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Temporal trend analysis of crop area and production dynamics: A case study of Bhiwani district

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Abstract

Long-term trends in agricultural production are crucial for food security, economic stability and climate resilience. By studying the temporal trends in the surface and production of the three main crops, namely, rice, cotton and millet, from 2010 to 2021. By identifying monotonous trends and rates of change through statistical and non-parametric methods, such as the Mann-Kendall trend test and the slope estimator of Sen. The results show a statistically significant positive trend in the surface of rice ($Z = 3.58, p < 0.01$) and the production ($Z = 3.81, p < 0.01$), with an annual growth rate of 35,27 hectares and 187,17 units of production, respectively. The cotton surface showed a significant upward trend ($Z = 2.80, p < 0.05$), which represents instability in the yield. In both sets of data, Mijo showed no trend in surface production over the long term (since interannual variability was observed). The results indicate a trend towards an increase in the cultivation of dry land rice, a limited commercialization associated with the cultivation of cotton and stagnation in the growth of traditional dry land crops. These structural changes have important implications for the future sustainability of resources, in particular the policies of adaptation to climate change and groundwater. The study reiterates that the diversity of farming systems is crucial for long-term agricultural resilience.

Keywords: Temporal trend analysis, Mann-Kendall test, Sen's slope, agricultural production, cropping pattern, rice, cotton, Bajra, non-parametric statistics

Introduction

Agricultural production systems around the world are experiencing a rapid transformation due to technological advances, political changes, the integration of markets and climate change. The analysis of temporal trends in the surface and production of crops helps to understand the structural changes in agricultural systems and their sustainability trajectories. The identification of statistically significant trends is fundamental to understand whether trends and fluctuations indicate a long-term transformation or a short-term variability. Rice, cotton and millet constitute three different agricultural categories: basic irrigation crops, commercial crops and traditional dryland cereals, respectively. Their analysis helps to understand agricultural intensification, commercialization and sustainability from a comparative perspective. Although the general temporal perspective covers two decades, this analysis will be based on the data available from 2010 to 2021. This study uses non-parametric statistical methods, commonly employed in the environmental and agricultural sciences, to analyze monotonous trends and annual rates of change.

Objectives

The objectives of this study are to:

- Detect trends in area and production for Rice, Cotton, and Bajra.
- Quantify annual rates of change.
- Compare structural changes across crops.
- Discuss sustainability implications.

Literature Review

The analysis of temporal trends has turned into a key tool in agricultural research to examine long-term changes in crop area, production and yield patterns. A non-parametric technique widely used in this field is Mann-Kendall's trend test, combined with Sen's slope estimator. This combination allows researchers to identify trends in time series data without the need to assume a normal distribution of the data.

These methods have frequently evaluated climatic impacts, the production trends and the yield of crops over a long period of time in different areas, such as the analysis of precipitation trends and yield of rice in the south of Bengal Occidental. Various studies have used trend analysis to measure rice production patterns over long periods. Kumar *et al.* (2025) ^[4] examined the trend patterns of rice production in the main growing states of India. The use of linear, exponential models reveals that the estimation of trends based on these models can highlight various aspects of changes in crop production over a long period of time. Also evaluating the fit of the model RMSE and the R^2 with statistical measures. Similarly, Annamalai and Johnson (2023) ^[1] used time series models, including ARIMA, to analyze the area of rice cultivation. Their work demonstrated that traditional time series models can effectively predict future trends and support agricultural planning. These studies highlight the importance of analyzing time series to identify underlying trends and anticipate future agricultural conditions.

The trend analyzes conducted at the state and regional level have provided important information on agricultural production sustainability. For example, Panwar and Dimri (2018) ^[6] conducted a long-term analysis of the production and productivity of crops in Haryana during fifty years. Their findings indicate significant transitions from secondary cereals to fine cereals, in particular wheat and rice, driven by intensification and the greater use of inputs. This underlines the dynamic nature of farming systems, conditioned by economic and political factors. Additionally, regional studies in arid and semiarid zones have applied statistical methods to evaluate the dynamics of crops in multiple districts. These studies reveal spatial diversification and the evolution of crop combinations over long periods of time, reflecting changes in adaptation and efficiency in response to environmental limitations.

The relationship between climate change, atmospheric time and crop trends has been exhaustively investigated within the framework of research with trend analysis. Choudhury *et al.* used the Mann-Kendall test with long-term meteorological data to evaluate temperature and precipitation trends, subsequently examining their effects on rice and jute yields and identifying associations between climatic trends and crop yields. Another study conducted in Bangladesh combined the trends analysis with the detection of all the change points and used regression modeling to evaluate the influence of change in climatic variables, rain and intensity of cultivation on the dynamics of rice yield, highlighting that the long-term trends of these climatic factors interact substantially with agricultural production. Taken together, these studies highlight the need to integrate climatic factors into the analysis of temporal trends in agricultural production of various crops.

Beyond individual crops, trend analyzes of cereal farming systems illustrate the temporal behaviors among different crop types. For example, a study of time series on cereal production in Ethiopia, which used the Mann-Kendall test and the ARIMA method, showed that the main cereals showed increasing production trends over a period of two decades, demonstrating the wide applicability of the time series methods in cereal crops beyond the main crops like rice and wheat. This supports the applicability of intercultural trend tests to understand the dynamics of production over the long term. The analysis of spatio-temporal trends has further enriched the investigation of

agricultural trends by integrating satellite data to detect changes in the cultivated area. A study in Nepal used MODIS temporal series and phenological algorithms to detect significant decreases in the surface area of rice cultivated over a decade, demonstrating how teledetection temporal series can improve the detection of trends in different landscapes. Additionally, studies that combine the analysis of trends with drought occur indices and residual series of crop performance have provided systematic evaluations of how changes in environmental conditions influence long-term performance trends in multicultivation systems. In summary, the literature review supports the use of non-parametric methods of temporal trends, such as the Mann-Kendall test and Sen's slope estimator, in agricultural research to detect long-term patterns in the surface and production of crops. The research applications cover the production of rice and cereals, the evaluations of regional productivity, the integration of climatic variables and forecasting approaches, which demonstrates both the methodological solidity and the contextual adaptability. These studies, together, highlight that trends in agricultural production are conditioned by a complex interaction between agronomic practices, climatic variability, political environments and market forces, which requires integral frameworks of temporal analysis in the research of agricultural systems.

Materials and Methods

Data Description

Time-series data collected annually for area (hectares) and production were analyzed for three crops (Rice, Cotton, Bajra) from 2010-11 to 2020-21. The dataset consists of eleven observations for each variable.

Statistical Framework

Given that agricultural production data of all the crops often exhibit non-normal distributions and potential outliers, non-parametric methods were employed.

Mann-Kendall Trend Test

The Mann-Kendall (MK) test is a non-parametric method which is based on ranks that is used to detect monotonic trends in time series data. It evaluates the relative order of the data points collected without assuming normality.

The null hypothesis (H_0) states that there does not exist a monotonic trend. The alternative hypothesis (H_1) states that there exists a monotonically increasing or decreasing trend. To calculate a standardized statistic, the statistical significance is determined at $\alpha = 0,05$ ($|Z| > 1,96$) and $\alpha = 0,01$ ($|Z| > 2,58$).

Sen's Slope Estimator

Sen's slope estimator quantifies the magnitude of a trend. It calculates the slopes between all possible data pairs and determines their median value. This method is more robust against outliers and skewed distributions.

Results

Rice

Area under Rice

The MK test indicates a statistically significant increasing trend in the surface area of rice ($Z = 3,58$, $p < 0,01$). The mountain slope suggests an annual increase of 35,27 hectares.

The surface area of rice increased from 1243 hectares in year 2010-2011 to 1525.77 hectares in year 2020-2021. This monotonous ascending pattern reflects a sustained agricultural intensification and the probable irrigation facilities expansion. The consistency of this growth suggests a structural transformation rather than a short-term fluctuation.

Rice Production

The production of rice showed a highly significant upward trend ($Z = 3,81, p < 0,01$). The slope of Sen indicates an annual increase of 187.17 units of production.

The production increased from 3465 units to 5633.5 units during the study period. The rate of growth of production exceeded the expansion of cultivated surface, implying improvements in yield. This suggests the adoption of improved varieties of seeds, mechanization, a greater use of fertilizers and better agronomic practices.

Cotton

Cotton Area

The area of cotton showed a statistically significant increasing trend ($Z = 2,80, p < 0,05$), with a slope of 1.5 which indicates an annual expansion of 18,57 hectares.

The surface area increased steadily during this study period, suggesting commercialization and diversification of all the crops. However, the fluctuations indicate the sensitivity to market and various environmental conditions.

Cotton Production

Cotton production did not show a statistically significant trend ($Z = -0,47, p > 0,05$). The slope of Sen indicates a slight negative variation (-17.78 units annually), although not statistically significant.

The production series shows a considerable interannual variability, including a marked decline in 2015-2016. This instability can be attributed to plagues, irregularities in precipitation and volatility of prices. Despite the expansion of the surface, the absence of a constant growth of production indicates instability in the yield.

Bajra

Bajra Area

No significant monotonic trend was observed in the surface of the mice ($Z = 0,00, p > 0,05$). The slope of the mountain indicates an insignificant annual change (2,01 hectares per year).

The surface initially decreased, but stabilized in later years, reflecting the effects of crop substitution, followed by a partial recovery.

Bajra Production

The production of millet did not show a statistically significant trend ($Z = 0,15, p > 0,05$). The slope of Sen suggests a modest increase of 12,43 units annually.

The variability of production seems to be closely related to rainfall patterns, which is in agreement with the drought-prone nature of the crop.

Discussion

The results revealed different agricultural trajectories for these crops. Rice shows an increase in productivity, which reflects a structural transformation towards rainfed agriculture. Cotton shows an expansion of cultivated area

without stable increases in production, indicating vulnerability to environmental, climate and economic risks. Millet remains relatively stable, and hence highlighting its role as a climate-resilient secondary crop.

The increasing dominance of rice suggests a possible subterranean hydrological stress in all areas. Cotton requires better pest management strategies to stabilize yields. Millet offers sustainability potential in conditions of climatic variability and deserves political attention.

Comparative Crop Performance

A comparative evaluation of the temporal trends reveals distinctive patterns among the three crops:

- Rice shows a solid and statistically significant growth in both surface area and production.
- Cotton shows a significant expansion of the surface, but not a significant trend in production.
- Millet remains relatively stable, with no significant long-term trend either in surface area or in production.

The results indicate a gradual transformation of the cropping pattern towards rainfed and high-value crops, in particular rice in this case. The expansion of rice cultivation suggests an intensification of agriculture area, while the stagnation of maize may relieve a lesser importance of traditional dryland crops.

Implications of Temporal Trends

The observed trends have important agricultural and environmental implications:

- The expansion of rice area could increase the pressure on underground water resources.
- Cotton cultivation requires yield stabilization strategies to reduce vulnerability.
- Millet, although resilient to climate, offers potential for sustainable agriculture in changing climatic conditions.

These results emphasize the need for a balanced planning of crops to guarantee long-term agricultural sustainability.

Conclusion

The analysis of temporal trends from 2010-11 to 2020-21 reveals:

- A statistically significant increasing trend in the surface area and production of rice.
- A significant increase in the surface area of cotton, but without significant changes in production.

No statistically significant long-term trend is observed in the surface and production.

Rice has consolidated as the most stable and valuable crop in the district, while cotton shows instability in production despite the expansion of the area. Millet remains relatively stable, but in secondary importance.

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