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Monsoonal Variability in Jodhpur Impacts and Adaptive Water Management Strategies

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ABSTRACT:

This study focuses on the effects of climate change on rainfall, agriculture, groundwater recharge, and urban infrastructure in Jodhpur district, Rajasthan.This study uses both quantitative and qualitative methods. For the quantitative analysis, rainfall and temperature data were analysed to identify trends. The study also correlated crop yields of kharif crops with rainfall patterns and assessed groundwater levels in relation to rainfall. It examined urban flooding through data on flooding incidents and drainage capacity. Qualitative analysis included interviews and surveys with local farmers and residents about their experiences with climate change and water management challenges. The study also observed traditional water conservation practices. The results show that extreme weather events are increasing and there is a negative correlation between rising temperatures and rainfall, leading to unpredictable rainfall patterns.The study shows inconsistent rainfall patterns affecting agriculture, with crops like bajra, moong, and guar being particularly vulnerable to delays and excesses in monsoon rain. Urban planning in Jodhpur is challenged by erratic rainfall and intense storms, leading to flooding and blocked drainage. The findings are similar in other western Rajasthan districts like Barmer and Bikaner, where rising temperatures and extreme weather patterns are also observed. The study suggests adaptive water management strategies, such as Integrated Water Resource Management (IWRM) and community-led conservation projects, to adapt to changing water access issues. It stresses the crucial role of local governance in implementing climate adaptation plans, education on climate change, partnerships with research institutions, and community involvement in climate initiatives. Finally, it recommends promoting rainwater harvesting and micro-irrigation to sustainably manage water resources in the semi-arid climate.

Keywords: Sustainable water management, climate change, urbanisation, strategies

Introduction

The impacts of climate change are increasingly threatening semi-arid regions such as Jodhpur, Rajasthan, where irregular rainfall, rising temperatures, and more frequent extreme weather events are endangering water resources, agriculture, and urban infrastructure (Agarwal & Narain, 1997; Sharma & Goyal, 2020). Shifting patterns of monsoon rainfall and the occurrence of intense storms underscore the necessity for adaptive strategies to address these emerging challenges (Singh et al., 2019; De & Dhote, 2024). Traditional water conservation methods are becoming less effective due to climate variability, highlighting the need to combine indigenous knowledge with modern technological solutions for sustainable water management (Kaushik, 2019; Khurana & Singh, 2024). Studies across Rajasthan and similar arid regions show that climate risks are regional and often transboundary, calling for regional cooperation to effectively tackle these issues (Agarwal & Narain, 1997; Central Ground Water Board, 2022). Effective policies, active community participation, and resilient infrastructure investments are essential to better equip these regions for future climatic uncertainties. Promoting sustainable practices and strengthening institutional frameworks are key steps towards mitigating climate impacts and ensuring water security for future generations.

Study Area

Rajasthan, located in northwestern India, is the country's largest state by area, covering approximately 342 239 km², which constitutes about 10.4 % of the nation's total geographical area. It lies between 23°30′ N and 30°12′ N latitude and 69°30′ E and 78°17′ E longitude, with the Tropic of Cancer traversing its southern extremity. The state shares an international border with Pakistan's Punjab and Sindh provinces to the west and northwest, and domestic borders with Punjab to the north; Haryana and Uttar Pradesh to the northeast; Madhya Pradesh to the southeast; and Gujarat to the southwest. Administratively, Rajasthan is divided into seven divisions and 41 districts, making it he third-most subdivided state in India by district count. Topographically, western Rajasthan is dominated by the arid expanse of the Thar Desert, where annual rainfall often falls below 100 mm, while the southeastern regions receive up to 650 mm of precipitation, illustrating significant spatial variability in moisture availability. The ancient Aravalli Range, one of the oldest fold mountains globally, bisects the state diagonally from southwest to northeast, exerting a pronounced influence on local climate and hydrology by intercepting monsoon winds and facilitating orographic rainfall. Rajasthan's climate ranges from arid in the west to semi-arid in the east, with summer temperatures frequently exceeding 45 °C and winter lows occasionally dropping to near freezing. Economically, the state's predominantly agrarian population relies heavily on monsoon-dependent agriculture, yet water scarcity and land degradation pose persistent challenges to sustainable livelihoods. Given its vast desert ecosystems, diverse physiography, and pronounced climatic gradients, Rajasthan constitutes an ideal study area for research on climate adaptation, sustainable resource management, and renewable energy potential in semi-arid environments.

Methodology

The methodology employed in this study integrates both quantitative and qualitative approaches to assess the impacts of climate change on rainfall patterns, agriculture, groundwater recharge, and urban infrastructure in Jodhpur district, Rajasthan.

Quantitative Analysis:

Rainfall and Temperature Data Analysis**:** Daily and monthly rainfall data from the India Meteorological Department (IMD) and temperature records from local meteorological stations were analysed using statistical methods such as the Mann-Kendall test and Sen's slope estimator to detect trends and variability in precipitation and temperature over the study period.

Agricultural Impact Assessment: Crop yield data for kharif crops like bajra, moong, and guar were correlated with rainfall patterns to evaluate the effects of rainfall variability on agricultural productivity.

Groundwater Recharge Estimation: Groundwater level data from the Central Ground Water Board (CGWB) were analysed to assess the temporal variations in groundwater levels and their relationship with rainfall patterns.

Urban Flooding Analysis: Data on urban flooding incidents, drainage capacity, and rainfall intensity were collected from municipal records and analysed to assess the adequacy of existing urban infrastructure in coping with extreme weather events.

Qualitative Analysis:

Field Surveys and Interviews: Structured interviews and surveys were conducted with local farmers, urban residents, and municipal officials to gather firsthand information on perceptions of climate change impacts, adaptation strategies, and challenges faced in water management.

Community-Based Observations: Observations of traditional water conservation practices, such as rainwater harvesting systems (taankas) and johads, were made to understand their current effectiveness and community engagement in water management.

Comparative Analysis:

The findings from Jodhpur were compared with data from other arid regions in Rajasthan, such as Barmer and Bikaner, to contextualize the observed trends and assess regional variations in climate change impacts.

Policy and Institutional Review:

An analysis of existing policies and institutional frameworks related to water resource management and climate adaptation was conducted through document reviews and consultations with local governance bodies to identify gaps and opportunities for enhancing climate resilience. This mixed-methods approach provides a comprehensive understanding of the multifaceted impacts of climate change in Jodhpur district and informs the development of targeted adaptation strategies.

Result and Discussion

The analysis of rainfall patterns in Jodhpur district indicates several significant trends: Erratic and Fluctuating Patterns: Rainfall has been characterised by erratic and fluctuating trends, making it difficult to predict annual precipitation levels accurately. Uneven Spatial Distribution: Certain tehsil within Jodhpur have experienced significantly less rainfall than others, highlighting a growing spatial disparity in rainfall distribution across the district. Reduced Moderate Rainfall Days: There has been a noticeable decrease in the number of moderate rainfall days, which are typically beneficial for groundwater recharge, leading to increased runoff losses. Increase in Intense Rainfall Events: Instances of heavy downpours have become more frequent, contributing to urban flooding and drainage issues. Impact on Agriculture: The variability in rainfall has adversely affected agricultural practices, particularly for rain-fed crops, leading to crop failures during drought years and water logging during excessive rainfall. Temporal Shifts in Rainfall Timing: There are indications that the timing and concentration of rainfall events have shifted, necessitating changes in agricultural practices and cropping calendars. Correlation with Temperature: The negative correlation between rainfall and temperature suggests that rising temperatures may be contributing to reduced effective rainfall due to increased evapotranspiration. Temperature Trends The study also highlights important trends in temperature: Overall Increase: There has been a consistent increase in temperature in Jodhpur, aligning with broader global and national trends associated with climate change. Heatwave Frequency: The frequency of heatwaves has risen, exacerbating the challenges faced by both agriculture and urban infrastructure. Extreme Weather Events: Increasing temperatures have been linked to a rise in extreme weather events, further complicating the climate resilience of the region. Impact on Groundwater: Higher temperatures contribute to changes in the hydrological cycle, affecting groundwater recharge and availability.

Impact on Agriculture

Agriculture in Jodhpur is predominantly rain-fed, with kharif crops like bajra (pearl millet), moong (green gram), and guar (cluster bean) depending heavily on monsoonal rainfall. Delayed or deficient monsoons have led to late sowing or crop failure in drought years like 2017 and 2021. Excess rainfall events in years like 2019 and 2023 resulted in crop damage and water logging, impacting yields. The observed shift in rainfall timing and concentration suggests the need to revisit cropping calendars and encourage climate-resilient agriculture, including drought-resistant crop varieties and contingency plans for irrigation.

Impact on Groundwater Recharge

Groundwater is a critical resource in the Jodhpur district, serving as the primary source of drinking water and irrigation. However,Inconsistent rainfall distribution has affected natural groundwater recharge cycles, especially in low rainfall years. The reduced number of moderate rainfall days, which are ideal for recharge, and an increase in intense short spells, have caused higher runoff losses with minimal infiltration. Rainwater harvesting structures like taankas, nadis, and khadins, traditional to Rajasthan, are increasingly less effective without consistent monsoon rainfall, highlighting the need for scientific watershed planning.

Impact on Urban Planning

Urban expansion in Jodhpur, especially in areas like Paota, Sardarpura, and Shastri Nagar, has seen rising challenges due to climate variability. Erratic rainfall and short-duration heavy downpours have led to frequent urban flooding and drainage congestion. Traditional stormwater systems are insufficient to cope with high-intensity events, demanding upgrades to urban drainage design standards. Urban water supply planning must consider climate-resilient infrastructure, including rainwater harvesting, stormwater management, and reuse of treated wastewater.

Comparison with Other Districts/Arid Zones

Similar patterns of rainfall variability have been observed in other western Rajasthan districts such as Barmer, Bikaner, and Jaisalmer. Studies from these regions corroborate findings in Jodhpur: rising temperatures, increasing frequency of extreme weather, and reduced rainfall predictability. However, Jodhpur, being semi-urban and economically diverse, shows slightly better resilience due to infrastructural investments, unlike remote arid blocks in Barmer and Jaisalmer. Comparative studies with arid zones in Kutch (Gujarat) and Thar Desert (Pakistan) also highlight the transboundary and regional nature of climate risks, emphasising the need for regional cooperation and knowledge sharing.

Policy Implications & Recommendations

Adaptive Water Resource Management: To address the emerging challenges in water availability due to shifting rainfall patterns, adaptive water resource management strategies are critical. Integrated Water Resources Management encourage a holistic approach that integrates surface and groundwater resources, with a focus on optimising water storage and distribution across Jodhpur district. Catchment-based Water Management involve watershed management practices to enhance rainwater infiltration and groundwater recharge, particularly in the more vulnerable western parts of Jodhpur, such as Balesar and Shergarh. Water-efficient cropping promote water-efficient irrigation systems and drought-resistant crop varieties to minimise water usage during the dry months. Water conservation infrastructure increase investments in community-based water conservation initiatives, like check dams, talabs, and micro-watershed planning to ensure water availability even in dry periods.

Role of Local Governance in Climate Resilience

Local governance plays a pivotal role in implementing and monitoring climate adaptation strategies. To enhance resilience Decentralised Climate Action Plans local bodies, including Panchayats, should develop and implement climate-resilient action plans tailored to the specific needs of each region (e.g., urban areas vs. rural areas). Capacity Building includes local government officials and community leaders should undergo climate change education and training to ensure effective implementation of adaptation strategies. Collaboration with Research Institutions Local governance should collaborate with academic and research institutions (such as ICAR and IMD) to ensure policies are data-driven and scientifically backed. Community Engagement Foster community participation in climate resilience activities, ensuring that local knowledge, especially on traditional water conservation practices, is incorporated into modern adaptation policies.

Potential for Rainwater Harvesting and Micro-Irrigation Systems

Expand the use of rooftop rainwater harvesting systems in urban areas and village-based harvesting ponds (taankas) in rural areas. Government incentives or subsidies could be used to encourage widespread adoption of such technologies. Micro-Irrigation Systems advocates drip and sprinkler irrigation systems in agricultural fields, especially in areas dependent on groundwater, to ensure efficient water use and reduced dependency on erratic rainfall. Watershed-scale rainwater harvesting projects should be introduced, especially in semi-arid regions, to reduce water loss through evaporation and enhance groundwater recharge during monsoons.

Early Warning Systems for Drought and Floods

To mitigate the adverse impacts of extreme weather events such as droughts and floods, the implementation of early warning systems (EWS) is essential. Drought Early Warning Systems (DEWS) is a regional drought monitoring systems that can predict onset dates and duration, providing farmers and local authorities with early alerts to plan water conservation measures and adjust crop planning accordingly. Flood Early Warning Systems (FEWS): Given the increasing frequency of extreme rainfall events leading to flash floods, it is critical to invest in flood forecasting using satellite-based data and rainfall-runoff models. A combination of community-based monitoring and technical forecasting systems can ensure timely evacuation and infrastructure protection. Mobile-based alerts and community outreach programs should be established, particularly in remote rural areas, ensuring that early warning systems are accessible to all populations.

Conclusion

Analysis of monsoonal variation in Jodhpur from 2015 to 2025 has drawn attention to important problems posed by climate change influencing urban planning, groundwater recharging, and agricultural output. Rising temperatures and irregular precipitation patterns highlight the pressing need of adaptive management solutions combining contemporary methods with traditional knowledge. Jodhpur's capacity to handle the consequences of climate change can be improved by using Integrated Water Resources Management and encouraging local participation in climate resilience projects. Improved infrastructure including contemporary drainage systems and effective irrigation techniques stands out as a key factor in reducing the impact of erratic weather patterns. Moreover, early warning systems for both drought and flooding are essential to equip local people with timely information, so enabling them to make wise decisions on crop planning and water conservation. An environment favourable to sustainable water management will be created by local government, research institutions, and community collaboration. The lessons learned from Jodhpur, together with comparisons to other places, highlight a more general view on the common problems abiotic environment of semi-arid terrains. Finally, adopting novel ideas and traditional methods can produce resilient and sustainable water management solutions that not only protect water resources but also improve the livelihoods of the local people depending on them.

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