Impact of Droughts on Agriculture Using SPI: A Case Study of Potohar Region, Punjab (Pakistan)

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https://doi.org/10.62345/jads.2025.14.3.100

Abstract

Drought is a complex phenomenon that can significantly impact agricultural production. This study aimed to assess the impact of drought on agriculture in the Potohar region of Pakistan using the Standardised Precipitation Index (SPI) for 30 years from 1986 to 2015. Monthly precipitation data were obtained from meteorological stations in Rawalpindi and Jhelum districts to calculate SPI values and analyse drought severity. The impact of SPI on the production of five major crops, rice, maize, bajra, jowar, and barley was investigated. The results showed that drought conditions, indicated by negative SPI values, often led to decreased crop production in both districts. In Rawalpindi, severe drought years such as 1988, 1990, 2002, and 2008 coincided with reduced yields of maize, bajra, and jowar. Similarly, in Jhelum, drought years such as 1986, 1992, 2006, and 2012 were associated with declines in rice and maize production. The Rawalpindi and Jhelum districts exhibit distinct seasonal precipitation patterns, underscoring the region's strong dependence on monsoon rainfall. July and August consistently show high SPI values, often exceeding 2.0, indicating intense wet spells and heavy monsoonal rain. A minor inconsistency was noted in Jehlum where 1999 was mentioned alongside 2014. The findings suggest that drought is a major limiting factor for agricultural productivity in the Potohar region. Climate change is expected to make droughts more severe and frequent, seriously jeopardising food security and rural livelihoods. Policymakers and stakeholders should prioritise investments in drought-resistant crop varieties, water-conservation techniques, and farmer capacity building to enhance the agricultural sector's resilience to drought stress.

Keywords: Agricultural Production, Potohar Region, Drought, Climate Change, SPI.

Introduction

Drought, defined as a prolonged period of deficient rainfall, is a complex climatic event with significant socio-economic, agricultural, hydrological, and environmental impacts (Nair et al., 2024). Globally, droughts are becoming more frequent and intense due to climate change, severely affecting water resources, food security, and human livelihoods (Jahura et al., 2024). Regions such as South Asia, including Pakistan, are particularly vulnerable due to their climatic variability and agricultural dependence.

In Pakistan, droughts frequently affect both arid and semi-arid regions, with the 1998–2002 drought among the most devastating (Usama et al., 2024). The Potohar region, comprising districts such as Rawalpindi, Chakwal, Jhelum, and Attock, is characterised by rainfed agriculture and is highly sensitive to rainfall variability. Given its dependence on monsoon rains, droughts in this region significantly impact crop production, particularly wheat, maize, barley, and groundnuts.

The establishment of the National Drought Monitoring Centre by the Pakistan Meteorological Department in 2005 aimed to improve drought monitoring and provide early warning (Black et al., 2024). Despite this, limitations in localised data and institutional coordination persist, affecting timely response and mitigation.

Materials and Methods

The Potohar is situated between around 72˚E and 74˚E longitude and between roughly 32.5˚N and 34.0˚N latitude. (Adnan et al., 2024). This area is located between the Jhelum and Indus river. From the Himalayas to the northern edge of the salt range, it is further expanded. The majority of Jhelum and Rawalpindi were also included in this area. (Kahlon et al., 2021). The Potohar region has 28488.9 square kilometres in total. The Potohar region's primary crops include barley, bajra, wheat, gramme, maize, and groundnuts (Adnan et al., 2024).

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Compliance with ethical standards: There are no conflicts of interest (financial or non-financial). This study did not receive any funding.

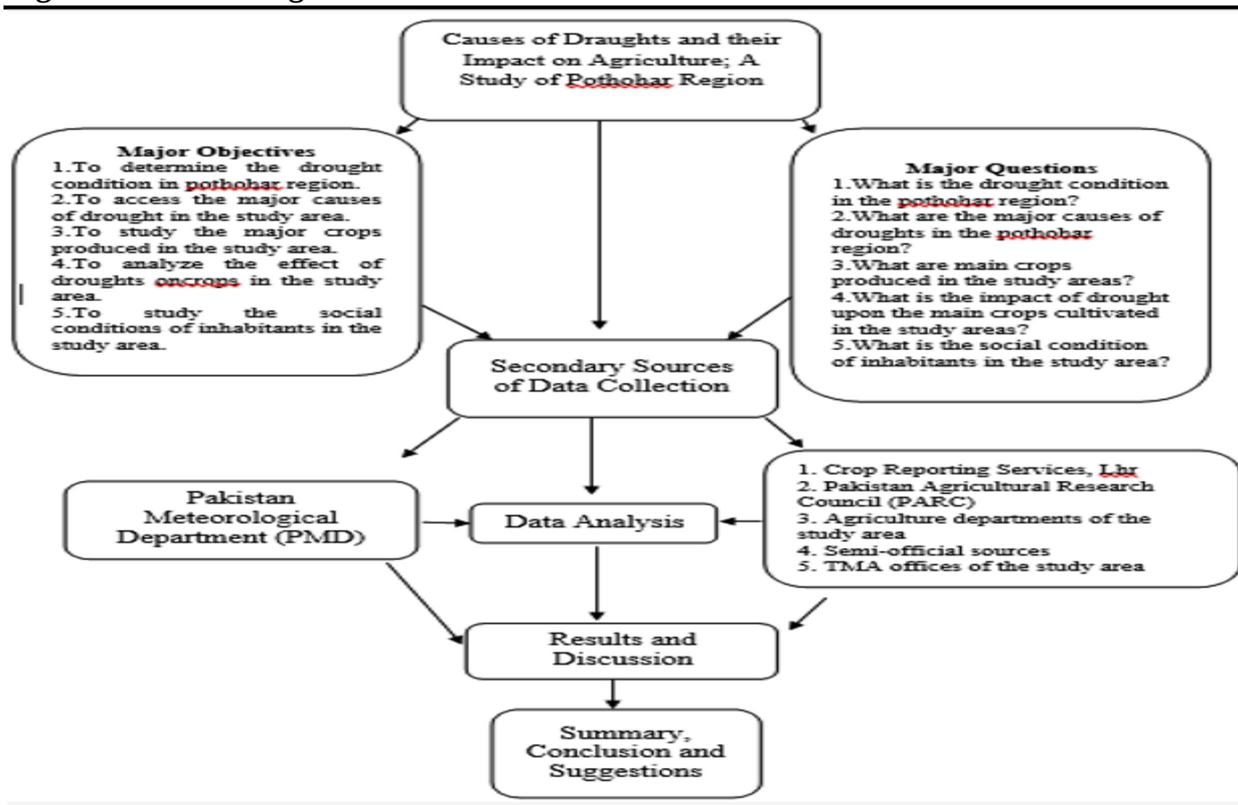
Figure 1: Map of the study area of Potohar Region, Punjab

This study focuses on analyzing the severity, causes, and agricultural impacts of drought in the Potohar region of Pakistan using a quantitative, secondary data-based approach. The methodology includes interpretation of research questions, data collection strategies, and the analytical framework applied. The Potohar region was selected due to its representative agricultural landscape and vulnerability to drought. The choice was based on personal interest and the region's agricultural and socio-economic importance. Key parameters included meteorological data (rainfall and temperature) and agricultural crop production data (wheat, maize, barley, bajra, rice, and jowar).

Data Acquisition

Secondary data were collected from Pakistan Meteorological Department (PMD**)** for climate data spanning 30 years., Pakistan Agricultural Research Council (PARC) and Crop Reporting Services for crop data, Pakistan Bureau of Statistics for supporting statistical information. The Standardized Precipitation Index (SPI) was used to quantify drought severity (Raziei & Pereira, 2024). SPI values were calculated using historical rainfall data. Negative SPI values indicated drought severity levels—ranging from moderately to extremely dry—while positive values indicated wet conditions. This index provided a standardized method for tracking drought intensity over time (Wei et al., 2021).

Figure 2: Methodological framework



Data Analysis

The Standardized Precipitation Index was developed by McKee et al. (1993). SPI adapts a mathematical function to the historical precipitation data and does its calculations solely using precipitation data. Because the fitting function standardizes the data, the SPI is intended to be comparable across time and space. Precipitation is the only basis for the SPI. The key strength of SPI' is its capability to be calculated across various time frames. Droughts may also be easily detected and tracked during the duration of the drought for specific places.

A long-term monthly precipitation database with at least 30 years of data is necessary to calculate the SPI for a given time period at any location. By fitting a function to the data, the probability distribution function is derived from the long-term record. When the SPI consistently falls and hits a value of -1.0 or lower, it is referred to as a drought event. (McKee et al., 1993; Paulo and Pereira, 2006). Figure 3 shown a visual depiction of drought features. McKee et al. (1993) defined drought intensities using a categorization scheme based on SPI values, as shown in figure 3.

In order to determine the drought severity index for the Jhelum and Rawalpindi districts, which are located in the Potohar Region, the precipitation records for these districts were received from the Pakistan Meteorological Department (PMD) and entered into the following mathematical formula:

$$SPI = \frac{X - \ddot{X}}{\sigma} \quad \text{...} \quad (i)$$

Where: σ = Standard deviation

Hence,

$$S.D. = \sqrt{\frac{\sum(X - \ddot{X})^2}{n}} \quad \text{...} \quad (ii)$$

To determine the standard deviation for specific places, data is first altered. The SPI of the Rawalpindi and Jhelum districts is then determined using the formula and the given standard deviation values. Data analysis for the Rawalpindi and Jhelum districts from 1986 to 2015 is displayed in tables and histograms.

Results and Discussion

The monthly variation of the Standardized Precipitation Index (SPI) for each year from 1986 to 2015 in Rawalpindi district highlights fluctuations between drier-than-normal (negative SPI values) and wetter-than-normal (positive SPI values) conditions. Negative SPI values indicate the presence of drought, while positive values represent periods of above-normal precipitation. The calculation of SPI for Jehlum and Rawaplindi districts is comprised on long-term record of precipitation i.e.1989 to 2015 (30-Years). SPI positive values is showing greater than median precipitation and in positive form is showing less than median precipitation. A drought event takes place when the SPI is become negative always. Alike the event ends when the SPI turns into positive value resultantly. The Standardized Precipitation Index (SPI) classification, which indicates varying levels of moisture conditions based on numerical values. SPI values of 2 or more reflect extremely wet conditions, while values between 1.5 and 1.99 signify very wet periods, and 1 to 1.49 indicate moderately wet conditions. An SPI range from -0.99 to 0.99 is considered near normal, representing typical precipitation levels. Negative values point to dryness, with -1 to -1.49 classified as moderately dry, -1.5 to -1.99 as severely dry, and values -2 or lower indicating extremely dry conditions.

The 30-year SPI data (1986–2015) for Rawalpindi District reveals distinct seasonal precipitation patterns, highlighting the region's strong dependence on monsoon rainfall. July and August consistently show high SPI values, often exceeding 2.0, indicating intense wet spells and heavy monsoonal rainfall particularly notable in years like 1995, 2000, 2001, 2004, and 2010. In contrast, the pre-monsoon months (April–June) and post-monsoon/winter months (October–December) frequently exhibit negative SPI values, reflecting widespread dry conditions. Severe droughts (SPI ≤ -1.0) are observed in multiple years, including 1986, 1991, 1993, 2005, and 2009 (Figure 3). The overall trend shows that while monsoon months can temporarily offset dryness, most of the year remains prone to moderate to severe droughts, particularly in May, November, and December. This variability emphasizes the need for effective water management strategies, drought forecasting systems, and agricultural planning to mitigate the impacts of seasonal and long-term precipitation extremes in the region.

This study summarizes the monthly variation of the Standardized Precipitation Index (SPI) for Jhelum District from 1986 to 2015, based on a 30-year precipitation record from Rawalpindi maintained by the Pakistan Meteorological Department. The SPI values indicate drought conditions when negative (drier-than-normal) and wetter conditions when positive (wetter-than-normal). Each year's analysis includes a monthly SPI variation diagram and a corresponding table (Tables 6.2.1 to 6.2.30) presenting the SPI values derived from long-term precipitation data. Drought conditions are specifically identified in months with negative SPI values. The consistent methodology applied across all years ensures a standardized approach to drought monitoring. This analysis is crucial for understanding historical drought and wet spell patterns in Jhelum District, aiding in water resource management, agricultural planning, and climate studies. A minor inconsistency was noted where 1999 was mentioned alongside 2014.

Figure 3: Drought conditions from 1986 to 2015 using SPI (Rawalpindi District)

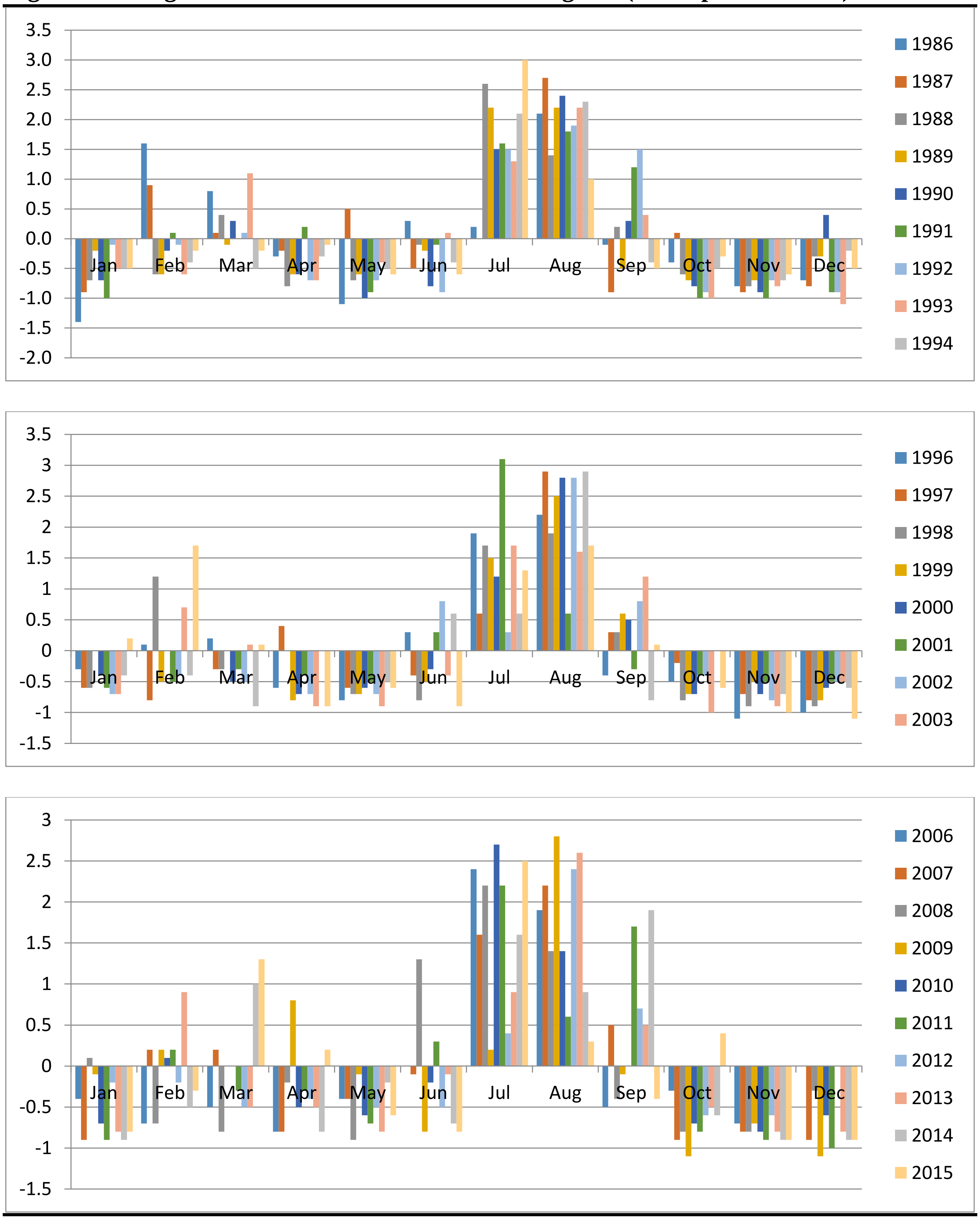
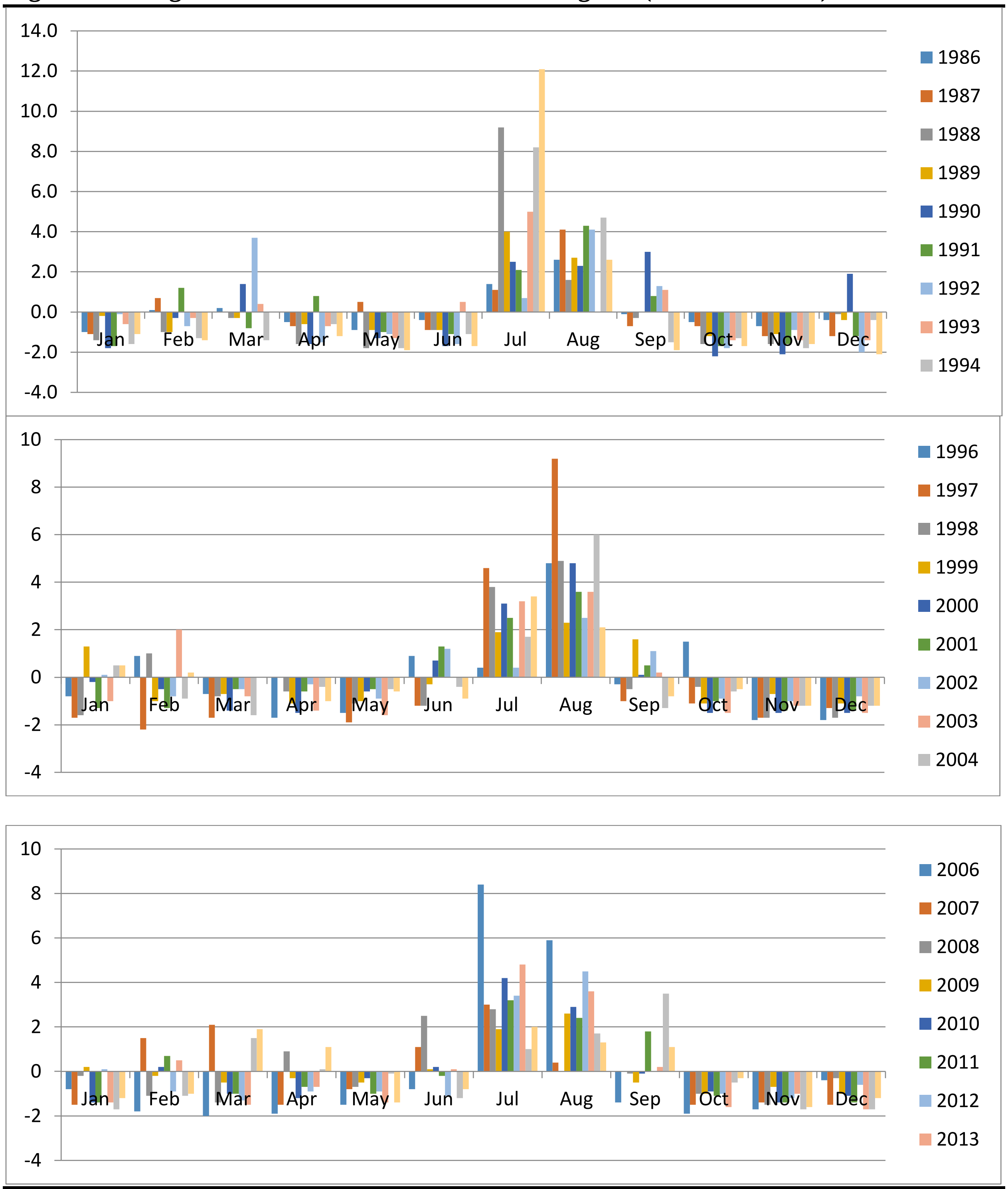


Figure 4: Drought conditions from 1986 to 2015 using SPI (Jhelum District)



Impact of SPI on Agriculture

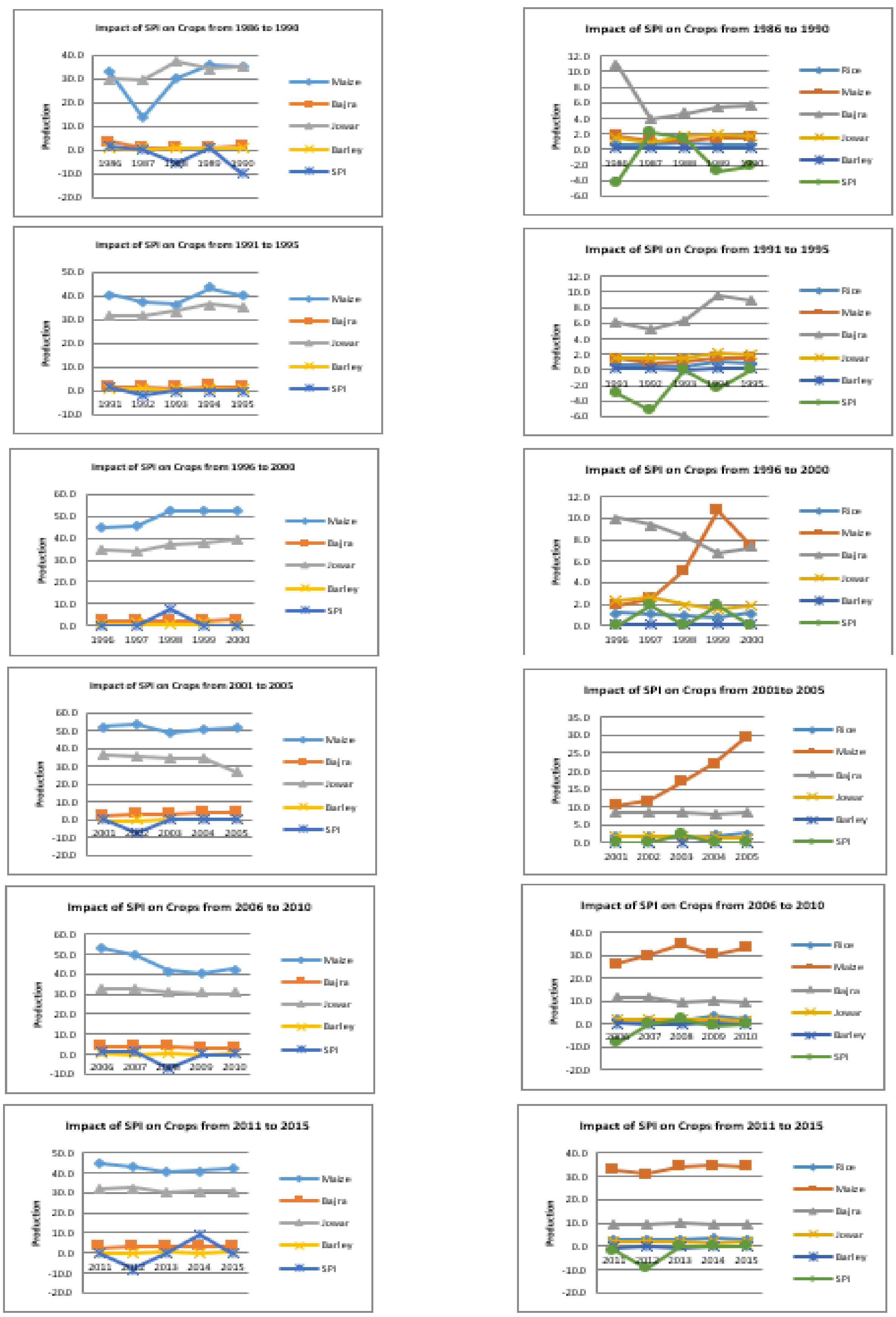
The weather and climate changes in a particular place have a direct impact on the agricultural goods produced there. It is anticipated that potential variations in precipitation levels would have a major effect on the agricultural growth in a given location. Climate change is currently one of the largest problems confronting the globe and future generations. The frequency and length of drought can be altered by variations in precipitation levels. Investigating the effects of the Standardized Precipitation Index (SPI) on the agricultural goods produced in Rawalpindi and Jhelum, two regions in northern Pakistan, is the goal of this study.

To investigate the impact of SPI on agricultural product, we select five agricultural products i.e.Rice, Maize, Bajra, Jowar and Barley. The SPI is used to measure precipitation shortage on the basis of volume of precipitation at different time scales of the specified areas.

The impact of Standardized Precipitation Index (SPI) on rice, maize, bajra, jowar and barley produced in the Rawalpindi district during year 1986 to 2015 is as under:

Figure 5: (SPI drought's impact on Agriculture in Rawalpindi and Jhelum districts 1986 - 2015)

Rawalpindi Jhelum



From 1986 to 2015, crop production trends in Rawalpindi district show significant fluctuations in relation to the Standardised Precipitation Index (SPI). Maize generally increased over time from around 33,000 tons in 1986 to above 40,000 tons in later years, though sharp declines occurred during severe negative SPI years (e.g., 1987, 1992, 2008, 2012). Bajra remained low but showed gradual improvement, rising from around 1–2 "000" tons in the late 1980s to above 3–4 "000" tons by the 2000s (Figure 5). Jowar production was comparatively stable between 30 38 and 000 tons, except for notable drops during drought years such as 2005 and 2008. Barley remained minimal (below 1.5 "000" tons) with slight decreases over time. The cultivated area for all crops generally expanded during the study period, especially for Maize, though production levels remained sensitive to rainfall variability as reflected in SPI values. Overall, the data highlight a strong association between negative SPI (drought conditions) and reduced crop yields, particularly for Maize and Jowar, while relatively stable rainfall supports higher yields.

From 1986 to 2015, agricultural production trends in Jhelum district show strong sensitivity to rainfall variability, as measured by the Standardised Precipitation Index (SPI). Rice production gradually increased from below 1.0 "000" tonnes in the late 1980s to around 3.0–3.4 "000" tonnes after 2010 (Fig. 4), while Maize rose sharply from less than 2.0 "000" tonnes in the 1980s to above 30 "000" tonnes in later years, reflecting both expanded cultivation area and improved yields. Bajra production fluctuated between 512000 tons, showing resilience but with notable reductions in dry years. Jowar remained relatively low (1.5–2.7 "000” tonnes) and Barley negligible (<0.2 "000" tonnes). Severe negative SPI years, such as 1986, 1992, 2006, and 2012, coincided with marked declines in Rice, Maize, and Jowar yields, while neutral or positive SPI years supported recovery in production. Overall, the data show a steady expansion of cultivated area for Maize and Rice, modest improvements for Bajra, and persistent low outputs for Jowar and Barley, with drought conditions consistently suppressing productivity across all crops.

Conclusion

The results varied between the two districts. In years when the SPI indicated severe drought conditions (highly negative values), decreases were seen in the production of certain crops compared to the previous year: In Rawalpindi, maize and bajra production decreased in 1988 and 1990, jowar decreased in 2002 and 2005, and barley decreased in some drought years in Jhelum, rice, maize, bajra, and jowar production declined in various years, with severe negative SPI values such as 1986, 1992, 2007, 2010, and 2012. Barley production remained constant at 0.1 in most years. The analysis suggests drought severity and its impact on agriculture may increase in the future without precautionary measures. Seasonality was found to be the most significant factor affecting the spatial accuracy of the results. The findings provide a valuable benchmark for further analysis on the effects of climate change in the region. Differences were noted between the two districts studied.

In conclusion, the SPI proved to be an effective tool to retroactively examine the impact of drought on agricultural production in the Potohar region over 30 years. The results can help inform drought mitigation and agrarian planning efforts. Further research should build upon this analysis to project future drought trends and impacts, and evaluate potential adaptation strategies for rainfed agriculture in the area. Recommendations include strengthening drought monitoring, improving water management, and adopting climate-resilient agricultural practices.

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