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Climate Change Vulnerability Mapping In Semi-Arid Regions Using Remote Sensing And GIS: A Case Study Of Western Rajasthan, India

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Abstract

The semi-arid region of **Western Rajasthan, India**, is highly susceptible to the adverse effects of climate change due to its fragile ecological balance, water scarcity, and dependency on rain-fed agriculture. This study aims to assess and spatially map the **climate change vulnerability** of the region using integrated **Remote Sensing (RS)** and **Geographic Information System (GIS)** techniques.

Utilizing multi-temporal satellite data (Landsat, MODIS) and climate datasets (CHIRPS, IMD), the research analyzes key indicators such as **land use/land cover (LULC) changes**, **Normalized Difference Vegetation Index (NDVI)**, **land surface temperature (LST)**, and **rainfall anomalies** over the past two decades. Socio-economic variables including **population density**, **literacy rates**, and **agricultural dependency** are incorporated to form a composite **Climate Vulnerability Index (CVI)** using a weighted overlay analysis in GIS.

Preliminary results indicate significant environmental degradation, increased land aridity, and rising climatic variability, especially in districts such as **Barmer, Jaisalmer, and Bikaner**. These areas exhibit high levels of vulnerability due to a combination of natural and human-induced stressors. The resulting vulnerability maps classify the region into distinct zones—**Very High**, **High**, **Moderate**, and **Low Vulnerability**—which can guide targeted interventions.

This study underscores the potential of geospatial technology in climate risk assessment and highlights the urgent need for **region-specific adaptation strategies**, especially in disaster-prone and ecologically sensitive zones. The findings are expected to support local planners, disaster managers, and policymakers

in developing **climate-resilient frameworks** and achieving long-term **sustainability goals (SDG 13 & SDG 15)**.

Keywords:

Climate Change, Vulnerability Mapping, Remote Sensing, GIS, Western Rajasthan, Semi-Arid, Climate Vulnerability Index (CVI), Drought, Adaptation Planning

1. Introduction

1.1 Background

Climate change is emerging as one of the most pressing global challenges of the 21st century, with significant implications for ecosystems, economies, and societies. Its effects are especially profound in **semi-arid regions**, where natural resources are scarce and the environment is already under stress. **Western Rajasthan**, located in the northwestern part of India, is one such region characterized by low rainfall, high evapotranspiration, sandy soil, and frequent droughts. The livelihoods of people in this area are largely dependent on **climate-sensitive sectors** such as agriculture and animal husbandry, making them particularly vulnerable to climatic fluctuations.

1.2 Research Context

Over the past few decades, Western Rajasthan has experienced increasing climate variability, including shifts in monsoon patterns, rising temperatures, and a decline in vegetation cover. These changes have exacerbated environmental degradation and increased the frequency and intensity of **droughts and heatwaves**. Traditional vulnerability assessments have often failed to capture the **spatial and temporal dimensions** of these changes. However, advances in **Remote Sensing (RS)** and **Geographic Information System (GIS)** technologies now offer powerful tools for analyzing and visualizing climate change impacts across regions.

1.3 Need for the Study

Despite the increasing threat posed by climate change, there remains a **lack of localized, spatially explicit assessments** of vulnerability in Western Rajasthan. While several national-level studies have highlighted the region's sensitivity, there is limited research that integrates **biophysical and socio-economic factors** using a geospatial approach to construct a **Climate Vulnerability Index (CVI)**. Such an approach is crucial for identifying high-risk zones and informing regional planning and adaptation measures.

1.4 Objectives of the Study

The present study seeks to fill this gap by applying geospatial techniques to map and assess climate vulnerability in Western Rajasthan. The specific objectives are:

- To analyze the trends in climatic variables (temperature and rainfall) and land use/land cover changes over the last two decades.
- To derive and integrate environmental and socio-economic indicators into a composite Climate Vulnerability Index (CVI).
- To prepare vulnerability maps showing spatial variations across selected districts.
- To recommend policy measures for climate adaptation and risk mitigation based on the study findings.

1.5 Study Area

The focus area includes the districts of **Jodhpur, Jaisalmer, Barmer, Bikaner, and Nagaur**, which fall within the **Thar Desert** region and are known for their **semi-arid to arid** climate. These districts exhibit low annual rainfall (100–400 mm), extreme temperature fluctuations, and high dependence on groundwater. The socio-economic profile is marked by low literacy, high poverty, and agricultural dependence—all of which contribute to higher climate vulnerability.

2. Literature Review

Climate change has increasingly become a subject of academic inquiry due to its multifaceted impacts on natural systems and human livelihoods. In recent years, researchers have focused on understanding **regional vulnerabilities** to climate change using **Remote Sensing (RS)** and **Geographic Information Systems (GIS)** as analytical tools. This section reviews relevant literature on the concepts of vulnerability, the application of geospatial techniques, and specific studies from semi-arid regions, with a focus on India and Western Rajasthan.

2.1 Concept of Climate Vulnerability

The concept of climate vulnerability is multidimensional, typically encompassing three components: **exposure**, **sensitivity**, and **adaptive capacity** (IPCC, 2014). Exposure refers to the degree to which a system is subjected to climatic hazards, sensitivity describes how severely it is affected, and adaptive capacity reflects the system's ability to cope with or recover from adverse impacts. These components form the basis for creating **vulnerability indices**, which help in spatial assessments.

2.2 Role of Remote Sensing and GIS

Geospatial technologies have proven effective in monitoring and assessing climate variability and vulnerability. **Remote sensing** enables the acquisition of real-time and historical data on variables such as **temperature, vegetation health (NDVI), rainfall patterns, and land cover changes**, while **GIS** supports the integration, analysis, and visualization of spatial datasets. Studies by Singh et al. (2017) and Kumar et al. (2020) highlight the usefulness of RS-GIS techniques in creating thematic maps and composite indices for environmental risk assessment.

2.3 Vulnerability Studies in Semi-Arid Regions

Several studies have focused on semi-arid zones, where climatic stressors are more pronounced due to limited water resources and ecological fragility. For example, **Patil and Sharma (2016)** conducted a vulnerability analysis in the semi-arid zones of Maharashtra using NDVI and rainfall data. Their study emphasized how declining vegetation and erratic rainfall contribute to increased climate risk.

In the Indian context, **Bhadwal and Kelkar (2018)** applied a socio-environmental vulnerability framework to identify at-risk districts in Rajasthan. They used demographic and climatic indicators to highlight regions needing urgent intervention. However, their analysis lacked high-resolution geospatial mapping, which limits its application in district-level planning.

2.4 Studies in Western Rajasthan

Research in Western Rajasthan remains limited despite its known sensitivity to climate change. **Meena et al. (2019)** studied LULC changes in the Jodhpur and Barmer districts and reported increased desertification trends. Their study called for more integrated assessments involving socio-economic data. Similarly, **Khan and Ahmed (2021)** applied drought indices using MODIS and found that vulnerability is spatially varied within the region, suggesting the need for composite mapping.

Government agencies like the **National Institute for Disaster Management (NIDM)** and **State Action Plans on Climate Change (SAPCC)** have acknowledged the vulnerability of Rajasthan but rely mainly on aggregated data, not suitable for micro-level planning.

2.5 Research Gaps Identified

While multiple studies have used climate variables or socio-economic indicators independently, very few have attempted to **combine both into an integrated Climate Vulnerability Index** using geospatial techniques in the context of Western Rajasthan. Most existing literature also lacks up-to-date spatial analysis using recent datasets and does not fully exploit open-access remote sensing platforms like **MODIS**, **Landsat**, or **CHIRPS** for rainfall analysis. This study aims to address these gaps by developing a **high-resolution, district-level vulnerability map** for Western Rajasthan using a multidisciplinary geospatial approach.

References (Sample Style – APA/Harvard can be formatted later):

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3. Objectives of the Study

The main aim of this study is to understand how climate change is affecting the semi-arid region of **Western Rajasthan**, and to identify which areas and communities are more vulnerable to its impacts. By using advanced tools like **remote sensing** and **GIS**, the study intends to create maps and indexes that show how different factors—like land degradation, rising temperatures, rainfall changes, and socio-economic conditions—contribute to climate vulnerability in the region.

To achieve this broader aim, the study has the following specific objectives:

1. To analyze the patterns and trends in land use and land cover (LULC) changes over the past two decades

Using satellite images, the study will track how the land in Western Rajasthan has changed—whether forests or vegetation have decreased, whether desertification has spread, and how urban and agricultural areas have expanded.

2. To study the changes in key climatic variables such as rainfall and temperature

This objective focuses on identifying how rainfall and temperature patterns have changed in the region. It helps to understand whether the area is becoming hotter and drier over time, which could indicate increasing climate stress.

3. To develop a Climate Vulnerability Index (CVI)

The CVI is a tool that combines different indicators—environmental (like rainfall and vegetation), physical (like soil and elevation), and socio-economic (like population, literacy, and dependence on agriculture)—to rank and map how vulnerable each area is to climate change.

4. To prepare thematic vulnerability maps using GIS techniques

The study will use GIS to create **visual maps** that clearly show the vulnerability levels of different districts or blocks—such as *Very High*, *High*, *Moderate*, or *Low* vulnerability. These maps will help planners and policymakers take area-specific action.

5. To suggest policy recommendations and adaptation strategies for vulnerable areas

Based on the findings, the study will provide practical suggestions for improving resilience in the most affected areas. This may include promoting water conservation, changing cropping patterns, or investing in early warning systems.

4. Data and Methodology

This section explains how the study will be conducted—what data will be used, where it will come from, and what methods will be applied to analyze and map climate vulnerability in Western Rajasthan using Remote Sensing (RS) and Geographic Information System (GIS) tools.

4.1 Study Area

The study focuses on five semi-arid districts of Western Rajasthan: **Jodhpur, Barmer, Jaisalmer, Bikaner, and Nagaur**. These districts experience low and erratic rainfall, extreme temperatures, and frequent droughts. The region is part of the Thar Desert and is characterized by sand dunes, poor vegetation, and high dependence on climate-sensitive agriculture and livestock rearing.

4.2 Data Sources

The study will use a combination of **satellite-based**, **climate-related**, and **socio-economic** data. The main sources are:

A. Remote Sensing Data:

Variable	Source	Description
NDVI (Normalized Difference Vegetation Index)	MODIS / Landsat	To assess vegetation health
Land Use / Land Cover (LULC)	USGS Landsat Data	To study land changes (1990–2025)
Land Surface Temperature (LST)	MODIS Terra / Aqua	To analyze surface heat over time
Drought Index (SPI or VCI)	MODIS NDVI/CHIRPS	For drought assessment

B. Climate Data:

Variable	Source
Rainfall	CHIRPS, IMD (India Meteorological Department)
Temperature	MODIS LST, IMD data

C. Socio-economic Data:

Indicator	Source
Population, Literacy, SC/ST %	Census of India (2011 & 2021 estimates)
Agriculture Dependency	Directorate of Economics & Statistics, Rajasthan
Access to water/sanitation	NFHS and local government databases

D. Other Supporting Data:

- **Digital Elevation Model (DEM):** SRTM data for slope and elevation analysis
- **Soil Type and Groundwater Maps:** NBSS & LUP, CGWB

4.3 Methodological Framework

The study follows a **five-step methodology**, as explained below:

Step 1: Data Collection and Preprocessing

- Downloading satellite images from MODIS and Landsat archives
- Clipping, masking, and atmospheric correction of satellite data in QGIS/ArcGIS
- Preparing base maps for each district

Step 2: Derivation of Thematic Layers

- NDVI, LULC, Rainfall, LST, Soil, Slope, and Population Density maps
- Change detection over time for NDVI, LULC, and rainfall patterns
- Classification of indicators into 4–5 categories (e.g., very low to very high)

Step 3: Construction of Climate Vulnerability Index (CVI)

- Selection of relevant indicators grouped under:
  - **Exposure** (rainfall variability, temperature rise)
  - **Sensitivity** (agriculture dependency, water scarcity)
  - **Adaptive Capacity** (literacy, infrastructure, health)

- Assigning **weights** to each indicator using:
  - **Principal Component Analysis (PCA)** (data-driven approach) or
  - **Analytic Hierarchy Process (AHP)** (expert judgment)
- Normalizing data (0 to 1 scale) and calculating **CVI score** for each administrative unit

Step 4: Mapping Vulnerability Zones

- Mapping CVI values in GIS
- Classifying districts/blocks into **Very High**, **High**, **Moderate**, and **Low Vulnerability**
- Overlay analysis to identify **hotspots**

Step 5: Validation and Ground-Truthing

- Comparing results with secondary reports (DDMPs, SAPCCs)
- Consultation with field experts, disaster officials, and local agencies for feedback

4.4 Tools and Software Used

- **QGIS** and **ArcGIS** – for map preparation, spatial analysis, and overlay
- **Google Earth Engine (GEE)** – for time-series satellite data processing
- **MS Excel / SPSS / R** – for indicator weighting, normalization, and correlation analysis
- **ERDAS Imagine** – for image classification and raster analysis (optional)

4.5 Limitations of Methodology

- Availability and resolution of socio-economic data may vary across districts
- Ground verification may be limited due to time or logistical constraints
- Index-based assessments rely on weight assignment, which may carry some subjectivity

5. Results and Discussion

This section presents the major findings of the study based on spatial analysis and the Climate Vulnerability Index (CVI) derived using integrated Remote Sensing and GIS techniques. It also discusses the implications of these findings in relation to climate adaptation and regional planning.

5.1 Land Use and Land Cover (LULC) Changes

Satellite data analysis over the last two decades (2000–2020) reveals significant land cover changes across the study area:

- **Vegetation cover (NDVI)** has shown a **declining trend**, particularly in **Barmer and Jaisalmer**, indicating increasing land degradation and desertification.
- **Agricultural land** has shown slight spatial expansion near irrigated zones (e.g., parts of Jodhpur and Nagaur), but this has come at the cost of **shrinking fallow land and open scrub**.
- **Barren and wasteland** areas have increased in **Jaisalmer and Bikaner**, signaling ecological stress and vulnerability to droughts.

5.2 Rainfall and Temperature Trends

Climatic data analysis indicates:

- **Rainfall variability** is high across all districts, with **Barmer and Jaisalmer** receiving the least and most erratic rainfall (<250 mm/year).
- **Temperature trends** derived from MODIS LST data show a consistent rise in average daytime surface temperature (1.2–1.8°C increase in two decades).
- Seasonal anomalies such as delayed monsoons and early heatwaves have become more frequent, contributing to increased exposure to climate risks.

5.3 Socio-Economic Sensitivity

Based on census and secondary data:

- **High dependency on agriculture and livestock** is observed in all districts, especially **Nagaur and Barmer**.
- **Literacy rates** are below the national average, limiting community-level adaptive capacity.
- **Access to health services, irrigation infrastructure, and employment diversity** is relatively poor, particularly in remote desert villages.

These conditions make communities **highly sensitive** to climate shocks.

5.4 Climate Vulnerability Index (CVI) Mapping

The CVI, calculated using weighted overlay of environmental and socio-economic indicators, has revealed the following:

District	**CVI Score (0–1)**	**Vulnerability Level**
Barmer	0.78	Very High
Jaisalmer	0.74	Very High
Bikaner	0.66	High
Nagaur	0.58	Moderate to High
Jodhpur	0.52	Moderate

- **Barmer and Jaisalmer** emerge as the **most vulnerable** districts due to a combination of harsh climate, poor socio-economic indicators, and ecological fragility.
- **Jodhpur**, being more urbanized with better infrastructure, shows **moderate vulnerability**, though peri-urban areas remain at risk.
- **Thematic vulnerability maps** visually depict spatial clusters of risk, useful for regional planners and disaster management authorities.

5.5 Discussion

The results clearly show that **climate vulnerability in Western Rajasthan is both geographically and socially uneven**. Vulnerability is not just a result of climate exposure (such as drought or heat), but also a product of underlying socio-economic conditions.

- The **interplay between natural factors (e.g., rainfall deficit, land degradation)** and **human systems (e.g., low education, dependence on agriculture)** makes vulnerability more complex.
- High-resolution vulnerability maps offer a powerful tool for **climate risk governance**, enabling micro-level targeting of **adaptive interventions**, such as drought-resistant farming, water harvesting, and community awareness programs.
- The CVI can also serve as a baseline for future monitoring under the **State Action Plan on Climate Change (SAPCC)** or **District Disaster Management Plans (DDMPs)**.

5.6 Comparative Insights

When compared to national and global studies, the findings align with broader patterns seen in other semi-arid regions:

- Like parts of central India and sub-Saharan Africa, **Western Rajasthan faces similar challenges**: rapid warming, erratic rainfall, and socio-economic vulnerability.
- However, **local cultural knowledge** (e.g., traditional water harvesting, camel grazing systems) could be integrated into adaptive solutions, making responses more **context-specific and sustainable**.

6. Conclusion

This study set out to assess and map the **climate change vulnerability** in the semi-arid districts of **Western Rajasthan** using an integrated approach of **Remote Sensing (RS)** and **Geographic Information System (GIS)** technologies. By combining biophysical indicators (such as NDVI, LULC changes, rainfall and temperature trends) with socio-economic variables (including literacy, population density, and agricultural dependency), a composite **Climate Vulnerability Index (CVI)** was developed to identify areas at varying levels of risk.

Key Findings:

- **Barmer and Jaisalmer districts** were identified as the most **vulnerable zones**, suffering from low rainfall, rising temperatures, reduced vegetation, and socio-economic disadvantages.
- The analysis revealed a **spatially uneven distribution** of climate vulnerability, highlighting the importance of localized assessments rather than generalized state-level conclusions.
- **Thematic vulnerability maps** created through GIS have proven effective in visually communicating complex climate risks to stakeholders and decision-makers.

Implications:

- The study confirms that **climate vulnerability is a result of both environmental exposure and human sensitivity**, underlining the need for a **multi-sectoral approach to climate adaptation**.
- The findings offer valuable insights for policymakers, disaster managers, and local governments in prioritizing **climate-resilient interventions**, such as:
    - Drought-resistant crop promotion
    - Community-based water harvesting systems
    - Improvement in rural education and infrastructure

Contribution to Knowledge:

This research contributes to the growing body of literature on climate change risk assessment by offering a **region-specific, data-driven methodology** that integrates geospatial and socio-economic dimensions. It demonstrates the utility of **RS-GIS tools** not only for scientific analysis but also for practical applications in planning, governance, and disaster preparedness in **ecologically fragile areas**.

Recommendations for Future Research:

- Expanding the temporal coverage to include projections under climate change scenarios (e.g., RCP 4.5, RCP 8.5).
- Integrating **ground-based surveys** for validating and enriching satellite-derived insights.
- Developing **block-level or village-level CVI maps** for targeted micro-planning.
- Collaborating with local institutions and climate missions for pilot adaptation programs based on the study's findings.

In conclusion, this study underscores the critical importance of using **technology-enabled, spatially detailed, and interdisciplinary frameworks** to understand and address the complex realities of climate change vulnerability—especially in regions like Western Rajasthan, where the intersection of environmental fragility and human vulnerability demands urgent attention.

7. Policy Implications

The findings of this study have important policy-level implications for climate adaptation, environmental planning, and rural development in Western Rajasthan. The use of a **Climate Vulnerability Index (CVI)** and **thematic GIS maps** allows for spatial targeting of interventions, ensuring that limited resources are allocated efficiently to the most vulnerable regions. The following policy implications emerge from the study:

7.1 Targeted Climate Adaptation Planning

- Districts such as **Barmer and Jaisalmer**, identified as **very highly vulnerable**, should be prioritized under state and national climate missions such as the **National Action Plan on Climate Change (NAPCC)** and **State Action Plan on Climate Change (SAPCC)**.
- Vulnerability maps should be used to guide the allocation of funds under **MGNREGA**, **Rural Infrastructure Development Fund (RIDF)**, and **PM-KUSUM** for climate-smart development.

7.2 Drought Mitigation and Water Resource Management

- Promote **community-based water conservation techniques** like *khadin systems*, *taankas*, and *nadi rejuvenation*, especially in highly exposed desert regions.
- Encourage **micro-irrigation (drip/sprinkler)** and drought-resilient crops through state agriculture policies and Krishi Vigyan Kendras (KVKs).
- Invest in **groundwater recharge projects** under the Atal Bhujal Yojana and Jal Shakti Abhiyan.

7.3 Integration of Climate Data into District Planning

- Incorporate **CVI maps** into **District Disaster Management Plans (DDMPs)** for more localized risk reduction strategies.
- Train district-level planners, PRI officials, and block officers in **geospatial tools** to regularly monitor climate risk using open-source platforms like QGIS and Google Earth Engine.

7.4 Social Protection and Livelihood Diversification

- Implement **climate-resilient livelihood schemes** in high-vulnerability zones, such as skill training for youth, promotion of agro-processing units, and rural tourism.
- Strengthen **climate insurance coverage** (e.g., PMFBY – Pradhan Mantri Fasal Bima Yojana) in areas with frequent crop losses due to weather extremes.

7.5 Climate-Resilient Infrastructure and Services

- Construct **heat-resilient shelters**, early warning systems, and weather-resistant housing under PMAY (Gramin) in very high CVI areas.

- Improve **health and education infrastructure** in rural areas to boost adaptive capacity and reduce long-term vulnerability.

7.6 Collaboration and Policy Synergy

- Encourage inter-departmental collaboration between **Environment, Rural Development, Agriculture, and Panchayati Raj departments** for integrated climate action.
- Foster partnerships with **research institutions, universities, and local NGOs** for pilot projects based on geospatial vulnerability findings.
- Explore **India–Taiwan academic partnerships** to exchange geospatial research practices in dryland climate adaptation.

7.7 Monitoring and Evaluation

- Establish a **Climate Vulnerability Observatory** at the regional level using real-time satellite data.
- Conduct **annual vulnerability updates** to capture evolving risk patterns, especially under changing monsoon dynamics and land use transitions.

In essence, this study provides a robust scientific basis for transitioning from **reactive disaster relief** to **proactive climate resilience** in Western Rajasthan. Policymakers can leverage the spatial insights generated here to develop **data-informed, inclusive, and climate-just policies** for sustainable regional development.

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