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A data driven study of regional variations in sugarcane production and yield trends in India

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Abstract

India, the second-largest producer of sugarcane in the world. Sugarcane and allied industries are key components of the rural economy. It provides for the sugar, jaggery and khandsari also known as 'desi khaand', helps millions of farmers, and is becoming more and more involved in ethanol-based biofuel projects. From 2018 to 2023, this study looks into the regional patterns in sugarcane output and yield, emphasizing differences among important states including Karnataka, Maharashtra, and Uttar Pradesh. The study uses Z-score normalization and year-over-year % change for three metrics i.e. area, yield, and production to analyse sugarcane farming trends in India from 2018 to 2023. The results show considerable variation, with notable contractions in 2020–2021 brought on by COVID-19 disturbances and climatic stress. Significant yield increases and the expansion of farming areas in regions like Tamil Nadu and Maharashtra were the main drivers of the robust recovery that was seen in 2022. The study determines growth trajectories and performance disparities using comparable indicators across 13 districts in India.

The results highlight that majority of regions fall into the moderate yield category, with the average sugarcane yield across all regions being 77.84 T/Ha. These findings emphasize the necessity of focused interventions under initiatives such as One District One Product (ODOP) in order to increase market resilience and regional efficiency for those districts which promote jaggery as ODOP product.

Keywords: K-Means clustering; Spatiotemporal analysis; Sugarcane; Regional disparities; Z-score

1. Introduction

An essential component of India's agrarian economy, sugarcane contributes significantly to export revenues, agro-industrial growth, and rural socio-economy. India produces more than 18% of the world's sugarcane, making it the world's second-largest producer. Millions of small and marginal farmers nationwide depend heavily on sugarcane agriculture for their livelihoods due to its deep socioeconomic roots. Uttar Pradesh (UP) is unique among the top states in that it has the most land area under sugarcane crop. However, in spite of the vast area, the state continuously falls short of its southern counterparts, such as Tamil Nadu, Karnataka, and Maharashtra, in terms of yield. Pointing to inefficiencies in local farming methods, this ongoing yield gap also highlights a significant chance for revolutionary expansion, particularly in light of the One District One Product (ODOP) program, which names jaggery as a vital agro-product in a number of districts promoting jaggery and applied products.

1.1. Sugarcane Landscape in India: Area vs. Yield Dichotomy

India has a widely varied sugarcane production terrain. When it comes to the area under cultivation, northern states like Uttar Pradesh, Bihar, Punjab, and Haryana are in the lead. Though these areas are in north of tropic of cancer, the yield per hectare in these areas is much lower than the states south of tropic of cancer, which have embraced high-

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yielding varieties, improved irrigation systems, effective crop management techniques also being in southern part the frost-free days, high temperature is most suitable for sugarcane crop. Despite having more than 2.2 million hectares under cultivation, Uttar Pradesh's average sugarcane production remained somewhat lower than the national average, which was roughly 80–85 tonnes per hectare in recent years, according to data from the Ministry of Agriculture and Farmers Welfare.

States like Tamil Nadu and Karnataka, on the other hand, often produce more than 100 tonnes per hectare, and Maharashtra has occasionally reported yields as high as 120 tonnes per hectare. The discrepancy indicates substantial technological, institutional, and policy disparities between the regions and is not just a reflection of climate variations. These include variations in farmer training, water resource management, mechanization levels, input use efficiency, and varietal acceptance.

1.2. Decadal Trends in Sugarcane Production (2018–2023)

India's sugarcane production has fluctuated during the past years due to market dynamics, input costs, and monsoonal unpredictability. The growth has been unevenly spread between pan India, even if overall production has increased. Although the area planted to sugarcane in Uttar Pradesh rose between 2018 and 2023, the yield increased only little, which caused the overall output to climb more slowly. Maharashtra, on the other hand, has experienced quick increases in output due to its emphasis on water-use efficiency and usage of drip irrigation. UP has the highest percentage of the country's sugarcane production (36–40%), according to data from 2018–2023, however this is mostly because of the massive area under cultivation rather than yield increases. Despite having an abundance of land and labour for agriculture, the trend indicates that UP is still limited by antiquated methods and disjointed supply chains.

1.3. Innovations in Southern India

Southern Indian states have shown remarkable progress in sugarcane productivity by embracing scientific, technological, and institutional innovations. These include:

- **Drip and Sprinkler Irrigation**: Widely adopted in Maharashtra and Tamil Nadu, these systems have dramatically increased water-use efficiency and improved cane yield, even in water-scarce regions.
- **Early-Maturing and High-Yielding Varieties**: Southern states have promoted early-maturing varieties like Co-86032 and CoC-671, which enable multiple harvests and optimize cropping intensity.
- **Mechanized Cultivation and Harvesting**: Karnataka and Maharashtra have mechanized over 50% of their sugarcane harvesting processes, reducing labour dependence and harvest losses.
- **Integrated Pest and Disease Management (IPDM)**: These practices help reduce input costs and maintain crop health throughout the growing cycle.
- **Farmers' Producer Organizations (FPOs)** and cooperative networks in these regions have enabled collective bargaining, timely input procurement, and better access to processing and marketing facilities.
- **GIS-based crop monitoring** and mobile advisory services have empowered farmers with timely weather, input, and market information.

1.4. ODOP and the Role of Jaggery in Uttar Pradesh

The One District One Product (ODOP) program of the Uttar Pradesh government is a pioneering step in the development of agro-industrial hubs at the district level. Made from sugarcane juice, jaggery, also known as "gur," is a traditional unprocessed sugar product. It has a high demand in both domestic and international markets, is nutrient-rich, and is ingrained in the rural economy of many states of India. ODOP has allocated districts from all over India like Shamli, Baghpat, Meerut, Muzaffarnagar, Anakapalli, East Siang, Hojai, Hazaribagh, Bagalkote, Belagavi, Mandya, Kolhapur, Satara, Parbhani, Fathegarh Sahib and many more for jaggery and sugarcane allied products. During the post-harvest months, thousands of small-scale jaggery businesses operate in these districts. However, the manufacturing of jaggery is still mostly disorganized, relies on manual labour and wood-fired furnaces, and frequently lacks quality control. These districts can increase their jaggery production, generating jobs, value addition, and export opportunities. Additionally, UP's and other districts standing in both home and international markets will be improved by coordinating the jaggery sector with sustainability objectives and climate-smart agriculture.

2. Methodology

This study evaluates regional differences in sugarcane output throughout the leading sugarcane producing Indian states using a comparative, data-driven methodology. Z-score normalization is used in this study for sugarcane variables including production, yield, and its area row-wise, that is, across years for each region. This made it easier to determine which years for each region differed most from the long-term norm. For each region, the percentage change was calculated column-wise, that is, from one year to the next. This approach was used to analyse the pace and direction of annual changes over the 2018–2023 timeframe for all three indicators: production, yield, and area. The methodology consists of the following key stages:

2.1. Objectives and Study Area

Analyse inter-state differences in sugarcane production by considering sugarcane area, sugarcane production and yield between 2018 and 2023. Examine the potential implications for jaggery production under the One District One Product (ODOP) scheme.

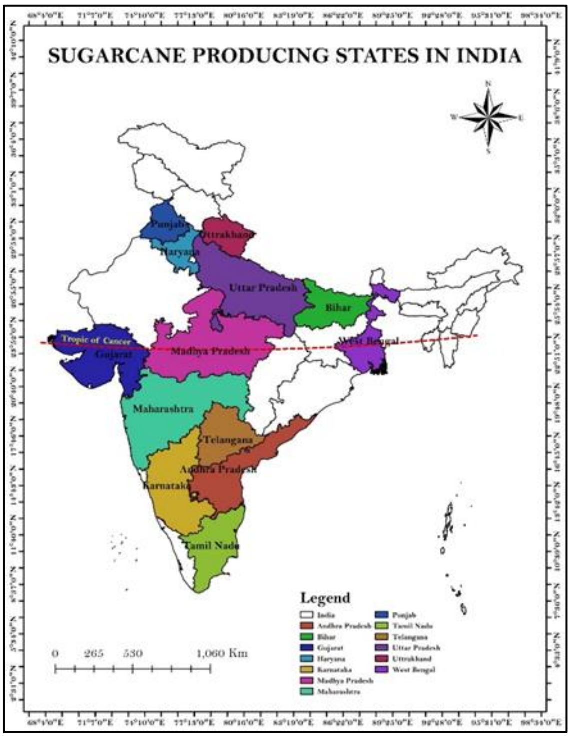

Figure 1 Study Area

2.2. Data Collection

2.2.1. Source of Data

Secondary data for sugarcane production, area under cultivation, and yield were collected for the period **2018–2023** from:

- Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.
- State agricultural departments' official records and publications.

2.3. Parameters Considered

Three key quantitative indicators were used:

- Production: Total sugarcane production (in million tonnes).
- Area: Area under sugarcane cultivation (in lakh hectares).
- Yield: Sugarcane yield (in tonnes per hectare).

2.4. Data Processing and Structuring

- Separate datasets were compiled for each indicator—sugarcane **production, area under sugarcane**, and **yield of sugarcane—**across 13 sugarcane producing states of India.

- The data were stored in .csv format and structured with regions as rows and years (2018–2023) as columns.
- Using Python in **Google Colab**, the data were reshaped from wide to long format using pandas.melt() for unified processing and visualization.
- Z – Score Normalization is computed by using the formula:

$$Z = \frac{X - \mu}{\sigma}$$

Where

Z = Z - score
X = Actual observed value
μ = Mean of the observed values
σ = Standard deviation of the observed values

- Year-Over-Year Growth Rate is also computed by using the given formula:

$$\% \text{ Change} = \left(\frac{X_t - X_{t-1}}{X_{t-1}}\right) X\ 100$$

Where

X_t = Value in the current year
X_{t-1} = Value in the previous year
% Change = Percentage change from previous year to the current year
2.4. Summary Statistics

- **Mean values** for production, yield, and area were calculated for each state over the 2018–2023 period using groupby() and mean() functions.
- Separate summary tables were generated for each state considered into study:

This provided a quantitative understanding of relative performance.

2.5. Qualitative Assessment of Best Practices

A qualitative review was conducted to examine the **agronomic practices and innovations** implemented in southern and western states, particularly:

- Drip irrigation systems
- Adoption of early maturing varieties
- Mechanized harvesting
- Integrated pest management
- Extension services and digital platforms

These practices were studied through:

- Literature reviews of state-specific agricultural innovations.
- Government policy reports and technology adoption case studies.
- Academic publications and expert interviews (where available).

3. Review of Literature

3.1. Global and National Trend in Sugarcane Production

Despite obstacles, the literature analysis notes a global increase in sugarcane production from 1965 to 2021, highlighting trends in climate change. Despite floods, production in Pakistan increased 2.8% to 91.1 million tons in

2022–2023. Temperature increases and unpredictable rainfall are two examples of climate change that lower yields, making drought-resistant cultivars and better irrigation necessary to maintain growth (Mudassar et al., 2024; Ali et al., 2021). This study looks at sugarcane farming patterns in India from 1950 and 2022. It finds that production increased from 57.05 to 431.81 million tonnes, while the area increased significantly from 1.71 to 5.15 million hectares. Despite geographical differences, yield advances are a result of irrigation expansion and technological breakthroughs (Kumar and Shobana, 2024).

Despite yearly variations brought on by weather and policy, the literature review examines the trends in sugarcane production in India, which has increased steadily over decades and peaked at 33.1 million tons in 2018–19. Low productivity and high costs are obstacles, yet expansion is fuelled by government incentives. In order to stabilize yields, studies emphasize the necessity of sustainable practices and contemporary technologies (Bokey and Maheshkar, 2023; Kumar and Singh, 2021; Mishra and Behera, 2020).

According to the literature analysis, which examines sugarcane production patterns in India between 1990 and 2019, Maharashtra (1741.500 tonnes/year) and Uttar Pradesh (5912.714 tonnes/year) had notable increases. Between 1997 and 2013, most states had increases, with the exception of Tamil Nadu and Andhra Pradesh, which saw decreases. Madhya Pradesh displayed significant instability, but Uttar Pradesh led with steady production (Singh et al., 2021; Rahman and Bee, 2019). Using statistical models, the literature review examines India's sugarcane growth and yield trends. Research shows a variety of tendencies, including an increase in Uttar Pradesh, a minor decline in Maharashtra, and an uneven pattern in Andhra Pradesh. Particularly in Uttar Pradesh, these trends are well captured by linear and exponential models, which are supported by chi-square tests and good R2 values (Arti and Rai, 2017; Kumar et al., 2024; Singh et al., 2021a).

3.2. Regional Trend in Sugarcane Growth in India

The literature analysis looks at Western Uttar Pradesh's sugarcane production trends, showing a 15.8% increase in area and different growth rates between 2000–01 and 2015–16. Despite notable shifts in districts like Pilibhit and Etah, productivity stayed constant (Lal et al., 2020). Uneven growth patterns from 1997 to 2017 are revealed by the literature study, which looks at the trends in sugarcane production in Uttar Pradesh's Shahjahanpur District. Government policies, monsoon fluctuation, and fluctuating areas all contributed to the production's modest (CAGR 0.25%) growth. Due to policy reforms like Fair and Remunerative Price, there were notable surges in 2005–06 and 2014–15 (Rahman and Bee, 2019; Upreti and Singh, 2017). The literature study looks at India's sugarcane crushing capacity trends between 2004 and 2014, with a particular emphasis on Uttar Pradesh and Maharashtra. As sugarcane production grew, crushing capacity also climbed, reaching a peak in 2006–07. Compared to Uttar Pradesh, Maharashtra had longer crushing times and higher sugar recovery. Regional differences in mill capabilities were found to have an impact on the fluctuations in crushed cane volumes (Misra et al., 2016; Mondal, 2015). The literature study examines the growth trends of sugarcane in Karnataka between 1997 and 2019, finding that irrigation, favourable prices, and low labour requirements drove an annual increase in area of 2.00%. Productivity decreased by -0.38%, but production increased by 1.60% each year. Because of the stability of the market, farmers gave sugarcane priority over other crops (Rani et al., 2022; Greeshma and Bhave, 2015).

According to the study, Karnataka's sugarcane shows stable growth from 1998 to 2019 with low and decreasing production instability between districts. With no instances of extreme instability, the majority of districts continuously exhibit low instability (<15%). Reasonable prices, robust market demand, and government procurement regulations are all responsible for this stability. Sugarcane is still a dependable crop even though some districts saw minor increases in instability between 2009 and 2019 (Rani et al., 2022). Climate variability has changed cropping patterns in Chitradurga, Karnataka, resulting in less sugarcane being grown due to higher temperatures and more intense rains. According to Markov chain analysis (1998–2011), finger millet displaced sugarcane in 78% of its land area, indicating a shift toward drought-tolerant crops. This transition reflects a decline in the cultivation of water-intensive crops, which is being driven by market pressures and climate change (Sagar et al., 2022). The literature analysis looks at Gujarat's sugarcane patterns from 1969 to 2018, revealing a notable growth in area up to 1999–2001, after which there was a fall. Production fell to 11.78 lakh tonnes by 2016–2018 from a peak of 17.97 lakh tonnes in 1999–2001. Due to rising prices and unsustainable input-driven growth, productivity first increased before plateauing (Bhopala et al., 2023; Dhandhalya et al., 2019). According to the literature assessment, sugarcane yield patterns in the Gangetic Plains of India from 1966 to 2011 show a sharp drop as a result of climate change. Rising temperatures and unpredictable rainfall might cause yields in the Middle Gangetic Plains to drop by 21% by 2100 and in the Upper Gangetic Plains to drop by 1.85% by the 2080s. To lessen the effects, adaptation measures are essential (Singh et al., 2019).

4. Results and Discussion

4.1. Parameters Considered in the Study

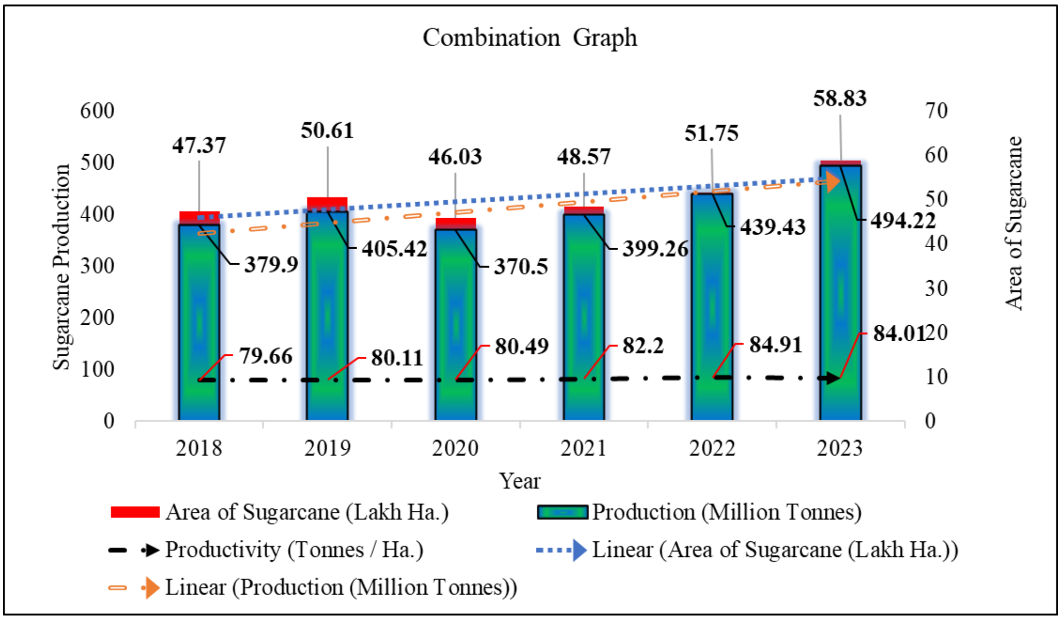

Figure 2 Combination Graph for Area under Sugarcane, Sugarcane Production and Sugarcane Yield

Three important metrics - area under cultivation of sugarcane, total production, and yield tonnes per hectare show noteworthy patterns in the statistics on sugarcane agriculture in Indian states from 2018 to 2023. From 47.37 lakh hectares in 2018 to 58.83 lakh hectares in 2023, the area under sugarcane cultivation has a typically increasing trend. The region grew gradually following a minor decline in 2020 (46.03 lakh ha.), mostly brought on by disturbances caused by COVID-19 pandemic. The largest growth, 51.75 lakh hectares, is seen between 2022 and 2023. The production of sugarcane, expressed in million tonnes, closely reflects the trend in the region. It rose by more than 114 million tonnes over six years, from 379.9 million tonnes in 2018 to 494.22 million tonnes in 2023. Production recovered well in the years that followed, with a particularly notable spike between 2022 (439.43 MT) and 2023, which corresponds with the area extension, despite a slight drop in 2020. The yield, which is a measure of productivity expressed in tonnes per hectare, improved gradually but stayed mostly constant. Yield peaked in 2022 at 84.91 T/Ha. after increasing slightly from 79.66 T/Ha. in 2018 to 84.01 T/Ha. by 2023. As a result of mechanization, enhanced crop management, and the adoption of improved cane varieties (KARAN 4, KARAN 2), India is able to increase efficiency somewhat while increasing the area under sugarcane agriculture. The years 2018–2023 demonstrate a strong growth in India's sugarcane production, both in terms of area and output, with a steady but modest increase in yield.

4.2. Region wise Correlation Analysis

Significant regional variation in the relationship between land usage and productivity is revealed by the correlation analysis between sugarcane output and sugarcane area across different Indian states. An increase in the area under sugarcane cultivation is often linked to an increase in sugarcane yield, according to the moderately positive correlation of r = 0.679 at the national level (All India). This implies that, on a national level, elements like increased irrigation, the use of better cultivars, and enhanced farm management techniques favourably impacting both area and production at the same time. The intensity and direction of relationships, however, differ significantly when broken down at the state level. Highlighting the regional differences in sugarcane growth dynamics. Andhra Pradesh (r = 0.583) and Gujarat (r = 0.502), for example, exhibit moderately high positive correlations, suggesting that areas with growing sugarcane acreage also typically see commensurate production increases. Two of India's leading sugarcane producing states, Karnataka (r = 0.484) and Uttar Pradesh (r = 0.373), also exhibit positive correlations, but to a lesser extent. Although yield increases in these states seem to be primarily area-driven, this link is probably mediated by other factors like crop rotation, policy incentives, and water availability. The positive but weaker associations for Maharashtra (r = 0.180) and Bihar (r = 0.343) imply that although area expansion boosts production, yield performance is constrained by climate variability, resource limitations and interest of farmers. Conversely, several states show negative relationships, suggesting that maintaining yield and increasing area may have to be traded off. Strong negative correlations are seen in Tamil Nadu (r = -0.448), West Bengal (r = -0.441), and Uttarakhand (r = -0.590), suggesting that rising area has been correlated with stagnant or declining yields. This pattern is the result of poor irrigation infrastructure, suboptimal input use and overextension of marginal fields. Despite greater coverage, many areas may be experiencing water stress or soil degradation, which would lower output. States such as Madhya Pradesh (r = -0.353) and Punjab (r = -0.042) have weak to moderate negative correlations, indicating limited adoption of yield-enhancing measures possible inefficiencies in land-use decisions as these regions focus on wheat crop also. It's interesting to see that Telangana (r = 0.129) and Haryana (r = -0.026) hover close to zero, suggesting that there is no obvious linear link between area and yield. The need to investigate sub-regional diversity within less well-known sugarcane-producing areas is further supported by the residual group, designated as "Others" (r = 0.205), which likewise has a modest positive association.

4.2.1. Area under Sugarcane and Sugarcane Yield

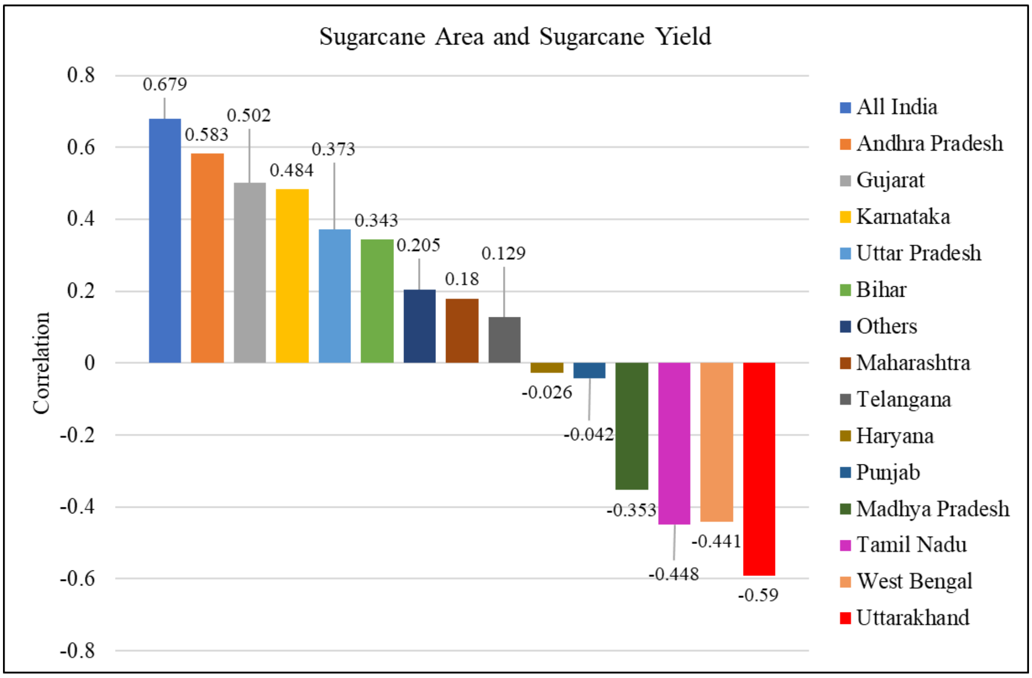

Figure 3 Correlation between Area under Sugarcane and Sugarcane Yield from 2018-2023

4.3. Sugarcane Production and Sugarcane Yield

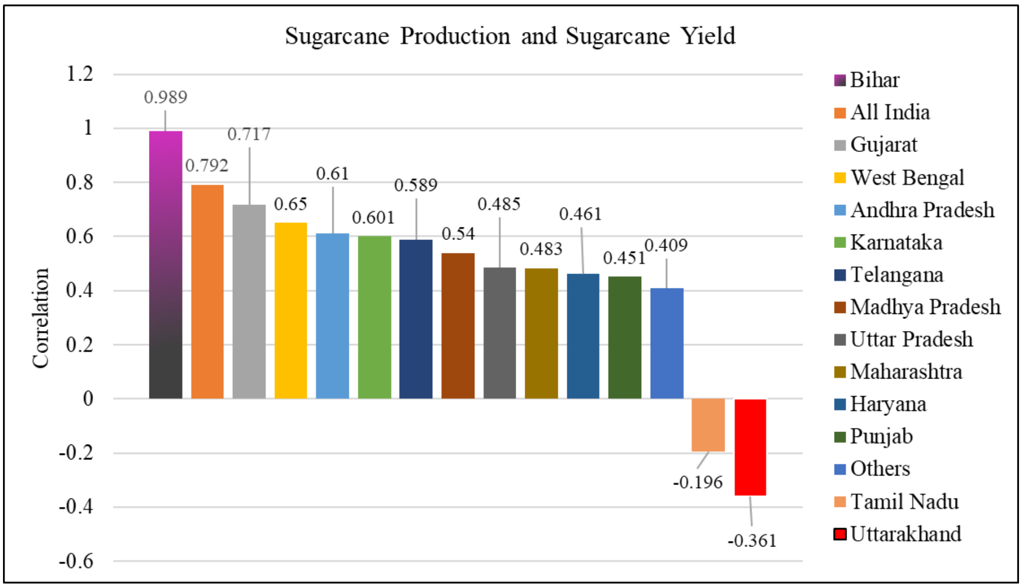

Figure 4 Correlation between Sugarcane Production and Sugarcane Yield from 2018-2023

Strong positive correlations are seen in the majority of regions between the area under sugarcane cultivation and sugarcane production across Indian states from 2018 to 2023, indicating that an increase in output typically coincides with an expansion in area. Area and production are strongly positively correlated at the national level, as indicated by the correlation coefficient of r = 0.792. This pattern exhibits exceptional constancy at the state level. A virtually perfect linear link between area and productivity is suggested by Bihar's extraordinarily strong correlation (r = 0.989). This suggests that changes in area are the primary cause of output oscillations in Bihar, with yield being largely constant throughout time. West Bengal (r = 0.650) and Gujarat (r = 0.717) show similar significant relationships, indicating that area expansion has been the main driver of production advances in both states, with yield improvements possibly playing a minor role. Strong positive relationships are also seen in states like Telangana (r = 0.589), Karnataka (r = 0.601), and Andhra Pradesh (r = 0.610), highlighting the significance of land usage in affecting output. India's top sugarcane-producing states, Uttar Pradesh (r = 0.485) and Maharashtra (r = 0.483), exhibit moderately positive correlations, suggesting that although area shapes production, other factors such as yield improvements, rainfall variability, and irrigation efficiency also have a significant impact on output. Haryana (r = 0.461) and Madhya Pradesh (r = 0.510) span a comparable range, indicating that output growth is partially, but not totally, area-bound. Relationships between Punjab (r = 0.451) and Others (r = 0.409) are comparatively weaker. Tamil Nadu (r = -0.196) and Uttarakhand (r = -0.361), on the other hand, have negative correlations, suggesting a different pattern production decreased as the area planted to sugarcane grew. This might be an indication of deteriorating yield trends brought on by ineffective crop management techniques, damaged soils, water scarcity. For planners, the negative connection in these areas raises concerns because it implies that more space alone does not equate to increased production.

4.3.1. Area under Sugarcane and Sugarcane Production

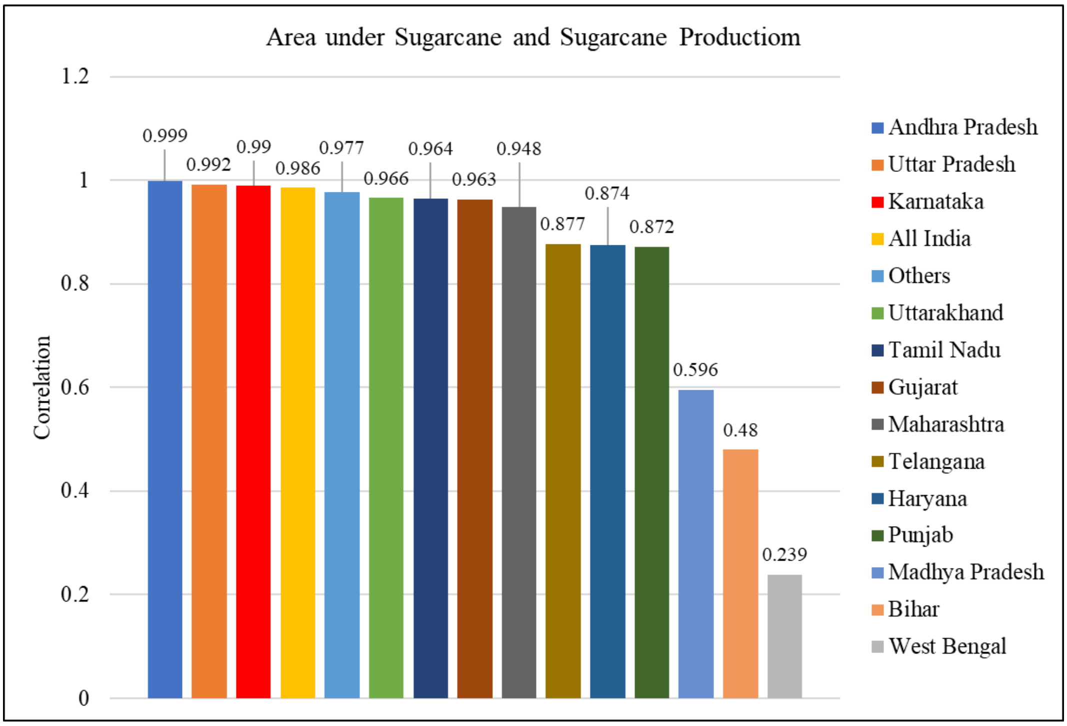

Figure 5 Correlation between Area under Sugarcane and Sugarcane Production from 2018-2023

There is a very significant and steady positive link between sugarcane area and overall production in practically every Indian state, according to the data. The correlation value at the All India level is r = 0.986, indicating that yield improvements have a significant impact on the country's sugarcane output. This implies that productivity increases per hectare have been the primary factor influencing national production trends during the research period, notwithstanding variations in regional areas. Andhra Pradesh (r = 0.999), Uttar Pradesh (r = 0.992), Karnataka (r = 0.990), Uttarakhand (r = 0.966), Tamil Nadu (r = 0.964), and Gujarat (r = 0.963) are among the states that report nearly perfect correlations. Strong positive correlations are also seen in Telangana (r = 0.877) and Maharashtra (r = 0.948), supporting the notion that yield-centric enhancements like drip irrigation, high-yielding cultivars, and effective input management are having a favourable impact on output. States with much weaker but nonetheless significant associations include Madhya Pradesh (r = 0.596), Punjab (r = 0.872), and Haryana (r = 0.874). The yield-production relationship may be moderated in these areas by greater variance in the cultivated area. It's interesting to see that West

Bengal (r = 0.239) and Bihar (r = 0.480) have far lower correlations. The "Others" group (r = 0.977) indicates that output is very yield-driven, even in less well-known sugarcane regions.

4.4. Year wise Correlation Analysis

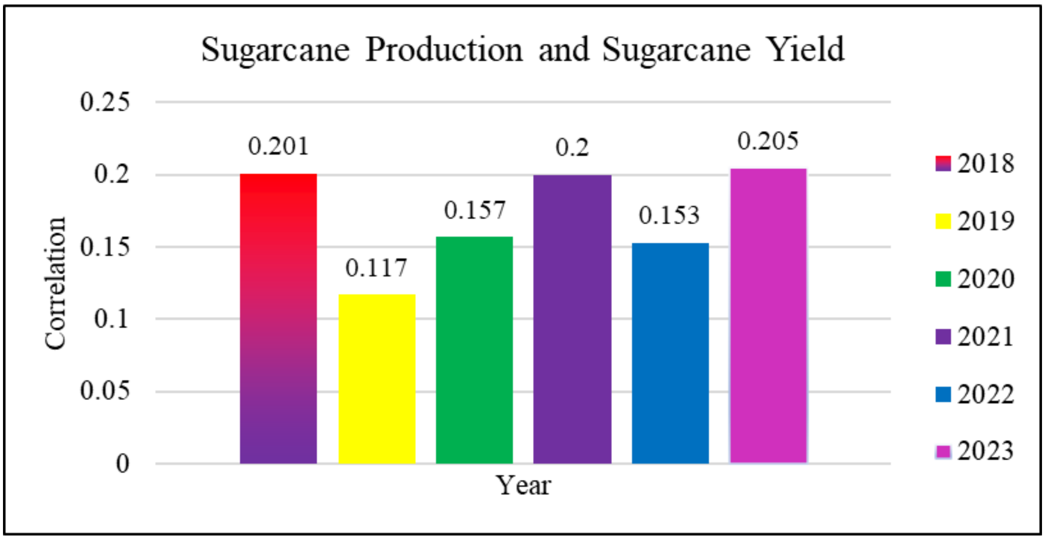

Figure 6 Year-wise Correlation between Sugarcane Production and Sugarcane Yield

With correlation values ranging from r = 0.117 in the year 2019 to r = 0.205 in 2023, the annual correlation between sugarcane yield and output throughout Indian during the 2018–2023 timeframe shows a continuously weak positive association. These figures show that regional production changes are not significantly linked to yield fluctuations from year to year, indicating that other factors most notably, the area under cultivation—are probably having a bigger impact on overall output over these years. Following a minor decrease in 2019 (r = 0.117) and 2020 (r = 0.157). A decoupling of sugarcane yield and output is evident in this trend, which is caused by erratic monsoon patterns, regional differences in water supply and uneven yield performances in high-production states such as Maharashtra and Uttar Pradesh. In 2021 and 2023, the correlation slightly improved (r = 0.200 and 0.205, respectively), but it is still not very strong. This consistently low correlation over six years suggests that state-level trends in sugarcane production are not all driven by yield.

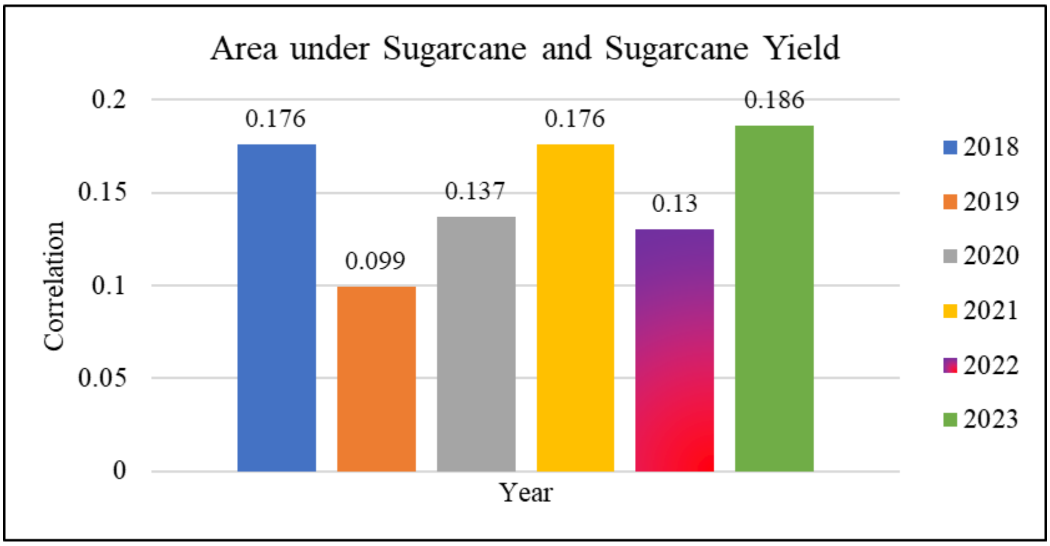

Figure 7 Year-wise correlation between Area under Sugarcane and Sugarcane Yield

With Pearson correlation values ranging narrowly from r = 0.099 (2019) to r = 0.186 (2023), the annual correlation between the area under sugarcane cultivation and crop output across India from 2018 to 2023 shows a continuously weak positive trend. The correlation between 2018 and 2021 was r = 0.176, indicating a slight positive relationship.

The association, however, diminished further in other years, such as 2019 (r = 0.099) and 2022 (r = 0.130), supporting the idea that higher yield per hectare is not always correlated with larger cultivation areas this is mainly because of the COVID-19. This pattern draws attention to a significant structural feature of sugarcane cultivation in India as area under sugarcane and yield frequently function independently, impacted by a number of variables, including: state-specific agroclimatic variations, soil fertility variations, water availability, as some part of Maharashtra is in shadow zone, input intensity (such as fertilizer or mechanization), and the type of sugarcane variety grown.

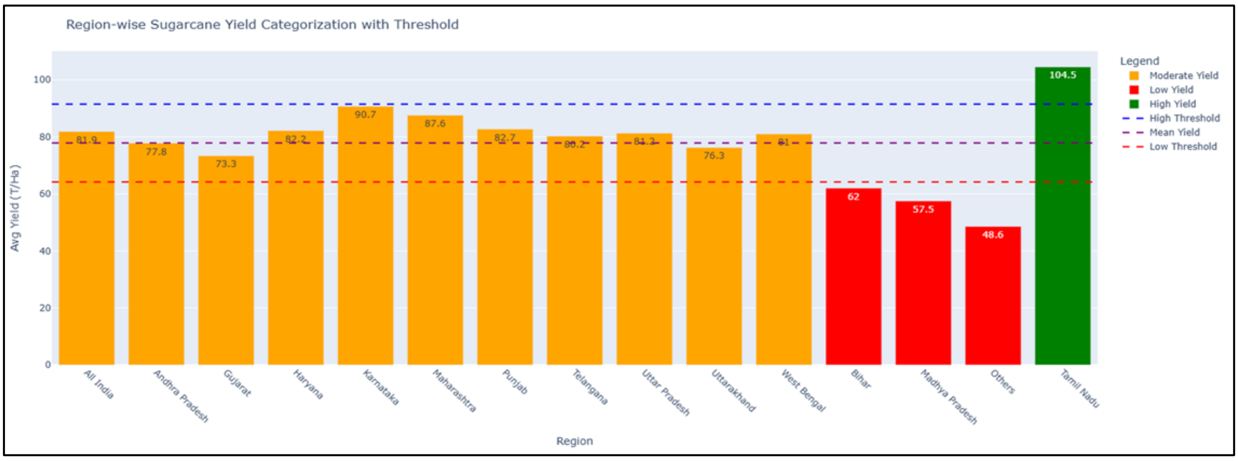

Figure 8 Region wise Sugarcane Yield marked with Threshold.

The middle-dashed line represents the mean yield (≈ 79.3 T/Ha). Blue dashed line on top indicates the high threshold (≈ 91.3 T/Ha). The red dashed line at the bottom indicates the low threshold (≈ 65.0 T/Ha). Low Yield Areas in Red Bars exhibit marked underperformance since they are below the low threshold. Bihar with 62 T/Ha., Madhya Pradesh having 57.5T/Ha. and 'others' contribute 48.6 T/Ha. Agronomic assistance, better irrigation, or variety adoption are examples of targeted interventions that are required in these locations. Average performances are represented by the moderate yield regions in orange bars. Telangana, Punjab, Maharashtra, Haryana, Gujarat, Andhra Pradesh, West Bengal, Uttarakhand, Uttar Pradesh, and All India are in this category. Karnataka with 90.7 T/Ha. for example, is close to the high threshold and has the potential to go into high-yielding areas. Tamil Nadu has a high yield of 104.5 T/Ha. shown in green bar.

4.5. K – Means Clustering based on Sugarcane Yield and Area under Sugarcane

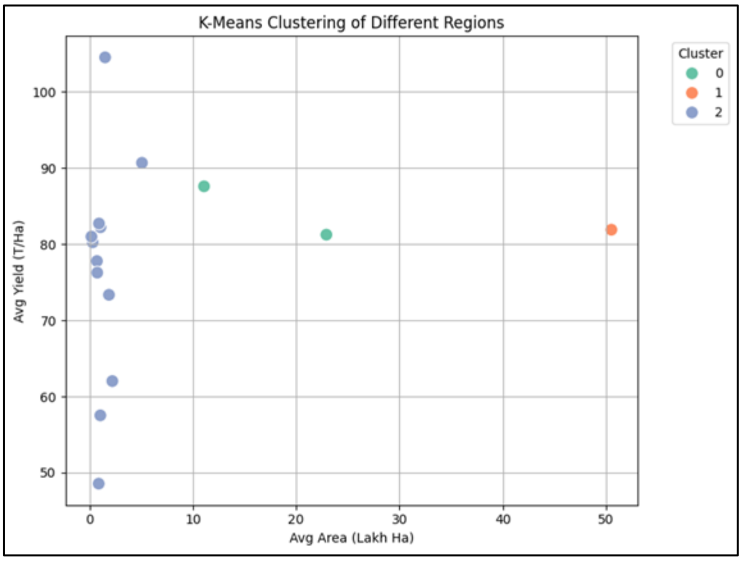

Figure 9 K- means plot showing 3 clusters based on Sugarcane Yield and Area under Sugarcane

Large Area, strong Production Backbone Cluster 0. In terms of the area under sugarcane crop Maharashtra and Uttar Pradesh hold a strong position. The yields in both states are moderate to high. These are considered important for sugarcane production. Cluster 0 stands for "bulk producers." Sum total of India is in Cluster 1 acts as the reference or “baseline cluster”. Cluster 2 - small to moderate area with varying yields. The majority of the remaining states are included in this cluster which exhibits significant heterogeneity. States with High Yields like Tamil Nadu, Karnataka, West Bengal, Punjab and Haryana. States of Low Yield like Bihar, Madhya Pradesh, Others. The majority of these states cultivate a limited area less than two lakh hectares.

4.6. Z – Score and Change Percentage Over Years

4.6.1. For Sugarcane Production

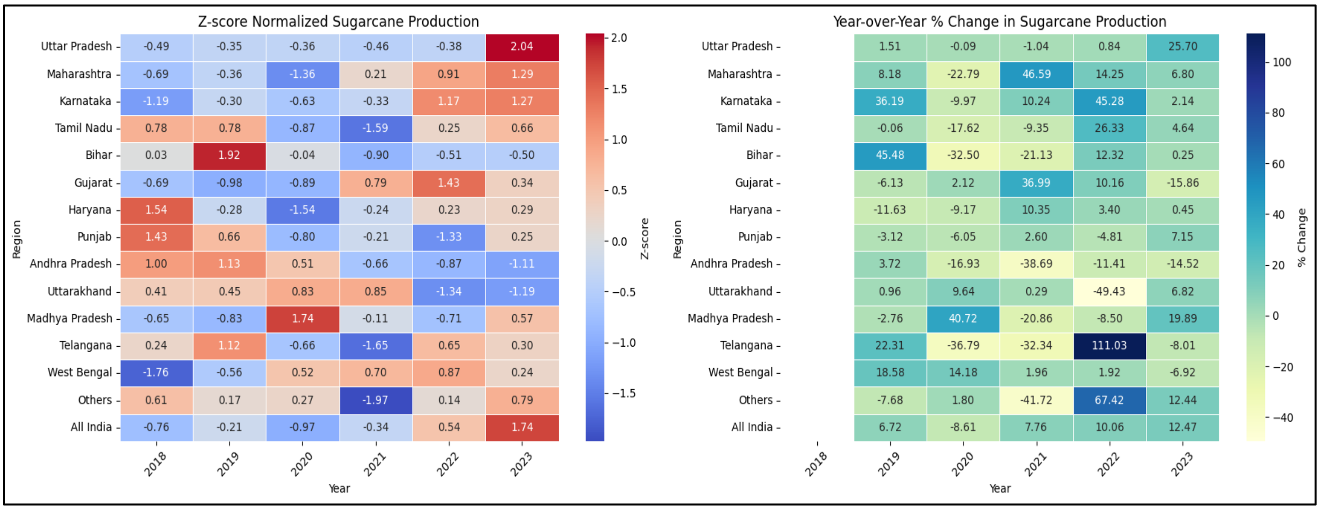

Figure 10 Z – score and Year-over-Year Change (%) for Sugarcane Production from 2018-2023.

For Z – Score and Year-on-Year % Change we have observed that volatility and performance Trends 2018 - 2019 with moderate YoY growth. With increasing Z - scores provide early indications of good momentum. Despite a few slackers, stability can be seen. 2020–202 years known for its negative output trends, declining Z-scores, and widespread stress. Increased volatility was accompanied by sharply unfavourable swings in several areas. 2022 year shown as a year of recovery, with a rebound in the Z-score and strong YoY growth. Some areas had record-breaking increases in production. 2023 year shows solidified growth, with tempered, less volatile YoY increases and high Z-score, indicating systemic stabilization and recovery.

4.6.2. For Sugarcane Yield

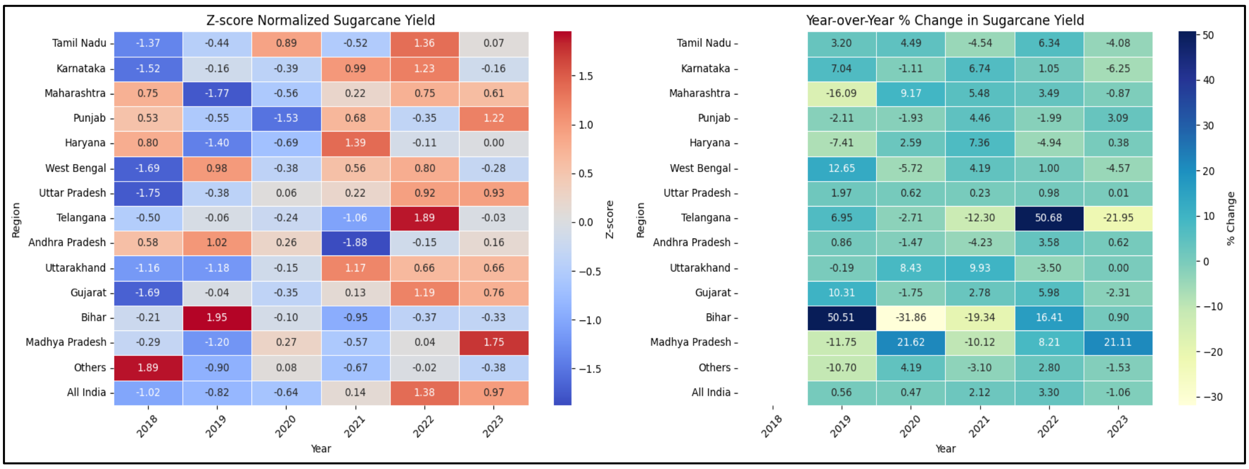

Figure 11 Z – score and Year-over-Year Change (%) for Sugarcane Yield from 2018-2023.

For the 2018 – 2019 years negative mean Z-scores indicate below-average yield across the major sugarcane producing states, with some exceptionally poor performers. For the year 2020 there is a tight distribution and a moderate rebound with low standard deviation, but the lack of notable highs suggests stagnation. For the 2023-year performance remained above average, although the mean decreased slightly from 2022.

Year-over-Year Change in Percentage: Important Findings with significant gains and fewer losses, 2022 is a yield turnaround year. A number of areas saw yield increases of more than 50%, indicating that post covid-19 farmers increased their production. Even with still-positive Z-scores, the YoY yield fell in 2023 (-1.1%), suggesting a slowdown in momentum. Yield stagnation and even regression were observed in 2020–2021, particularly in 2021 when average growth is negative.

4.6.3. For Area under Sugarcane

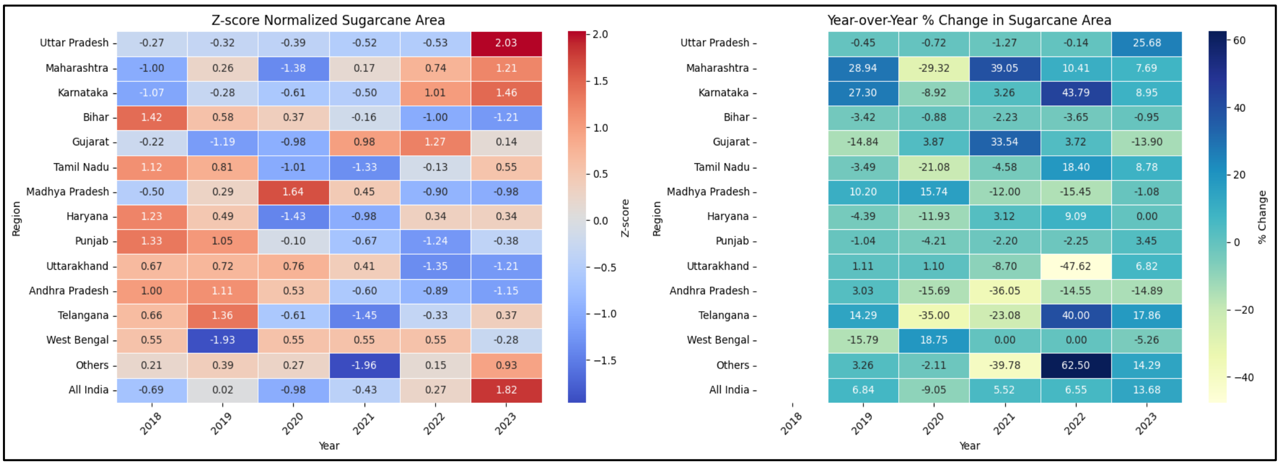

Figure 12 Z – score and Year-over-Year Change (%) for Area under Sugarcane from 2018-2023.

Area decreases occurred back-to-back in 2020 and 2021. In some regions, area decreases of 35% is noted in 2020. The largest area expansion (+7.39% avg.) occurred in 2022, with some states experiencing increases of up to 62.5% in area under sugarcane, showing vigorous re-adoption of sugarcane. It can be concluded that growth in 2023 slowed but was still positive and stable with lowest standard deviation since 2019. In the majority of regions, the area planted to sugarcane performed moderately to strongly between 2018 and 2019.

5. Conclusion

An examination of the patterns of sugarcane production in India between 2018 and 2023 reveals a dynamic interaction between regional difference, recovery and volatility. Production fell precipitously between 2020 and 2021, most likely as a result of pandemic-related disruptions as it had its lowest Z-score mean of -0.40 in 2021. But there was a significant recovery that peaked in 2023 at +0.47. The most variable was the cultivated area, which increased in 2018–2019, fell during the COVID years, and then recovered spectacularly in 2022–2023. Record expansions in certain states are reflected in the 2023 Z-score of +2.03. These results highlight the sector's potential and resilience while highlighting the necessity of region-specific approaches to reduce risk and encourage sustainable growth.

The correlation metrics triangle of sugarcane yield, its production and area under sugarcane shows that both acreage and yield have a significant impact on sugarcane production, although yield is the factor that drives output the most. While big areas alone cannot make up for low yield years, high yields greatly increase productivity.

India's sugarcane industry recovered well between 2018 and 2023, while regional differences still exist. Northern areas like Uttar Pradesh and Bihar trailed behind southern states like Maharashtra and Tamil Nadu in terms of yield. This disparity emphasizes the necessity of focused agronomic assistance and legislative changes. In these areas, bolstering the jaggery sector under ODOP can promote economic expansion and rural development.

Compliance with ethical standards

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Disclosure of conflict of interest

Author declares no conflict of interest.

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