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Title of the study

ARIMA BASED TREND PREDICTION AND MODELLING OF RAINFALL AND TEMPERATURE- A SPATIO-TEMPORAL ANALYSIS OF GUJARAT, INDIA

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Abstract

The unprecedented acceleration of global climate change in recent decades has been reflected in increasing global temperatures, with rates increasing from 0.08°C per decade since 1880 to 0.18°C since 1981. This rapid warming has led to substantial disruptions in environmental systems, evident in global temperature shifts, altered rainfall patterns, and the increasing frequency and intensity of extreme weather events. Fundamental variables like temperature and rainfall are crucial indicators of these changes due to their extensive long-term datasets and their measurable impacts on water resources, agriculture, ecosystems, and infrastructure. The IPCC AR6 report highlights a 1.09°C increase in global surface temperatures between 2011 and 2020 compared to pre-industrial levels. With every additional increment of global warming, extremes, and risks intensify. For example, every 0.1°C increase leads to discernible increases in the intensity and frequency of temperature and rainfall extremes. The World Meteorological Organization projects a 66% chance that global near-surface temperatures will exceed 1.5°C above pre-industrial levels for at least one year between 2023 and 2027, highlighting the urgent need for climate mitigation. Surpassing the 1.5°C threshold could trigger critical climate tipping points, leading to abrupt, irreversible, and potentially catastrophic consequences for humanity, with mainly severe impacts on vulnerable regions worldwide. South Asia, particularly prone to climate extremes, faces severe economic and humanitarian consequences, with India standing out as one of the most affected nations. Between 1901 and 2018, India experienced a 0.7°C increase in average temperature. In 2019 alone, it was ranked the 7^{th} most affected country by climate-related extreme events, reporting 2,267 fatalities and $66.18 billion in economic losses. India's dependence on the Southwest Monsoon (SWM), which accounts for 80% of its annual rainfall, adds to its vulnerability, as spatiotemporal variability in SWM patterns intensifies water scarcity and disrupts agriculture and power generation. This reliance, combined with global temperature increases, intensifies the unpredictability of the SWM, leading to hydrological extremes such as floods and droughts, with average annual flood-related losses of $3 billion or 10% of global economic flood losses.

Among all the mainland states of India, Gujarat is particularly vulnerable to climate risks due to its extensive coastline and frequent exposure to extreme weather events. It is also ranked among the top 50 regions globally facing high climate risk, as highlighted in the 'Gross Domestic Climate Risk' report by the Cross Dependency Initiative. Despite its proximity to the Arabian Sea, Gujarat predominantly experiences a dry, arid to semi-arid climate across most of its areas, largely due to its proximity to the Thar Desert in the north. The increasing

variability in climate patterns has substantial implications for water resources, agriculture, and human livelihoods, necessitating region-specific assessments of future climate scenarios. The state is divided into five physiographic regions: Central Gujarat, Kutch, North Gujarat, Saurashtra, and South Gujarat, each exhibiting distinct climatic conditions with significant spatiotemporal variability in temperature and rainfall distribution. Overall, rainfall gradually decreases while temperature increases from the southwest to the northeast of Gujarat, placing the northwest part, Kutch, at greater risk of aridity and drought. The frequency of rainy days also varies, ranging from approx. 24 days in Kutch to over 80 days in South Gujarat. Droughts are a frequent occurrence, with two to three events every five years and a severe drought striking roughly once a decade. Between 1981 and 2010, Gujarat experienced 15 major droughts, as reported by the IMD, with some affecting up to 80% of the state's land area. Besides, Gujarat faces a substantial risk of waterlogging from floods, with the last two decades being particularly severe, as various parts of the state have experienced recurrent and intense flooding. The state is increasingly prone to other extreme events, such as cyclones and heatwaves, which have become more frequent and intense in recent decades. Projections indicate that the frequency and intensity of these extreme events will likely continue to increase, highlighting the urgent need for effective climate adaptation and mitigation strategies.

To address these challenges, the study utilises 60 years (1961-2020) of high-resolution dataset from IMDLIB to analyze trends in rainfall, temperature, and their extremes using conventional methods, such as the Mann-Kendall test and Sen’s Slope estimator, along with contemporary approaches like the Innovative Trend Analysis (ITA). Besides, a 3-month running mean of ERSST.v5 SST anomalies in the Niño 3.4 region (Oceanic Niño Index, ONI) and the Indian Ocean Dipole Mode Index (DMI), which influence the studied climate variables, were incorporated from NCEP's Climate Prediction Center, spanning six decades. Future values are forecasted using Auto Regressive Integrated Moving Average (ARIMA) or Seasonal ARIMA models, with the best-fit model determined by minimizing the Akaike Information Criterion (AIC) and validated using performance metrics such as Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). Furthermore, the study identifies regions likely to experience future water deficits or surpluses, providing insights to support enhanced planning and adaptation strategies for addressing the challenges of climate variability and extremes.

The study highlights disparities between the ITA and conventional trend analysis tests, with ITA proving particularly effective in detecting complex rainfall trends. However, similar findings were observed for temperature trends across methods. The results indicate increasing annual rainfall and temperature trends across all regions, with seasonal variations. The findings also highlight an increasing frequency of extreme events, such as heatwaves and Rather Heavy to Extremely Heavy Rainfall (RHTE), while severe cold events are becoming less frequent. Forecasts project a substantial increase in annual and SWM rainfall across regions, with annual rainfall increasing by 67.5%, 52.7%, 8%, 7.1%, and 5.9% for Saurashtra, Kutch, Central Gujarat, South Gujarat, and North Gujarat, respectively, compared to the observed mean. Although winter and pre-monsoon seasons contribute negligible to annual rainfall, they exhibit high variability, with Kutch, Saurashtra, and North Gujarat projected to experience increases of 85.6%, 42.7%, and 32.4%, respectively, in winter, while South Gujarat is expected to decline by 14.5%. During pre-monsoon, most regions will experience a decline, except Kutch and Saurashtra, with increases of 347.1% and 58.2%, respectively. For post-monsoon, South Gujarat is expected to experience an 87.4% increase, followed by Kutch at 39% and Saurashtra at 29.8%, while Central Gujarat and North Gujarat will decline by 35.9% and 15.3%, respectively. Despite seasonal variations, overall annual rainfall projections indicate increases across all regions. Similarly, temperature trends show a consistent increase in both Tmin and Tmax across all regions, with projections indicating an average annual temperature increase of 0.5-0.8°C by mid-century compared to the observed mean. Kutch and Saurashtra, in particular, are expected to exceed the 1°C threshold for mean annual temperatures, highlighting significant climate risks. The results also show evolving water balance patterns, with July and August consistently exhibiting a surplus. However, September reveals a shift, with Kutch and North Gujarat transitioning from a negative to a positive water balance by mid-century.