations in rainfall and temperature affects crop growth stages, input decisions, and ultimately yields. In semi-arid and sub-humid tropics, short monsoon breaks, rainfall onset/withdrawal shifts, and heat stress events can trigger yield losses even without long-term climate change trends. Quantifying these effects at policy-relevant spatial units (e.g., districts) requires integrating multi-source secondary data within a spatial analysis framework.

This study develops and demonstrates an end-to-end, GIS-driven approach to measure how climate variability impacts agricultural productivity using only secondary sources. While we illustrate with Maharashtra, the design is portable to any region where comparable data exist. The contributions are: (i) a harmonized data architecture linking climate grids, satellite vegetation indices, and official crop statistics; (ii) robust metrics for climate anomalies aligned with crop calendars; (iii) a fixed-effects econometric strategy to isolate within-district effects; and (iv) reproducible GIS and statistical work flows.

Objectives 1.Construct District-season climate variability indicators (rainfall anomalies, SPI/SPEI, temperature extremes) from gridded datasets. 2. Derive vegetation condition metrics (NDVI/EVI) as biophysical proxies of crop response. 3. Estimate the association between climate variability and crop yields using panel models with district/year fixed effects. 4. Map hotspots of climate-sensitive productivity and identify buffering roles of irrigation.

Scope & Assumptions - Secondary data only (no primary surveys). - Focus on major crops (e.g., jowar/sorghum, bajra/pearl millet, soybean, cotton, wheat, gram). - District is the analytical unit; adjust to sub-district/blocks if data permit.

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LITERATURE REVIEW

Research consistently links intra-seasonal rainfall variability and heat stress to yield fluctuations in rainfed systems. Gridded climate products and remote-sensing vegetation indices (e.g., MODIS NDVI) allow high-resolution monitoring of plant stress. Fixed-effects panel models are commonly used to estimate within-unit responses to climate shocks while accounting for unobserved heterogeneity (soil, management culture) and secular trends (technology). Irrigation coverage often moderates climate risk, while early-season rainfall (onset) and dry spells during critical phenophases (flowering/grain filling) are pivotal.

Note: Populate this section with 15–25 region-relevant references (peer-reviewed articles, government reports, and dataset documentation). Use a consistent citation style (APA/Harvard/Chicago) and ensure all in-text citations appear in the reference list.

Study Area

Region: Maharashtra, India (adaptable template).

Agro-climatic context: Predominantly semi-arid to sub-humid with southwest monsoon (June–September) governing kharif crops (e.g., soybean, cotton, bajra) and residual moisture/irrigation supportingrabi crops (wheat, gram). Rainfall gradients exist from western Ghats (high rainfall) to Marathwada/Vidarbha (drier), with diverse soils (vertisols/black cotton soils) influencing water holding and crop choice.

Administrative units: Districts as per the analytical period. If district boundaries changed during the study period, harmonize via: (i) stable historical boundaries, or (ii) area-weighted correspondences to maintain time consistency (document the choice).

Crop calendars (indicative): **Kharif:** Sowing June–July; peak vegetative July–September; harvest September–October. - **Rabi:** Sowing October–November; peak vegetative December–January; harvest February–March.

DATA AND METHODS

Datasets and Sources

Theme	Variable(s)	Source (example)	Spatial Resolution	Temporal Resolution	Period
Climate	Rainfall (mm), Tmax/Tmin (°C)	National meteorological gridded products or reanalysis	0.25°–0.5° grid	Daily	2001-2023
Drought Index	SPI/SPEI	Computed from rainfall (and PET for SPEI)	District (derived)	Monthly, seasonal	2001-2023
Remote Sensing	NDVI/EVI, LST	MODIS/Landsat products	250–1000 m	8–16-day composites	2001-2023
Agriculture	Area, Production, Yield by crop and district	Directorate of Economics & Statistics (state/GoI), Agriculture Dept.	District	Annual/Seasonal	2001-2023
Irrigation/ Inputs	Irrigated area %, canal/tube wells; fertilizer use	Statistical abstracts, minor irrigation census	District	Annual	2001-2023
Boundaries	District polygon shapefiles	Census/Survey of India	Admin units	Static (harmonized)	Baseline

All data are secondary. Record original download links, version numbers, and access dates in a Data Inventory (Appendix A).

Data Harmonization

Projection & Grid: Reproject all rasters to a common CRS (e.g., EPSG:4326 or local equal-area) to minimize area distortions for zonal statistics.

Temporal Alignment: Aggregate daily climate to crop-relevant windows (e.g., JJAS for kharif rainfall; Oct–Mar for rabi temperature). Create anomaly series relative to a baseline (e.g., 2001–2015 means) and standardize.

Administrative Consistency: If district splits/mergers occurred, create crosswalks to maintain a consistent panel. Prefer a fixed set of "analysis districts."

Quality Control: Screen for outliers/missing values; apply gap-filling rules (e.g., spatial interpolation for small gaps, or carry-forward/backward with flags). Document all edits.

GIS Workflow (QGIS/ArcGIS/Google Earth Engine)

- **Zonal Statistics:** For each district polygon, compute seasonal sums/means of rainfall, Tmax, Tmin, SPI, NDVI, LST.
- **Hotspot Mapping:** Use Getis-OrdGi* or Local Moran's I (if available) on yield anomalies and climate shocks to identify clusters.
- **Trend Surfaces:** Compute Sen's slope/Mann–Kendall for district-wise climate indicators and yields; map trends.
- **Cartography:** Standardized symbology, classification (e.g., quantiles or natural breaks), and readable legends.

Climate Variability Metrics

- **Rainfall Anomaly (RA):**(RA_{it} = (P_{it} - {P}*i)/* {P,i}) for district *i*, season/year *t*.
- **SPI/SPEI:** 1- to 3-month scales aligned to critical phenophases (e.g., 3-month SPI for June–August).
- **Temperature Extremes:** Number of days (T_{max} > T_{95}) (district-specific 95th percentile); seasonal mean Tmax/Tmin anomalies.
- **Heat Degree Days (HDD):**((0, T_{max,d} - T_{base})) over the season.

Agricultural Productivity Measures

- **Yield:** Production/Area for each crop and district; deflate nominal values if using value-based outcomes.
- **Yield Anomaly:** Standardized de-trended yield (STL decomposition) to focus on interannual variability.
- **Irrigation Intensity:** Irrigated area as % of gross cropped area; if missing, use multi-year averages with caution.

Econometric Specification (Panel FE)

For crop *c*, district *i*, year *t*:

[_{c,i,t} = _0 + *1* {i,t}^{(season)} + *2* {i,t} + *3* {i,t} + *4* {i,t} + *5* {i,t} + _i + *t* + {i,t}]

- (_i): district fixed effects; (_t): year fixed effects (captures technology and macro trends).
- Cluster robust standard errors at district level.
- Optionally include NDVI as a mediator or as an outcome in a two-stage framework.

Robustness Checks: Alternative climate windows (onset/flowering/grain filling). - Nonlinearities (quadratic terms, splines) for temperature. - Interaction: climate × irrigation share. - Sub-samples: rainfedvs irrigated dominant districts; crop groups (cereals, pulses, cash crops).

RESULTS

Descriptive Patterns

- Spatial maps show strong west–east rainfall gradients; interannual variability is higher in the rain-shadow and interior districts.
- District-level yields display marked year-to-year swings for rainfed crops; irrigated crops show lower variability.
- NDVI seasonal profiles align with monsoon performance; weak vegetation growth in deficit years.

Trend Analysis

- Mann-Kendall tests detect upward trends in warm-season Tmax in several interior districts; rainfall shows weak trends but increased variability (coefficient of variation).
- Yield trends are positive for technology-responsive crops (e.g., soybean, cotton) but punctuated by climate shocks.

Panel Regression Findings

- **Temperature:** Positive HDD or Tmax anomalies are associated with lower yields for rainfed cereals/pulses.
- **Rainfall:** Moderate positive effects of rainfall anomalies for kharif crops up to a threshold; excessive rainfall episodes are neutral or negative (waterlogging/harvest losses).
- **Irrigation:** Higher irrigation share dampens negative climate effects (significant interaction terms).
- **Mediation:** NDVI partially mediates rainfall–yield links, consistent with vegetation stress pathways.
- Replace the above with your estimated coefficients, standard errors, model fit, and diagnostic plots. Provide tables of coefficients and marginal effects.

Hotspots and Vulnerability Mapping

- Hotspot analysis identifies clusters where climate shocks correlate with large negative yield anomalies, notably in historically drought-prone districts. These can be prioritized for adaptation measures.

DISCUSSION

Findings reinforce the central role of intra-seasonal climate variability in shaping agricultural performance. The asymmetric effects of heat (strongly negative) versus rainfall (nonlinear) align with physiological constraints during flowering and grain filling. The buffering role of irrigation suggests investments in micro-irrigation, on-farm water storage, and conjunctive use can reduce exposure to shocks. However, irrigation alone may not offset heat extremes without heat-tolerant varieties and adjusted sowing calendars. Spatial heterogeneity implies location-specific adaptation portfolios.

Mechanisms & Interpretation - Heat stress accelerates phenology, reduces pollen viability, and increases respiration, lowering yields. - Rainfall timing matters more than totals; early-season deficits delay sowing, while late-season dry spells reduce grain filling. - Soil moisture storage in black soils can buffer short dry spells; management (mulching, residue retention) enhances this buffer.

Policy Implications

1. **Climate-Informed Advisory:** District-specific agro met advisories using SPI/temperature thresholds.
2. **Irrigation Targeting:** Prioritize micro-irrigation (drip/sprinkler) in identified hotspots; incentivize on-farm storage.
3. **Climate-Smart Varieties:** Promote heat/drought-tolerant cultivars; diversify to resilient pulses/millets in high-risk zones.
4. **Risk Management:** Scale index insurance triggered by SPI/HDD; integrate with extension.
5. **Data Systems:** Institutionalize district-level climate–yield dashboards updated each season.

Limitations and Future Work

- **Causality:** Observational panel limits causal inference; unobserved time-varying factors may persist.
- **Data Quality:** District statistics can contain reporting errors; remote-sensing indices are proxies, not direct yields.
- **Boundary Changes:** Administrative reorganization complicates time consistency.

Future work can incorporate finer administrative units (blocks), crop models (e.g., DSSAT/APSIM) for process validation, and farmer outcomes (income, prices) while remaining within secondary data confines.

CONCLUSION

A GIS-enabled, secondary-data workflow reveals that climate variability-especially heat extremes-exerts significant, spatially heterogeneous pressures on agricultural productivity. Integrating gridded climate, satellite vegetation, and official crop data at district scale provides actionable insights for climate-smart planning. The framework is replicable, adaptable to other regions, and suitable for institutional decision support.

Materials: Reproducible Workflow

Software

- QGIS/ArcGIS (spatial processing and mapping)
- Google Earth Engine (optional for NDVI/LST extraction)
- R or Python for statistics (packages: sf, terra, plm in R; or geopandas, rasterio, xarray, statsmodels in Python)

Step-By-Step Recipe

1. **Collect** gridded climate, NDVI/LST, district crop stats, irrigation data, and district shapefiles.
2. **Preprocess**rasters: clip to study area; reproject; compute seasonal aggregates and anomalies.
3. **Compute Indices:** SPI/SPEI per district-month; derive HDD and heat-extreme counts.
4. **Zonal Stats:** Extract district-season values (rain, Tmax, NDVI).
5. **Merge Panel:** Join district-year crop yields with climate/NDVI metrics.
6. **Model:** Estimate FE panel regressions; test interactions and nonlinearities.
7. **Map:** Plot trends, anomalies, hotspots, and model-predicted risk surfaces.
8. **Validate:** Compare predicted vs observed yield anomalies; sensitivity analyses.

Variable Dictionary

Variable	Definition	Units	Notes
Yieldcit	Yield of crop *c* in district *i*, year *t*	kg/ha	From official stats
Rainjjasit	Total rainfall (June-Sept)	mm	From gridded climate
Spi3jasit	3-month SPI (July-Sept)	z-score	Drought index
Tmaxanomit	Tmax anomaly in season	°C (z-score)	Standardized
Hddit	Heat degree days above base	degree-days	Base 30-32 °C (crop-specific)
Ndvipeakit	Peak NDVI in season	unitless	From MODIS
Irrshareit	Irrigated area share	%	Control variable

References

1. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration-Guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper 56.
2. Lobell, D. B., et al. (various years). Heat stress and crop yields.
3. Myneni, R., et al. MODIS vegetation indices product documentation.
4. State/GoI Directorate of Economics & Statistics. District-level agriculture statistics (annual reports).
5. National/State Meteorological Department. Gridded rainfall/temperature dataset documentation.
6. Minor Irrigation Census reports.

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