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Advanced Intelligent Systems for Quantitative Analysis of Crop Production and Efficiency in Maharashtra

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Abstract: Agriculture plays a pivotal role in the economic growth of any country, and India is no exception. Approximately 70% of India's population depends on agriculture, either directly or indirectly. According to the Ministry of Agriculture and Farmers Welfare, the agricultural and allied sectors contribute 20.2% to the total economy's Gross Added Value (GAV), per the Provisional Estimates of Annual National Income. Given India's dense population, ensuring optimal crop production is essential to meet the nation's food demand. This study focuses on the correlation between crop production and temperature in Maharashtra, a key agricultural state. Maharashtra produces a variety of crops, including staple cereals like jowar, rice, and wheat, as well as pulses such as gram, tur, and urad. It is also a significant producer of oilseeds, including groundnut, sunflower, and soybean. Additionally, important cash crops like sugarcane, cotton, and turmeric contribute to the state's agricultural economy. As climate factors like temperature play a critical role in crop growth, this study aims to analyze how temperature fluctuations affect the yield and efficiency of various crops in Maharashtra to optimize agricultural productivity to support economic growth and food security.

Keywords: Crops Analysis; Temperature and Agriculture; Maharashtra Climate Change; Productivity and Irrigation Projects; Rainfall and Crop Production; Gross Added Value (GAV).

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1. Introduction

Climate change has a major impact on human life directly and indirectly. Even the smallest changes in climate conditions or patterns can cause a cascading effect on all ecological systems. Small changes in climate will majorly affect agriculture; the effect on agriculture directly impacts humans. Climate change also affects other ecological systems, such as the migration of animals and many other things [1]. India is a country where 70% of its population depends on agriculture for its livelihood. Thus, agriculture is a matter of high importance. Although the country is agriculture intensive, there still needs to be a lot of development in the agriculture sector. Many parts of India still grow crops using older methods and fail to commit to modern standards. Crop yield is much lower than the optimum production [2]. The government of India acknowledges the importance of Agriculture in many ways. One way is through priority finance. There is a guideline that the banks need to follow, which states that 18% of the Adjusted Net Bank Credit must be met through agricultural lending. The government has also introduced multiple reforms in the marketing of agricultural produce and support for irrigation projects and its allied sectors [3].

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In India, the crops are divided into two major categories. The first one is food crops. Some of the major food crops that are grown in India are rice, wheat, millets, maize, pulses, sugarcane, oilseeds (major ones include groundnut, mustard, coconut, sesamum (til), soybean, castor seeds, cotton seeds, linseed and sunflower), tea, coffee and also horticulture crops (major one are mangoes from states like Andhra Pradesh, Maharashtra and West Bengal, oranges from Meghalaya and Nagpur, bananas from Mizoram, Kerala, Tamil Nadu and Maharashtra, litchi and guava from Bihar and Uttar Pradesh, pineapples, grapes, apples, pears, apricots and walnuts from various other states)[4]. The second one is cash crops. Some major cash crops are cotton, sugarcane, jute, groundnut, rice, wheat, millets, maize, pulses and tea. This paper aims to study the production of major crops that are grown in India, specifically in the state of Maharashtra. The study will relate the yield of crops to varying mean temperatures.

2. Review of Literature

Talhar et al., [5] analyzed rainfall patterns in different regions of India. They took into account four talukas with contrasting rainfall from low to high. The four talukas are Thane, Phulambri, Atpada (regions with low to moderate rainfall in India) and Mahabaleshwar (region with highest rainfall in India). Analysis and forecasting were done using statistical, Machine Learning and deep learning approaches on data from 1998-2018. They predicted rainfall till 2025.

Sharma et al., [6] conducted a survey comprising 39 papers relating to crop production and its different areas that implement machine learning algorithms and image processing computations. Then, they propose a model to study the maturity of crops using image processing and machine learning techniques.

Aslam et al., [7] studied the efficiency of wheat and rice production in China, India and Pakistan. They used a data envelopment analysis model, which concluded that India and China are relatively more efficient in wheat and rice production. At the same time, Pakistan was the country that produced the least amount of CO_2 emissions during the period of study.

Abishek et al., [8] considered most of the important factors like land evaporation, transmission rates, groundwater, humidity and temperature to determine the effective rainfall and predict crop water needs in Bijapur, a district in Karnataka, to maximize the yield of crops and to tackle problems like over-irrigation in that area.

Much research has been conducted in the area of crop yield prediction. There are multiple approaches in this domain. Jayakumar et al., [9] proposed a climate-based regression model for forecasting crop yield. They considered coffee the crop to focus on in India’s humid tropical region of Kerala. Gandhi et al., [10] used the Support Vector Machine algorithm to predict rice crop yield. Khosla et al., [11] used aggregated rainfall-based modular artificial neural networks and SV algorithm to predict Crop yield. Other techniques include data mining, neural networks, and algorithms like SARIMA [12]; [13]; [14].

Many researches have also been conducted to study the impact of climate change on crop production. Some of these include research done by Bhatla et al., [15] study the variability of monsoon season in regions of India using regional climate models; Sharma and Sai Sabitha [16] used data mining to identify factors for productivity and sustainability of crops. Many research studies have been conducted in this area [17]; [18]; [19]. Machine learning is not only used in prediction but also classification. Koppaka and Moh [20] have used machine learning and satellite image processing to classify Indian crops.

Then, there have also been studies that conducted breakpoint analysis and tipping point analysis on the productivity of crops [21]; [22]. Rajasekaran et al., [23] studied the growth and stagnation of agriculture in Bangladesh and Eastern India. All the mentioned research has been directed towards crops and climate; Masih et al., [24] took a different approach and studied crop production from an economic standpoint in the Ganga region of India and assessed the water resources and crop yield for future climate scenarios in the Warangal district of Telangana in India. They used the SWAT (Soil and Water Assessment Tool) and RCMs (Regional Climate Models) models. Their findings show that the district’s cotton crop is threatened as the model predicted increased rainfall events and its extremity.

3. Data

The data used in this research comes from two sources. The first source provides temperature and relative humidity data for Maharashtra. Temperature data is collected daily and divided into many parts. Mean Temperature, Temperature 2m above ground level, minimum temperature and maximum temperature of a place are given for each day. This data is available at geographical coordinates. Data points are to the longitude and latitude of the respective places in Maharashtra. The second dataset is aggregated. This data comprises monthly crop production numbers from various districts in Maharashtra. The crop data has been collected from data portals and state/central government reports published on official government portals for open data and available freely online. The collected data comprises annual production, productivity, and area from 2000 to

2021. The data is district-wise. Some districts are Thane, Palghar, Raigad, Ratnagiri and Pune. Some crops include Bajra, Ragi, Mung, Udid, Soybean, Nigerseed and Tobacco.

4. Area of Study

Maharashtra is India's third-largest state by area and second in terms of population. It covers 307,713 square kilometres, has 35 districts, 358 blocks, 43711 villages, and a total population of 112,372,972. Of 33,500 square kilometres of irrigated land is being used for crop cultivation. There is a substantial variation in the spatial rainfall distribution across the state.

Maharashtra ranks relatively higher in the country in terms of its contribution to the total production of various commodities at the country level. Despite being one of the most economically developed states in the country, the state does not rank among India's advanced states when analyzed in terms of agricultural development. Maharashtra's agriculture is distinguished by crop production instability, exacerbated by sudden climatic variability. Several crops are grown throughout the state, but the major crops with high economic value are sugarcane, cotton, and rice, which are cultivated during the kharif season.

The sugar sector is critical to the socio-economic and educational growth of the state's rural districts. For the past 68 years, the Maharashtra sugar sector has grown without hindrance. Sugarcane agro-climatic zones 4 (peninsular zone) and 5 (coastal zone) comprise the tropical sugarcane area, which encompasses the states of Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat, Madhya Pradesh, Goa, Pondicherry, and Kerala. Sugarcane is Maharashtra's most significant cash crop, and the state is the second-largest sugarcane-growing state in India. Sugarcane grows all year and experiences climatic changes such as extremely high temperatures in summer and extremely low minimum temperatures in winter; the weather components greatly impact the crop's output. The state spans around 9.4 lakh acres in the tropical zone and produces 61.32 million tonnes.

Cotton is one of India's most important cash crops, contributing significantly to the country's economic prosperity. Cotton offers a direct source of income for 6 million farmers in India, while the cotton trade and processing employs 40-50 million people. Our country is the world's second-largest cotton producer. Cotton cultivation directly and indirectly employs a substantial portion of India's population. The crop is grown in three separate agroecological zones in India to understand the geographical distribution. The North Zone (Punjab, Haryana, and Rajasthan), The Central Zone (Madhya Pradesh, Maharashtra, and Gujarat), and The South Zone (Andhra Pradesh, Karnataka and Tamil Nadu). Maharashtra is India's second-largest cotton grower.

Cotton is very critical to the socio-economic development of the state's populace. Maharashtra's cotton-producing areas are the Vidarbha, Marathwada, Khandesh, and The Deccan Canal regions. Khandesh is Maharashtra's second-largest cotton grower. Raw cotton output in Maharashtra is marketed through Public Marketing Channels (Agencies) and Private Marketing Channels (Agencies).

5. Methodology

The annual sugarcane and cotton data from 2000 to 2020 was aggregated from the government portals. Two datasets were formed. One was a time series dataset with rows for each district in Maharashtra and columns as years from 2000 to 2020 for Sugarcane in Tonnes/ha. The second dataset was a similar time series dataset with data points from 2000 to 2020 for each district in Maharashtra for the cotton in 170kg/bale.

Maharashtra is divided into eight divisions and 34 districts. The analysis done in this paper is done for productivity.

$$\text{Productivity} = (\text{produce/area})$$

Productivity is defined as production per unit area. In this case, the area is in Hectare, and production depends on the crop. In the case of sugarcane, it is tonnes/ha, while in the case of cotton, it is 170kg/bale.

We conducted a time series analysis for the productivity of sugarcane and cotton from 2000 to 2020 for the following districts: -

- Nashik
- Pune
- Aurangabad
- Latur
- Nagpur

These districts are among the major districts in Maharashtra (Figures 1 and 2).

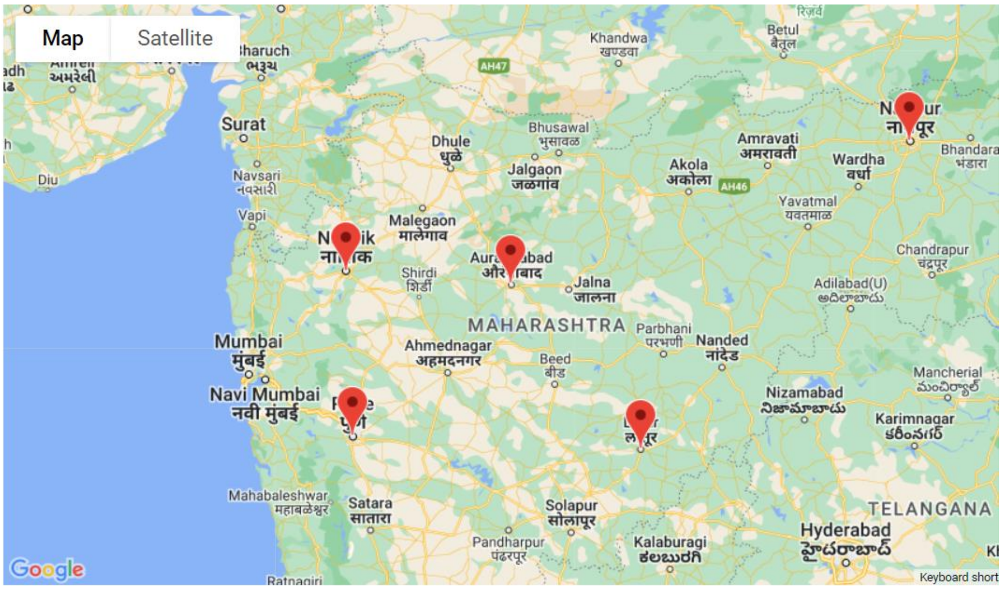

Figure 1: Map View of the five districts

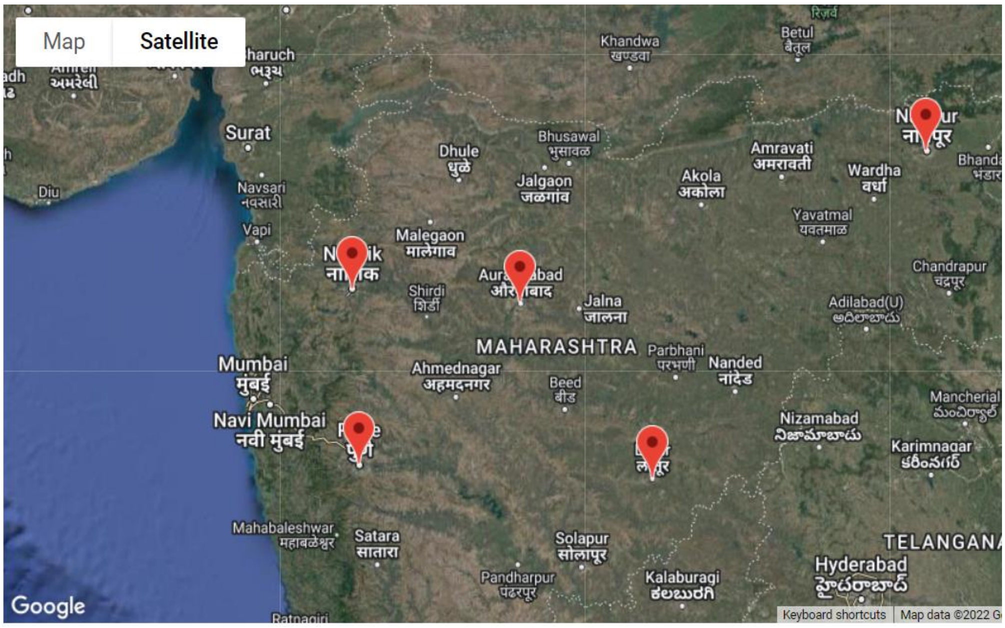

Figure 2: Satellite View of the Districts

6. Results and Analysis

After Studying the time series analysis, we found some interesting facts about the productivity of sugarcane and cotton in these districts. The following figures show the results visually.

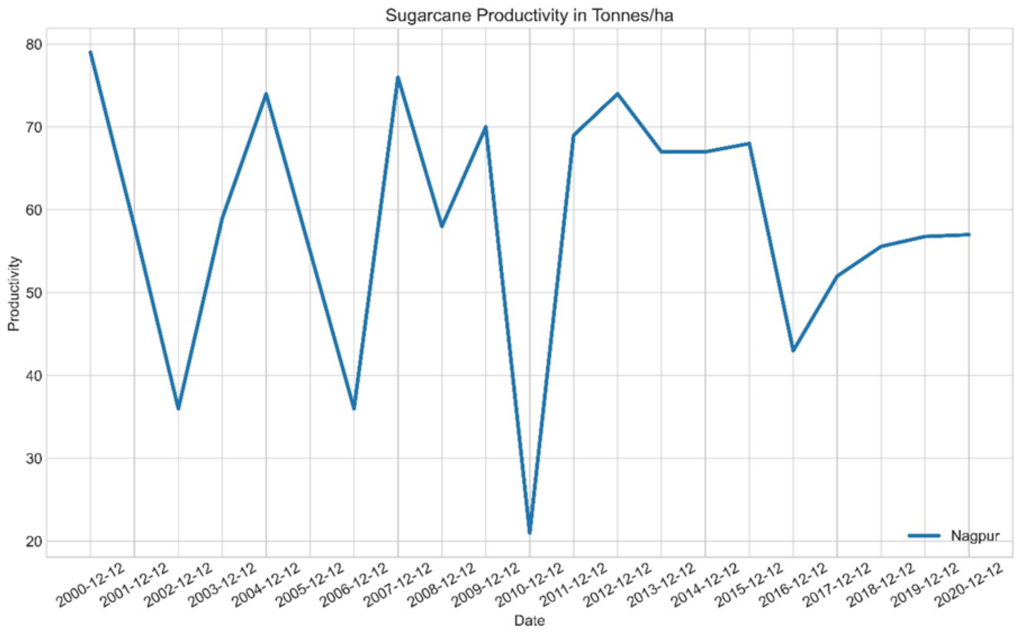

Figure 3: Sugarcane Productivity in Nagpur District

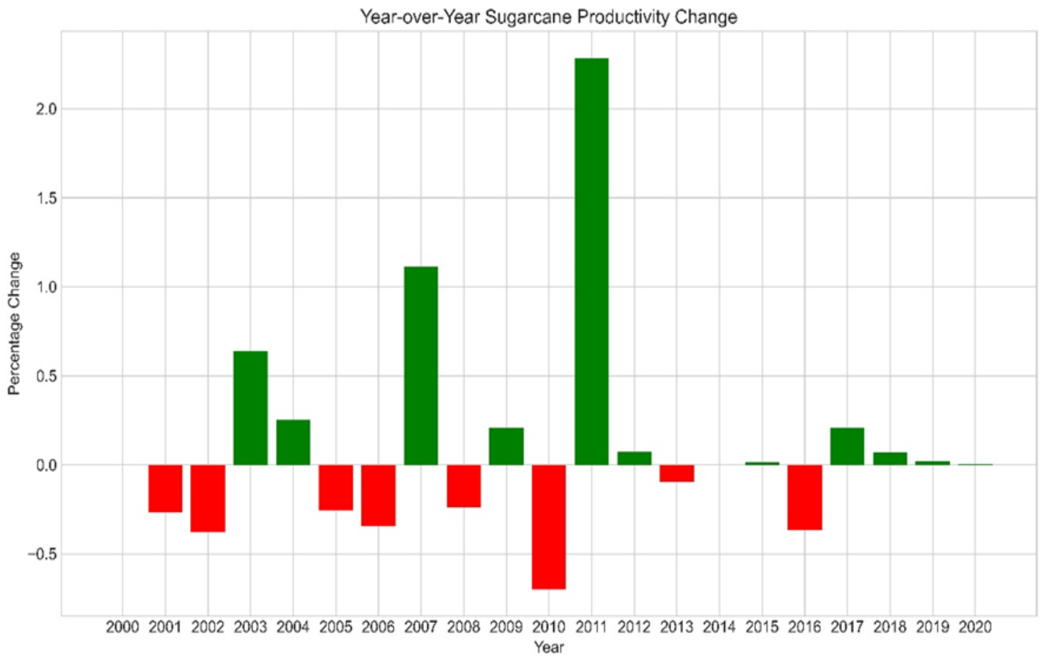

Figure 4: Year-over-year change in Productivity of Sugarcane in Nagpur District

Figure 3 shows that the sugarcane productivity in Nagpur has decreased in 20 years. But it is slowly increasing with time. From FIgure 4, we can see that the increase in productivity year over year is decreasing; thus, the productivity is reaching a saturation mark.

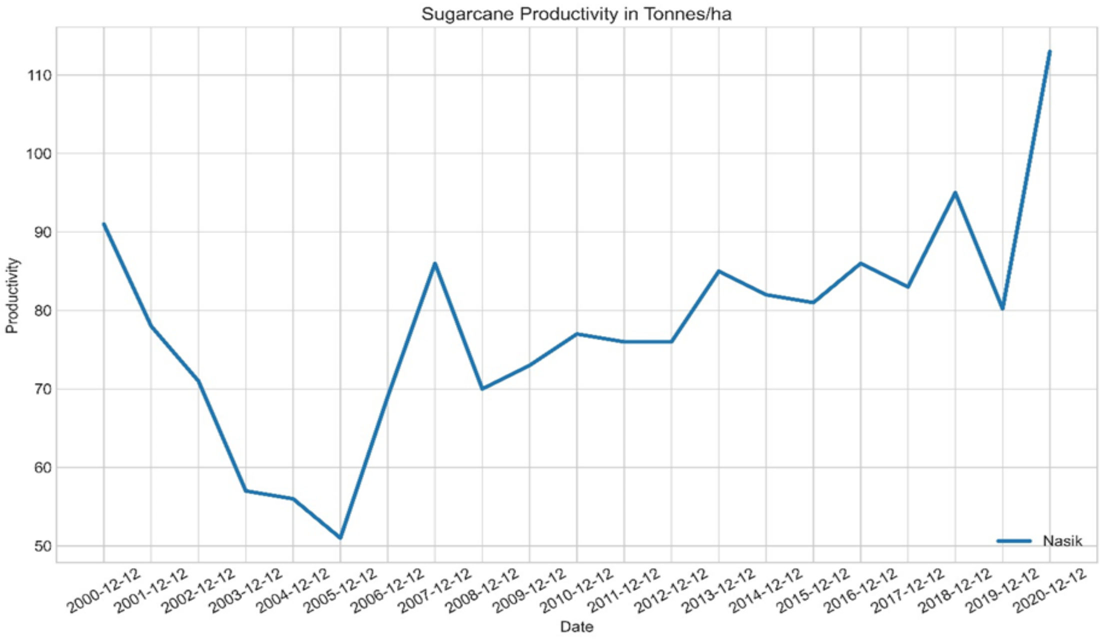

Figure 5: Sugarcane Productivity in Nasik District

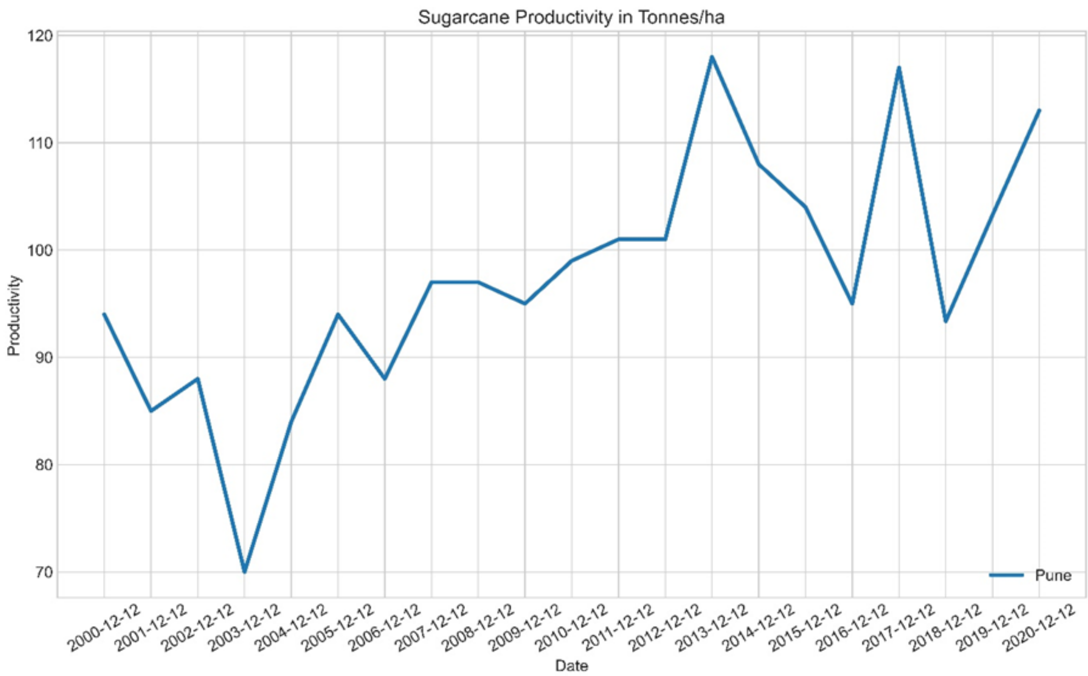

Figure 6: Sugarcane Productivity in Pune District

In contrast to Nagpur, Pune and Nasik districts have seen steady productivity increases over the years (Figures 5 and 6). By studying the graphs, we can conclude that both districts have focused on increasing sugarcane productivity in the past five years.

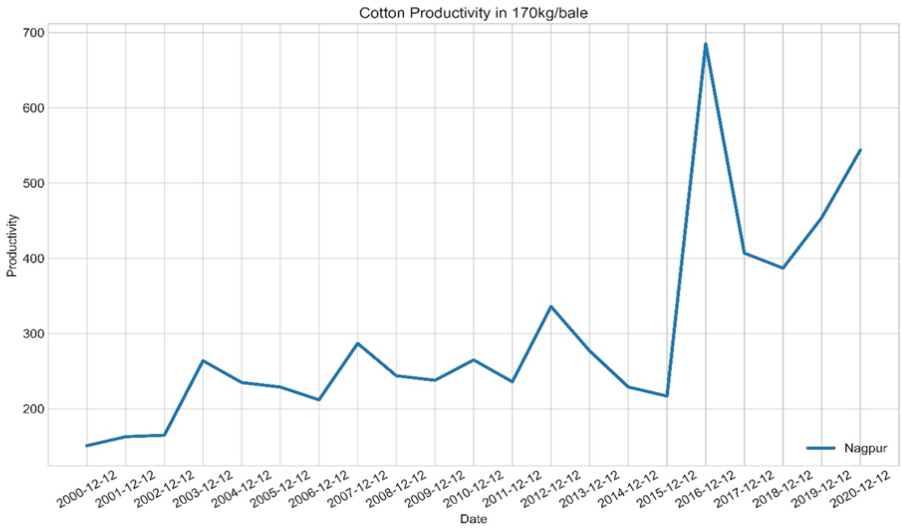

Figure 7: Cotton Productivity in Nagpur

From Figure 7, we can observe that cotton productivity has drastically increased in the Nagpur District. These results are consistent with those of other districts considered as well. Only in the Pune district has the productivity of cotton seen oscillations around the 400 mark. This can be observed from Figure 8.

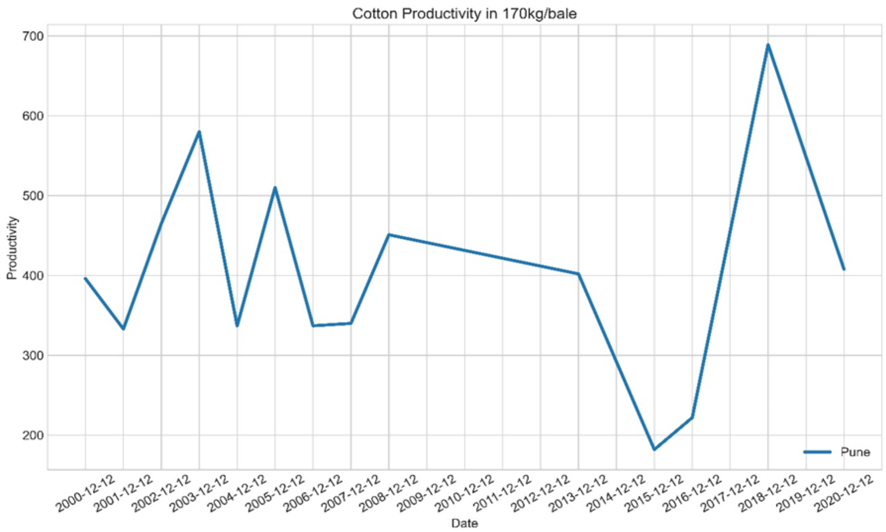

Figure 8: Cotton Productivity in Pune

The line graph depicts the cotton productivity in Pune, measured in 170 kg/bales, over the years from 2000 to 2020. The graph shows fluctuations in productivity, with several notable peaks and drops. At the beginning of the observed period, in 2000, productivity was approximately 400 bales, followed by a sharp increase in 2002, peaking at around 600 bales in 2003. This high point was followed by a decline and a period of instability between 2004 and 2010, where productivity varied but remained mostly around the 400 to 500 bales range.

A significant drop occurred around 2014, with productivity falling below 300 bales, marking the lowest point on the graph. However, the following years saw a steep recovery, culminating in another peak close to 650 bales around 2018. After this sharp rise, the graph shows a decrease again by 2020, settling just above 400 bales. Overall, the data suggests high variability in cotton productivity in Pune over the two decades, with significant peaks in 2003 and 2018, and notable declines, particularly around 2014. This volatility may be attributed to a range of factors such as climate, agricultural practices, or market influences affecting cotton production in the region. Tables 1 and 2 show the net increase or decrease in productivity in the considered districts over 20 years from 2000 to 2020.

Table 1: Cotton Crop Productivity from 2000 to 2020

District	Percentage Change in Cotton Productivity 2000-2020
Nagpur	260.26%
Latur	182.78%
Aurangabad	342.25%
Pune	3.03%
Nasik	170%

Table 2: Sugarcane Crop Productivity from 2000 to 2020

District	Percentage Change in Sugarcane Productivity 2000-2020
Nagpur	-27.85%
Latur	10.14%
Aurangabad	11.43%
Pune	20.21%
Nasik	24.18%

7. Comparative Analysis

Maharashtra is the second most populous state in the country. Yet, it is not the one with the highest productivity in sugarcane. Many factors contribute to sugarcane productivity, such as soil, weather conditions, and land. Here is a comparative analysis of sugarcane productivity in other states. Maharashtra ranks 3rd in sugarcane productivity, behind Karnataka and Tamil Nadu (Table 3).

Table 3: Sugarcane Productivity in other states (in tonnes/ha)

State/UT	2020-21*	Average (2015-16 to 2019-20)
Tamil Nadu	102.73	99.70
Karnataka	95.00	83.22
Maharashtra	**88.90**	**81.53**
Haryana	86.18	79.12
Punjab	83.82	80.06
West Bengal	83.00	86.44
Uttarakhand	82.90	69.01
Uttar Pradesh	81.50	74.66
Andhra Pradesh	74.88	77.78
Gujarat	73.69	70.59
Telangana	67.90	74.24
Others	54.32	46.14
Madhya Pradesh	53.45	53.29
Bihar	48.92	63.01
All India	**82.20**	**76.00**

**4th Advance Estimates 2020-21, Source: E&S, DAC, New Delhi*

Figure 9 provides a comparative view of sugarcane productivity (measured in tonnes per hectare) across different states of India for the year 2020-21, juxtaposed with the average productivity from 2015-16 to 2019-20. Tamil Nadu emerges as the top performer in sugarcane productivity, exceeding 100 tonnes/ha, followed closely by Karnataka. Maharashtra, represented in blue, shows a slightly lower productivity rate, close to 75 tonnes/ha, which is below both the top-performing states and the national average. The red line represents the five-year average productivity (2015-16 to 2019-20), providing a baseline for comparison. The trend shows that most states maintain a steady productivity rate over the years, with minor fluctuations. For example, Haryana, Punjab, and Uttar Pradesh are close to the national average, while states like Gujarat, Telangana, and Madhya Pradesh demonstrate slightly lower sugarcane productivity.

Bihar stands out with a significantly lower sugarcane productivity rate compared to other states, but it still aligns with its five-year average performance. The overall productivity across India, shown in red, indicates that while some states perform exceptionally well, the national average remains balanced at around 80 tonnes/ha. The chart suggests that productivity trends vary widely across states, influenced by regional factors such as climate, soil quality, and agricultural practices. It highlights the importance of understanding state-level disparities to improve overall national productivity in sugarcane farming.

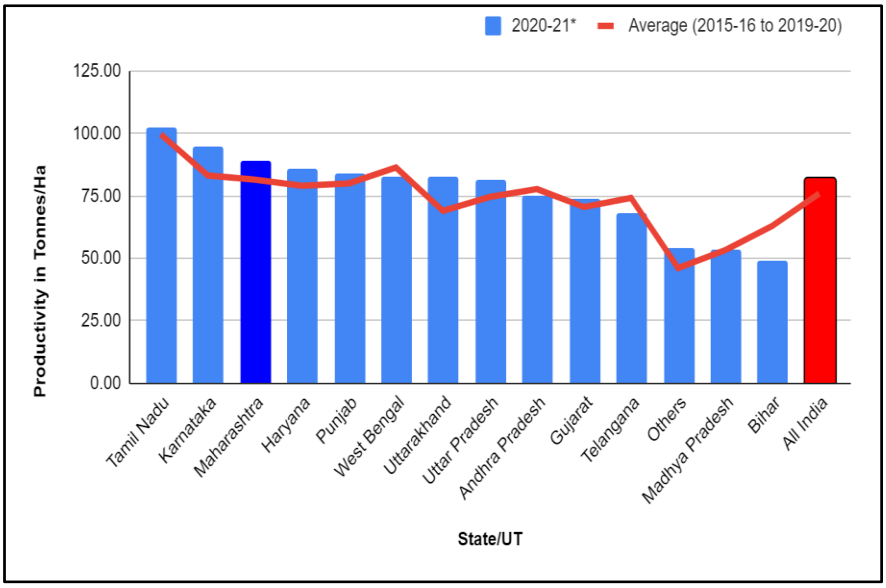

Figure 9: Sugarcane Productivity in Different States

In the case of cotton, Maharashtra lags behind many states. A comparative analysis can be seen below Table 4.

Table 4: Cotton Productivity in other states (in kg/ha)

State/UT	2019-2020
Punjab	827.00
Andhra Pradesh	649.00
Rajasthan	624.00
Haryana	584.00
Odisha	579.00
Gujarat	552.00
Telangana	546.00
Karnataka	485.00
Madhya Pradesh	430.00
Tamil Nadu	418.00
Maharashtra	**251.00**
All India	**455.00**

Source: Ministry of Agriculture and Farmers Welfare, Government of India

Figure 10 illustrates the cotton productivity (measured in kilograms per hectare) across various states and union territories of India, providing a comparative analysis with the national average. Punjab leads with the highest productivity, reaching close to 750 kg/ha, followed by Andhra Pradesh and Rajasthan, which also show strong cotton production levels, nearing 650 kg/ha. States like Haryana, Odisha, and Gujarat follow with slightly lower productivity figures but still maintain a robust output above

500 kg/ha. Telangana, Karnataka, Madhya Pradesh, and Tamil Nadu exhibit moderate productivity levels, falling between 400 and 500 kg/ha.

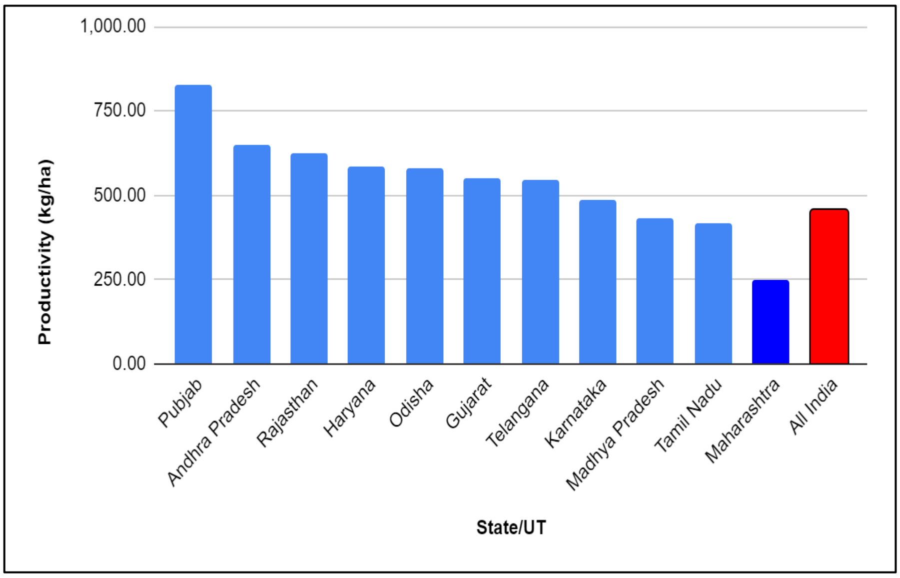

Figure 10: Cotton Productivity in Different States

In contrast, Maharashtra, a major cotton-growing state, has a significantly lower productivity rate, highlighted in blue, positioned at around 300 kg/ha, falling below the national average of approximately 400 kg/ha, represented in red. This disparity in cotton productivity indicates potential regional variations in factors such as climate, agricultural practices, and resource availability, affecting yield performance. The graph emphasizes the need for addressing productivity challenges in states like Maharashtra to meet or exceed the national average and maintain competitiveness in cotton production across India.

8. Conclusion

From the above analysis, it is evident that the districts considered in this study show a clear shift in productivity from sugarcane to cotton, with farmers reallocating resources to boost cotton production over sugarcane. Productivity, measured per unit area, reveals that in Nagpur, productivity decreased by 27% from 2000 to 2020. This shift suggests economic or environmental factors influencing farmers' crop choices. Future research could extend the study to include other significant crops in Maharashtra, such as oilseeds, rice, and jute, to provide a more comprehensive view of agricultural trends. Forecasting future production and demand would also offer valuable insights, helping stakeholders adapt to market changes and ensure food security. A comparative study across other regions in India, with readily available government data, could reveal broader agricultural patterns. Additionally, a cost-benefit analysis could highlight the financial drivers of crop migration while investigating the reasons behind the shift from one crop to another, which would clarify the environmental or policy factors affecting these decisions. Exploring these areas can deepen our understanding of agricultural productivity trends and support more informed agricultural planning and policy-making.

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Conflicts of Interest Statement: The authors have no conflicts of interest to declare. This work represents a new contribution by the authors, and all citations and references are appropriately included based on the information utilized.

Ethics and Consent Statement: This research adheres to ethical guidelines, obtaining informed consent from all participants.

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