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Long-Term Spatio-Temporal Variability of Climate in the Shekhawati Region of Rajasthan, India (1981–2025): Implications for Dryland Ecosystems and Biodiversity

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***Abstract*— *The Shekhawati region of north-eastern Rajasthan is a dryland ecosystem. It has high temperatures, uneven rainfall and substantial climatic fluctuations create challenging environmental conditions for natural vegetation and biodiversity. This study assessed long-term changes in key climatic variables, including minimum, mean and maximum temperature, annual rainfall, relative humidity and wind speed, across Churu, Sikar and Jhunjhunu districts over the period 1981–2025. Temporal patterns were examined using decadal averages, descriptive statistical measures and linear regression analysis to identify the direction and magnitude of climatic change. The analysis revealed an overall warming pattern across the three districts, although the magnitude of change varied spatially. Churu generally experienced higher temperatures, with a long-term annual mean temperature of 26.77 °C, followed by Jhunjhunu (26.18 °C) and Sikar (26.05 °C). Rainfall remained highly variable from year to year; nevertheless, a positive long-term trend was observed in all three districts. The estimated annual rates of increase were 3.714 mm year^{-1} for Churu, 5.028 mm year^{-1} for Sikar and 4.533 mm year^{-1} for Jhunjhunu, and the regression analyses indicated significant temporal relationships. Relative humidity also showed a clear upward tendency, particularly in Churu, where the regression model explained 54.7% of the observed variation ($R^2 = 0.547$). The annual wind speed was observed in range from 2.0–2.5 m s^{-1} in Churu, 2.1–2.5 m s^{-1} in Sikar, and 1.9–2.4 m s^{-1} in Jhunjhunu. The district-level climatic trends provide an important baseline for evaluating climate-related changes in biodiversity and for developing appropriate conservation and ecosystem-management strategies in the semi-arid landscapes of the Shekhawati region.*

***Keywords*— climate variability, climate change, Shekhawati, Rajasthan.**

I. INTRODUCTION

Climate is a primary source of ecological structure and function. It regulates the physiological performance, phenology, distribution, reproduction and survival of organisms. Changes in temperature, precipitation, atmospheric moisture and wind regimes can modify ecological processes at multiple spatial and temporal scales. Climate change is not considered merely a physical or meteorological phenomenon. Its effects also extended to terrestrial and freshwater biodiversity and ecosystem functioning. The climate change has transformed terrestrial and freshwater ecosystems globally. There is changes in species distributions, phenology, physiology, abundance and ecosystem structure (IPCC, 2023).

The ecological consequences of climatic change are chiefly important because biological systems respond not only to changes in mean climatic conditions but also to changes in climatic variability and extreme events. Temperature increases can alter physiological thresholds, growing seasons and reproductive timing. The change in precipitation can influence soil-water availability, productivity and habitat suitability. Changes in atmospheric humidity and wind can further modify evapotranspiration, energy exchange, dispersal processes and near-surface microclimates. Thus, the assessment of climate change at the ecosystem level requires consideration of multiple climatic variables rather than reliance on temperature alone. Earlier ecological studies revealed a coherent relationship between observed biological changes and recent climatic trends. There is shifts in species distributions and phenological timing (Parmesan and Yohe, 2003).

Dryland ecosystems are particularly sensitive to climatic variability because water availability is often a major ecological constraint. Semi-arid landscapes are characterized by strong seasonality, high evaporative demand, irregular precipitation and frequent fluctuations in environmental conditions. Under such circumstances, even relatively modest changes in temperature or rainfall can influence vegetation productivity, soil moisture, plant recruitment and habitat suitability. The interaction between climatic stress and biodiversity is therefore likely to be especially important in dryland regions where organisms have evolved under conditions of environmental variability.

Climate-driven changes in temperature and precipitation can alter geographic ranges and seasonal biological events and can disrupt interactions among species. The climate-related changes in phenology can produce temporal mismatches between interacting organisms, while shifts in climatic suitability can result in redistribution of species and changes in community composition (IPCC, 2022). Pecl et al. (2017) similarly emphasized that climate-driven redistribution of biodiversity can influence ecosystem functioning and human well-being. Such evidence indicates that regional climate assessments are an important prerequisite for understanding potential biodiversity responses at local scales.

India represents a particularly important region for climate-change assessment. India has large climatic diversity, strong dependence on the monsoon system and substantial ecological heterogeneity. Long-term assessments indicate that India's climate has undergone significant changes during the twentieth and early twenty-first centuries. Krishnan et al. (2020) reported that India's surface air temperature increased by approximately 0.7 °C during 1901–2018 and identified clear signatures of human-induced climate change across the Indian region. It also highlighted changes in the mean, variability and extremes of important climatic parameters, including temperature and precipitation.

Rainfall change is mainly important in India. The precipitation is strongly influenced by the southwest monsoon and exhibits substantial spatial and temporal variability. Changes in rainfall totals do not necessarily represent the complete nature of hydroclimatic change. India has documented substantial changes in extreme rainfall characteristics. Roxy et al. (2017) reported a marked increase in widespread extreme rainfall events over central India during 1950–2015. It revealed that changes in rainfall variability and extremes can occur even when seasonal or regional rainfall exhibit different tendencies.

The north-western Indian region is especially important for climate-change. It is comprised of extensive arid and semi-arid environments where ecological processes are strongly influenced by temperature and water availability. Pingale et al. (2014) studied mean and extreme rainfall and temperature trends across 33 urban centres of Rajasthan and reported substantial spatial and temporal variability in both rainfall and temperature. Their analysis identified significant warming trends in minimum, average and maximum temperature at many locations and demonstrated that climatic trends vary considerably across the arid and semi-arid areas of Rajasthan.

Shekhawati is in north-eastern part of Rajasthan and comprises the districts of Churu, Sikar and Jhunjhunu. The region extends approximately between 27°00′–29°00′ N and 74°40′–76°40′ E. It represented a heterogeneous semi-arid landscape characterized by sand dunes, sandy plains, scrub vegetation, grasslands, agricultural ecosystems and scattered tree cover. The south-eastern part includes rocky pediments, isolated hillocks and low ridges associated with the Aravalli landscape. The north-western part has widespread sandy terrain. The environmental heterogeneity makes Shekhawati an important landscape for investigating spatial differences in climatic change. In the present study, the long-term climatic variability and trends in the three major districts of the Shekhawati region has been evaluated. The study focuses on minimum, mean and maximum temperature, annual rainfall, relative humidity and wind speed during 1981–2025.

II. STUDY AREA AND METHODOLOGY

Study Area

Shekhawati region is situated in the north-eastern part of Rajasthan, India. It is comprised of three districts namely, Churu, Sikar and Jhunjhunu. For the present climatic analysis, these three districts were considered as the representative units of the Shekhawati region. The study area extends approximately between 27°00′–29°00′ N latitude and 74°40′–76°40′ E longitude. The region forms an important semi-arid landscape of north-western India. It is characterized by substantial climatic variability, particularly in temperature and rainfall. The landscape is environmentally heterogeneous. Differences in temperature, rainfall, atmospheric humidity and wind conditions may generate spatially different environmental pressures on vegetation and biodiversity.

Study period and climatic variables

The study was undertaken to analyse a 45-year climatic data (1981–2025) for Churu, Sikar and Jhunjhunu. Long-term meteorological data for the Shekhawati region were obtained from the India Meteorological Department (IMD), Pune. The annual observations were analysed for the climatic variable such as temperature (°C), annual rainfall (mm), annual average relative humidity (%) and annual average wind speed (m s^{-1}). The climatic data were also summarized using decadal averages and descriptive statistics, including mean, standard deviation, minimum, maximum and coefficient of variation. Temporal trends were assessed using linear regression. The regression equation was used to estimate the direction and magnitude of change. The coefficient of determination (R^2) was used to assess the proportion of variability associated with the temporal trend.

III. RESULTS AND DISCUSSION

The analysis of the 1981–2025 climatic record revealed considerable spatial and temporal variability in the climatic conditions of Churu, Sikar and Jhunjhunu districts (Figure 1-4). The three districts exhibited a broadly semi-arid climatic characteristic. The substantial differences were observed in temperature, rainfall, relative humidity and wind speed. It was observed that annual rainfall and relative humidity increased. The annual wind speed showed a significant declining trend. The magnitude and direction of these changes varied among the three districts. It demonstrates that the climatic response of the Shekhawati region is spatially heterogeneous. Churu generally exhibited the highest temperature values and comparatively lower rainfall and humidity. Sikar and Jhunjhunu generally have higher rainfall and atmospheric humidity.

The analysis of minimum, mean and maximum temperature demonstrated a general warming tendency across all three districts during 1981–2025. The decadal averages showed an overall increase from the earlier part of the record, with particularly high values during 2001–2010. Some moderation was observed during 2011–2020, followed by relatively higher values during 2021–2025. Churu consistently recorded the highest temperature values. Its decadal mean temperature increased from 26.60 °C during 1981–1990 to 27.23 °C during 2001–2010 and was 26.78 °C during 2021–2025. Sikar exhibited lower values, increasing from 25.93 °C during 1981–1990 to 26.53 °C during 2001–2010, before reaching 25.96 °C during 2021–2025. Jhunjhunu showed intermediate conditions, with mean temperature increasing from 26.04 °C during 1981–1990 to 26.67 °C during 2001–2010 and 26.04 °C during 2021–2025. Minimum temperature also showed an overall increasing pattern. Churu recorded the highest minimum temperature throughout study period. Jhunjhunu generally recorded the lowest values during the earlier decades. Maximum temperature followed a similar spatial pattern, with Churu recording the highest values and Sikar the lowest. The positive regression slopes reported for the temperature variables indicate a gradual long-term warming tendency in all three districts.

Annual rainfall displayed substantially greater temporal variability than temperature. Alternating wet and dry periods were evident throughout the 1981–2025 record. It reflected the irregular nature of monsoon precipitation in the semi-arid environment. Churu recorded the lowest decadal rainfall during 1991–2000 (390.2 mm), followed by a progressive increase, reaching 615.6 mm during 2021–2025. Sikar showed comparatively stable rainfall during the earlier part of the record but increased markedly after 2010, reaching 750.8 mm during 2021–2025. Jhunjhunu similarly showed a marked increase during the later periods, reaching 715.6 mm during 2021–2025. Sikar exhibited the largest increase in annual rainfall, with a regression slope of 5.028 mm $year^{-1}$, equivalent to approximately 50.28 mm $decade^{-1}$. Jhunjhunu showed an increase of 4.533 mm $year^{-1}$ (45.33 mm $decade^{-1}$), whereas Churu recorded an increase of 3.714 mm $year^{-1}$ (37.14 mm $decade^{-1}$). All three trends were statistically significant ($p < 0.05$).

Relative humidity showed a clear increasing tendency across all three districts. Churu recorded the lowest relative humidity throughout the study period. It increased from 31.8% during 1981–1990 to 43.4% during 2021–2025. Sikar increased from 35.3% to 47.0%, while Jhunjhunu increased from 35.5% to 46.6%. Linear regression showed statistically significant increasing trends in annual relative humidity across all three districts. Churu exhibited the strongest increase, with a slope of 0.269% $year^{-1}$, followed by Sikar at 0.249% $year^{-1}$ and Jhunjhunu at 0.235% $year^{-1}$. These correspond to increases of approximately 2.69%, 2.49% and 2.35% per decade, respectively. Churu recorded the highest R^2 value (0.547), followed by Sikar (0.372) and Jhunjhunu (0.347). All three trends were statistically highly significant ($p < 0.001$).

Wind speed analysis revealed a significant declining tendency in annual mean wind speed across all three districts (Fig. 4). Sikar recorded the highest long-term mean annual wind speed (2.27 ± 0.11 m s^{-1}), followed by Churu (2.19 ± 0.12 m s^{-1}) and Jhunjhunu (2.13 ± 0.13 m s^{-1}). The observed annual wind-speed range was 2.0–2.5 m s^{-1} in Churu, 2.1–2.5 m s^{-1} in Sikar and 1.9–2.4 m s^{-1} in Jhunjhunu. The relatively low coefficients of variation indicate that annual wind speed was comparatively stable over the study period. Although, Jhunjhunu showed greater relative variability (CV = 5.91%) than Churu (5.36%) and Sikar (4.82%). Jhunjhunu exhibited the strongest declining trend (approximately −0.055 m s⁻¹ decade⁻¹). Churu and Sikar showed declines of approximately −0.045 m s⁻¹ decade⁻¹. The negative correlation coefficients indicate consistent inverse relationships between year and wind speed. The strongest correlation was observed in Jhunjhunu (R = −0.572), followed by Sikar (R = −0.534) and Churu (R = −0.505).

Climatic factors such as temperature, rainfall, humidity and wind affect vegetation water balance, productivity, phenology, habitat conditions, reproductive and dispersal processes. In the present study, the substantial climatic alteration found across the Shekhawati region during 1981–2025. There was increase in temperature, relative humidity and annual rainfall. At the same time, annual wind speed declined significantly. These climatic changes have potential implications for biodiversity because temperature, precipitation, atmospheric moisture and wind jointly influence ecosystem processes. Increasing temperatures may increase thermal stress and alter phenological processes. The changes in rainfall can modify water availability and vegetation productivity. Increasing relative humidity may influence evapotranspiration and near-surface moisture conditions. The declining wind speed may affect atmospheric exchange and wind-mediated dispersal processes. The district-level differences observed in the present analysis provide an important basis for such future ecological assessments. Churu has warming and relatively drier conditions. Sikar exhibits the greater rainfall in Sikar. Jhunjhunu has declining wind-speed trend. Due to these district level differences, the ecological effects of climate change may vary considerably across the Shekhawati landscape. The climatic trends observed in this study provide a baseline for subsequent assessment of biodiversity responses in the Shekhawati region.

IV. CONCLUSION

The regional climate has observed simultaneous changes due to change in climatic factors like increasing temperature, changing rainfall, increasing relative humidity and the declining wind-speed trend. These changes may influence evapotranspiration, atmospheric moisture exchange, pollen and seed dispersal, vegetation dynamics and habitat conditions.

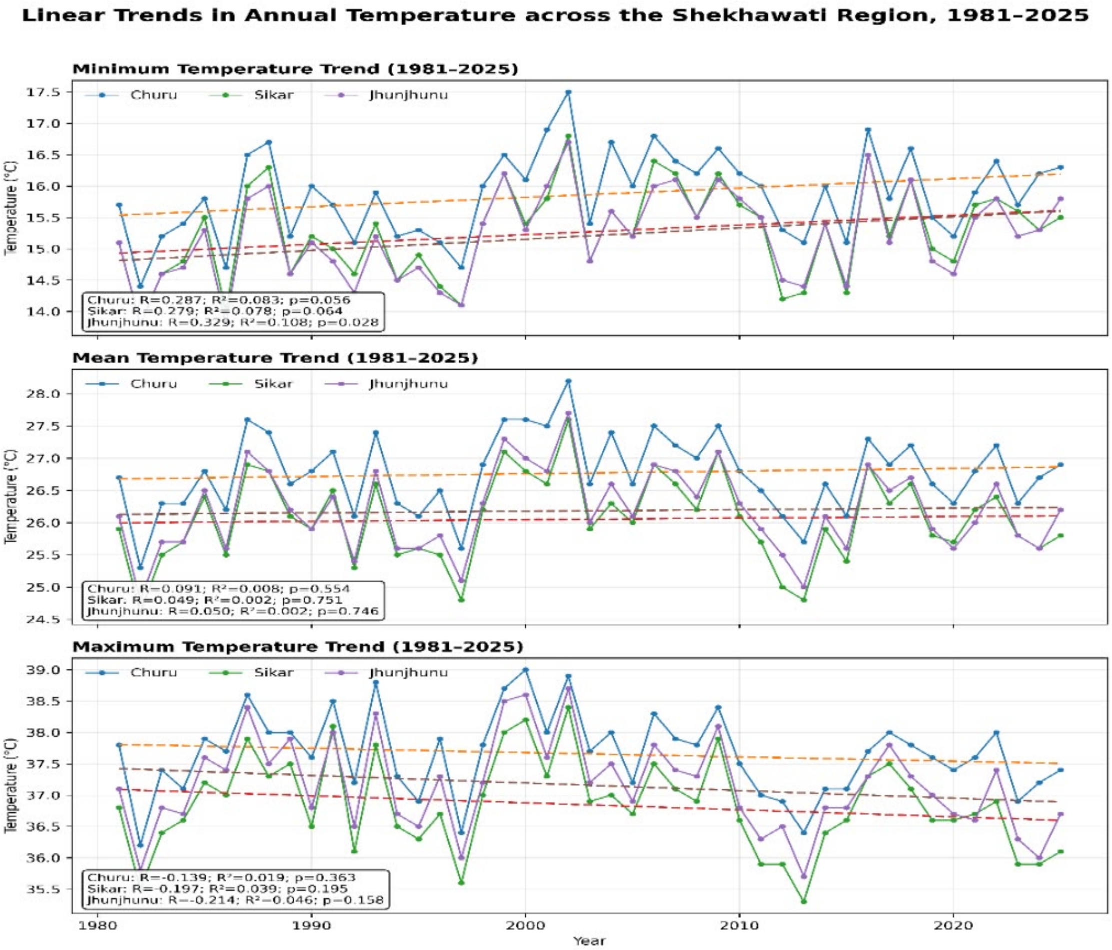

Fig.1: Annual minimum, mean and maximum temperature of Shekhawati Region

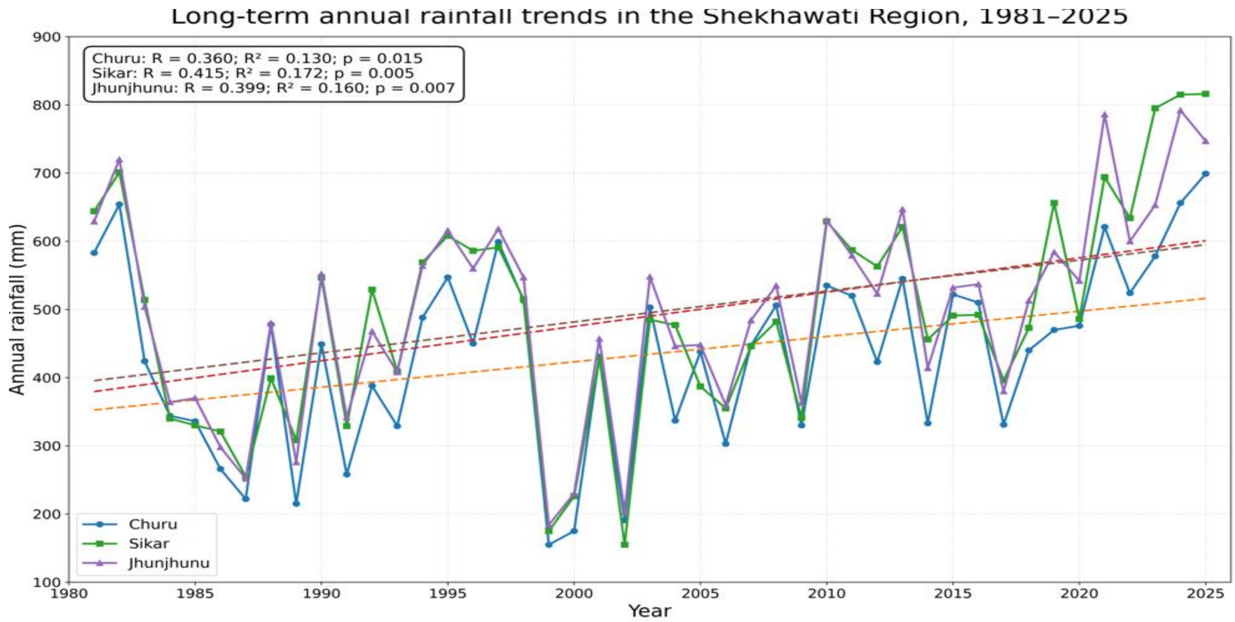

Fig.2: Annual Rainfall of Shekhawati Region

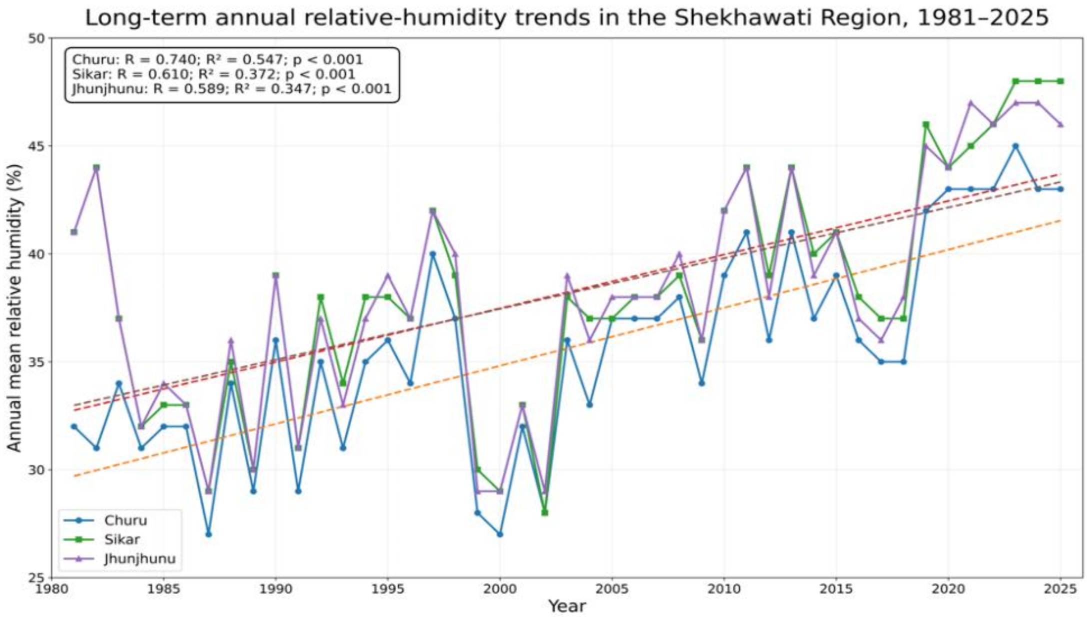

Fig.3: Annual relative humidity of Shekhawati Region

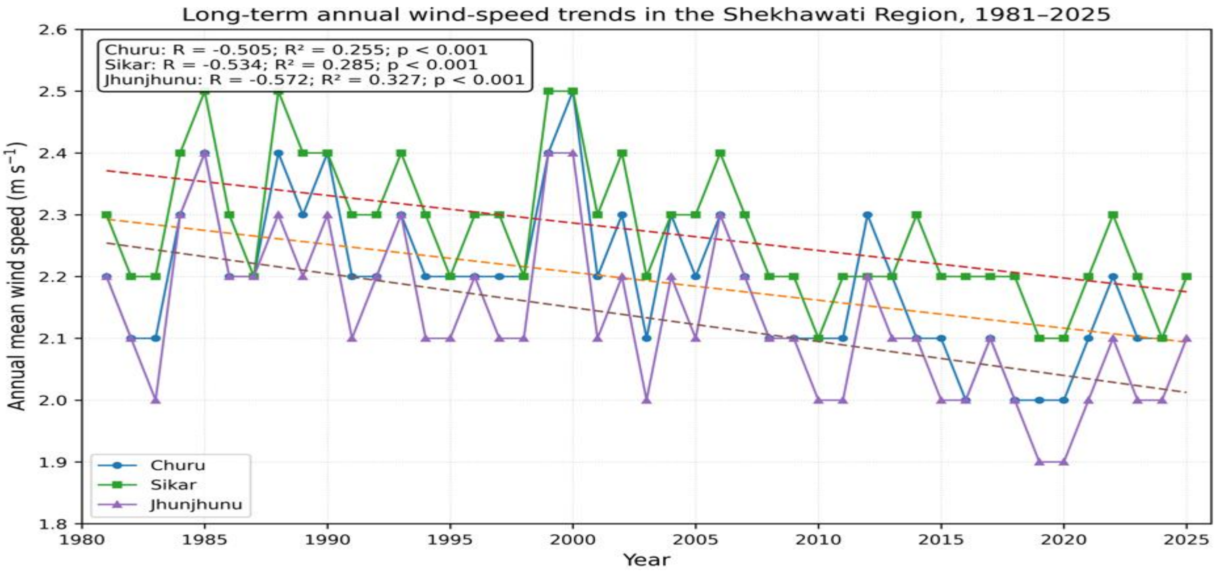

Fig.4: Annual wind speed of Shekhawati Region

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