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Research Paper

Strategic targeting and tailoring of Agromet Advisory Services for *Kharif* sorghum in India

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ABSTRACT

Timely availability of reliable, location- and crop-specific weather information is critical for prioritizing actions and minimizing agricultural losses. To tailor and target advisories specific to crop and location, a nested approach was adopted. This approach was applied to *Kharif* sorghum in which four production zones (Primary, Secondary, Tertiary and others) and four efficiency zones (most efficient, efficient, not efficient, and inefficient) were delineated for two recent decades (2001–2010) and (2011–2020) across 168 sorghum-growing districts. Nesting these zones revealed significant transitions over time, with more than 30 districts showing a notable decline in the most efficient cropping zone (MECZ) and efficient cropping zone (ECZ), underscoring the need for focused attention and intervention. By prioritizing transition zones and tailoring advisories using integrated decision support tools and feedback mechanisms, this approach aims to build resilience and minimize losses due to climate variability and extreme weather events in the miller growing regions.

Keywords: Agromet information, Production zones, *Kharif* sorghum, Cropping efficiency zones, Relative spread index (RSI), Relative yield index (RYI)

The agricultural sector faces the daunting task of producing sufficient food for the rapidly growing world population amidst the challenges posed by climate variability and change. In India, adverse weather conditions aggravated by climate change, manifests as frequent drought, floods, cold waves, heat waves, strong gusty winds, dust storms, heavy rainfall and cloud bursts. These conditions significantly impact the production and productivity of agriculture and allied sectors (Chattopadhyay and Chandras, 2018). In this context, the India Meteorological Department disseminates reliable climate information through accurate forecasts of various temporal and spatial resolution. This information is disseminated through a multi-channel system like Television, All India Radio (AIR), newspapers and Internet, different social media, SMS and IVR (Interactive Voice Response Technology) etc., are made on a wider scale. In addition to this, India Meteorological Department (IMD), Ministry of Earth Sciences (MoES), Government of India making efforts through the Gramin Krishi Mausam Seva (GKMS) scheme to deliver tailored weather forecast information along with agro advisory services to practice climate-smart agriculture by managing day to day agricultural operations in different crops to enhance potential capacity of farmers by considering all other issues of crop growing (Chattopadhyay and Chandras, 2018; Hansen, 2002).

As the Government of India celebrated International Year of Millets, IMD concentrates its services to millet growing areas. Millets encompass various groups of small-grained dry land cereals, known as “Neglected crops” which are underutilized and are gaining importance in the recent decade and promoted through national schemes and awareness (Ejigu *et al.,* 2025). Millets are growing under arid and semi-arid regions of the Deccan Plateau, Central and Western India apart from a few places in Northern India. The major millets-producing states are Rajasthan, Karnataka, Maharashtra, Uttar Pradesh, Haryana, Gujarat, Madhya Pradesh, Tamil Nadu, Andhra Pradesh and Uttarakhand accounting for 98 per cent of millets production during the period 2020-21 (APEDA, 2024).

In the context of fluctuating production and productivity of millets across various regions of India due to increasingly erratic

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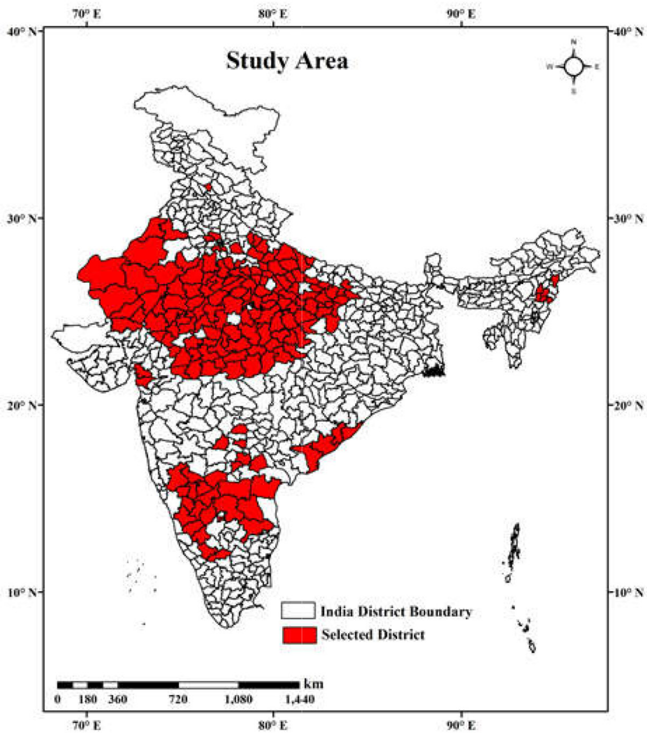


Fig. 1. Study area of major *Kharif* sorghum

rainfall patterns, adverse weather conditions, and the effects of climate change, there is a pressing need to delineate production zones (Jamidi *et al.,* 2025). To mitigate the negative impacts of weather vagaries, crop-specific agromet advisory services are crucial. These services, coupled with integrated management practices such as selecting suitable varieties, adjusting sowing times, managing supplemental irrigation, and adopting soil moisture conservation practices, can significantly contribute to sustaining millet yields (Boomiraj, 2012). Sandeep *et al.,* (2017) reported increasing trend in crop water requirement over majority of sorghum regions in *Kharif* and *Rabi* seasons with significant increase over the core growing area of *Rabi* sorghum and identified the regions where moisture stress is likely to be severe during both seasons. Present study is attempted through a nested approach, which involves identifying zones of change, prioritizing, and targeting climate information services for most challenging sorghum-growing areas.

MATERIALS AND METHODS

Study area and data

This research primarily encompasses the regions of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Nagaland, Rajasthan, Telangana, and Uttar Pradesh, renowned for their significant cultivation of *Kharif* sorghum. Maharashtra, despite its favourable topography and conducive monsoon patterns for *Kharif* Sorghum farming, was excluded from the present study due to unavailability of relevant data. Major sorghum growing regions selected in the present study are shown in Fig. 1. The district wise information on *Kharif* sorghum cultivation, including the area under cultivation, production, and productivity, as well as the total cultivable area of the sorghum for 20 years period (2001 to 2020) was collected from the Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare, Government of India. The collected data were divided into two decades: 2001-2010 and 2011-2020, to examine decade-wise changes in *Kharif* sorghum cultivation practices and outcomes.

Table 1: Criteria for classification of efficient cropping zone

RSI	RYI	Cropping zone
>100 (High)	>100 (High)	Most efficient cropping zone (MECZ)
>100 (High)	< 100 (Low)	Efficient cropping zone (ECZ)
< 100 (Low)	>100 (High)	Not efficient cropping zone (NECZ)
< 100 (Low)	< 100 (Low)	Highly inefficient cropping zone (HICZ)

Identification of production zones

District-wise data on area and production of *Kharif* sorghum from 2001 to 2010 (Decade 1) and 2011 to 2020 (Decade 2) was utilized to classify crop areas into distinct production zones for each decade. These zones, namely primary, secondary, and tertiary and others were determined based on the distribution of area under the crop across all districts. Districts were arranged in descending order according to their area under the crop, with the top districts covering 50% of the total cropped area categorized as the primary production zone. The subsequent 35% of the area (districts covering 50% to 85% of the total) were classified as the secondary production zone. Districts with negligible area (<1000 ha) under the crop were designated as 'others', while the remaining districts were classified as belonging to the tertiary production zone (Murthy *et al.,* 2007). This classification provides insight into areas where crop intensity is highest (primary zone), followed by secondary and tertiary zones. Subsequently, all district-wise data on area and production of *Kharif* sorghum was categorized into these delineated zones.

Classification of economic cropping zones

The analysis encompassed data pertaining to the area, production, productivity, and total cultivable area of *Kharif* sorghum across diverse districts and states over a 20-year period from 2001 to 2020, Decade-wise Relative Spread Index (RSI) and Relative Yield Index (RYI) (Kokilavani and Geethalakshmi, 2013) were derived from this dataset using the following formulae and presented in Table 1.

$$RSI = \frac{Areaofparticularcropexpressedas\ \%\ oftotalcultivableareainthedistrict}{Areaofcropexpressesaspercentagetothetotalcultivalbeareainthestate} * 100$$

$$RYI = \frac{Meanyieldofparticularcropinadistrict}{Meanyieldofcropinthestate} * 100$$

Trend analysis

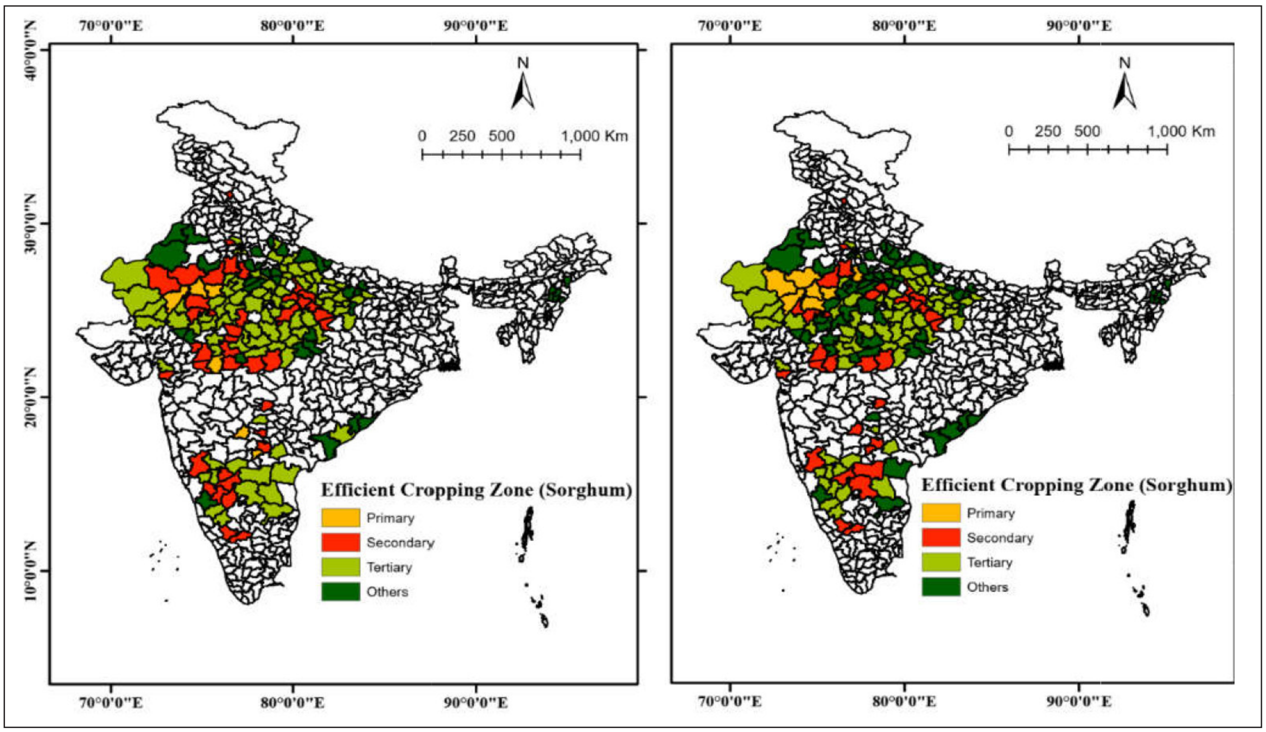
The Mann–Kendall (MK) test (Kendall, 1975; Mann, 1945) was employed to assess the trends in district wise area and productivity. It is a non-parametric test, which has no prerequisite conditions on the data to be normally distributed (Tabari *et al.,* 2011). The true slope (change per unit time) was predicted using Sen's

Table 2: Number of districts under different production zones of sorghum

Zones	Number of districts	
	Decade1 (2001-2010)	Decade2 (2011-2020)
Primary	6	7
Secondary	38	30
Tertiary	88	69
Others	36	62
Total	168	168

Table 3: Number of districts under different cropping efficient zones of sorghum

Efficient zones	Number of districts	
	Decade1 (2001-2010)	Decade2 (2011-2020)
Most efficient (MECZ)	31	33
Efficient (ECZ)	36	38
Not efficient (NECZ)	49	37
Highly inefficient (HICZ)	52	60
Total	168	168



Decade 1 **Decade 2**

Fig. 2: Distribution of sorghum production zone across two decades

slope (SS) estimator (Sen., 1968). The R package "modifiedmk" (Patakamuri *et al.,* 2020) was used to perform the above mentioned non-parametric tests.

RESULTS AND DISCUSSIONS

This study employed a nested approach to identify, prioritize, and target climate information services for *Kharif* sorghum cultivation, aiming to enhance resilience and adaptation strategies in response to climate variability. By classifying sorghum-growing areas into production-based zones and efficiency-based cropping zones, spatial and temporal dynamics were assessed across 168 major sorghum-growing districts of India over two decades.

Production zones of Kharif sorghum

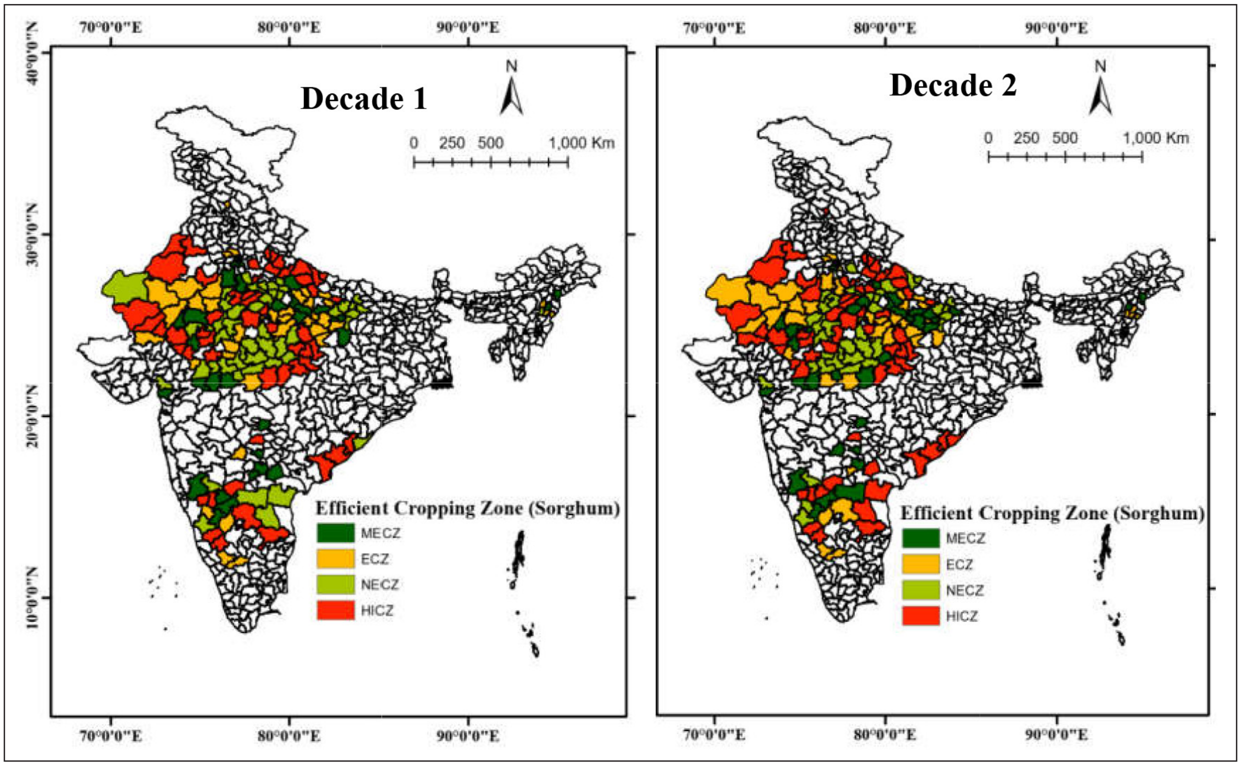
Kharif sorghum production zones were delineated into four categories based on the proportion of the crop's cultivated area. Table 2 presents the number of districts in each zone across both decades. A notable increase in the number of districts under the 'Others' category was observed in Decade 2 (62 districts), signifying an expansion of *kharif* sorghum cultivation into marginal or emerging areas with small-scale coverage. This trend could reflect changes in local cropping preferences, policy-led diversification, or climate-induced shifts. Fig. 2 depicts the spatial distribution of production zones highlighting dynamic changes in zone boundaries and the emergence of new sorghum clusters. These maps suggest that while core production zones have remained relatively stable, peripheral regions are increasingly engaging in sorghum cultivation, possibly in response to water stress or changing rainfall patterns. The clustering of production in specific districts further provides valuable indicators for identifying agro-ecological suitability and potential intervention hotspots.

Efficiency-based cropping zones (ECZ) of sorghum

Table 3 shows that between the two decades, the number of districts under MECZ increased from 31 to 33, ECZ from 36 to 38, and HICZ from 52 to 60, while NECZ saw a significant reduction from 49 to 37. These transitions reflect gradual improvements in cropping efficiency in certain regions, potentially driven by better

Table 4: Temporal dynamics of *Kharif* sorghum production zones (number of districts) with focus on efficient cropping zones (ECZ) over two decades

Zones	Decade1(2001-2010)					Decade2 (2011-2020)				
	MECZ	ECZ	NECZ	HICZ	Total	MECZ	ECZ	NECZ	HICZ	Total
Primary	2	4			6		7			7
Secondary	16	18	3	1	38	16	11		3	30
Tertiary	11	12	34	31	88	13	16	15	25	69
Others	2	2	12	20	36	4	4	22	32	62
Total	31	36	49	52	168	33	38	37	60	168



Decade 1 **Decade 2**

Fig. 3: Distribution of sorghum efficient cropping zones in two decades

agronomic practices or favourable climatic windows.

Spatial mapping of these zones (Fig. 3) reveals the regional shifts and clusters associated with changes in efficiency. Notably, the increase in MECZ and ECZ points toward regions achieving higher resource use efficiency and better yield outcomes, possibly due to improved varietal adoption or better climate information uptake. On the other hand, the decline in NECZ districts, coupled with a simultaneous increase in HICZ, highlights the need for targeted support in areas falling behind in productivity.

Nesting of production and efficiency zones

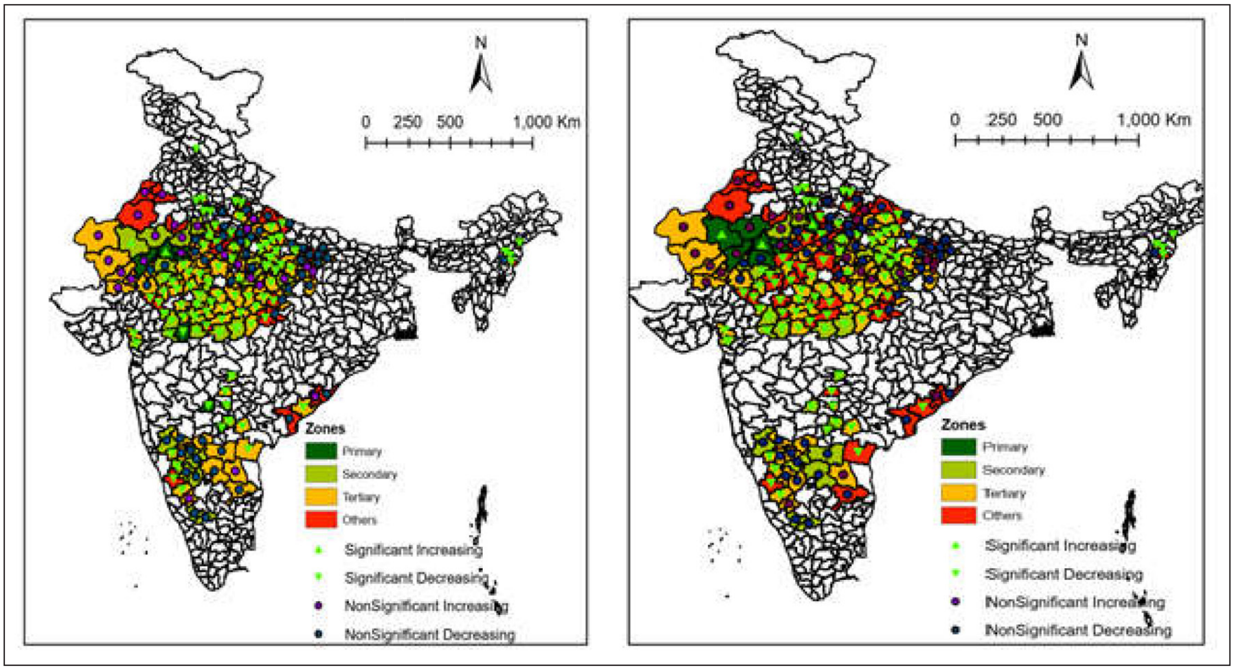
An integrated analysis of production and efficiency zones (Table 4) shows evolving district-level dynamics. In Decade 1, MECZ districts were largely aligned with Secondary production zones, while ECZ districts were more evenly distributed across Secondary and Tertiary zones. By Decade 2, MECZ expanded in size, while the number of ECZ districts remained stable, indicating plateauing efficiency in some regions. Meanwhile, NECZ districts reduced, but the increase in HICZ reflects a need to reassess input usage, climate risk management, and extension support. This combined zonation provides a deeper understanding of how cropping area, yield efficiency, and production trends interact over time and space. Such analysis is essential for identifying which districts can serve as climate-smart production zones and which require urgent interventions for yield stabilization.

Trends in Kharif sorghum production

District-wise production trends for each ECZ category are summarized in Table 5. The MECZ demonstrated a consistent and significant increase in production across both decades, reinforcing the positive trajectory of high-efficiency districts. The ECZ experienced both gains and losses, suggesting variability in performance. NECZ districts largely recorded production declines or stagnation, while HICZ districts, despite starting from a lower baseline, showed modest but significant increases. These variations underscore the complexity of factors influencing production trends across zones. It also suggests that efficient zones may be stabilizing

Table 5: Trends in number of districts sorghum efficient cropping zones using Mann-Kendall test

Efficient zones	Decreasing				Increasing			
	Significant		Non-significant		Significant		Non-significant	
	Dec.1	Dec.2	Dec.1	Dec.2	Dec.1	Dec.2	Dec.1	Dec.2
Most efficient (MECZ)	**17**	**21**	11	9	**1**	**-**	2	3
Efficient (ECZ)	**19**	**14**	7	11	**2**	**3**	8	10
Not efficient (NECZ)	**25**	**21**	18	15	**-**	**-**	6	1
Highly inefficient (HICZ)	**26**	**31**	15	16	**1**	**1**	10	12



Decade 1 **Decade 2**

Fig. 4: Trend of *Kharif* sorghum under different production zones

production through better input management and climate adaptation practices, while inefficient zones still lag due to biophysical or socio-economic constraints.

Statistical trend analysis and implications

To assess long-term trends in cropped area, a Mann-Kendall trend analysis was performed (Fig. 4). A statistically significant decreasing trend in *kharif* sorghum area was detected in the Secondary zones during Decade 2. Among these, 11 districts in the MECZ and 5 in the ECZ showed negative trends in area, signalling a critical need for region-specific interventions. These findings imply that even among relatively efficient districts, there is a risk of area decline, possibly due to climatic stress, market volatility, or a shift toward alternative crops. Districts under 'Tertiary' and 'Others' zones, especially those in MECZ and ECZ, require special attention, as they represent transitional zones where area expansion may be occurring but without commensurate efficiency gains. Climate information services (CIS) tailored to the needs of these regions can help bridge this gap.

Climate information services (CIS) and agromet-advisories

In the context of decreasing area and fluctuating efficiency, the strategic deployment of CIS becomes essential. More than 30 districts across MECZ and ECZ exhibited declining cropped area over the two decades, underscoring the urgency of targeted communication and intervention. Disseminating customized CIS in these districts translated into localized agro-advisories can enable timely agronomic decisions, reduce climate risks, and support sustainable intensification. Farmer Awareness Programmes (FAPs) and decentralized dissemination networks are vital for ensuring that CIS reach last-mile users effectively. Feedback loops and participatory engagement are equally important for refining services based on farmer response and ground realities. Location specific management options can be adopted to mitigate the negative impacts of the change in climate in future projected scenarios, as they are found beneficial (Sandeep *et al.,* 2018).

CONCLUSIONS

The findings of this study demonstrate substantial spatial and temporal shifts in *Kharif* sorghum productivity across India's major growing districts. This crop-based zoning approach has enabled the identification of regions experiencing declining efficiency, serving as a baseline for targeting agro-advisory services. While the present study was based solely on crop data, it is acknowledged that both climatic and non-climatic factors contribute to yield fluctuations. To address this, future studies will incorporate long-term weather data—including rainfall, temperature, and moisture indices—aligned with critical phenological stages of sorghum. This study demonstrates the utility of spatial zonation combined with efficiency analysis for targeting climate services. By identifying shifts in production, area, and efficiency, the study offers a pathway to strengthen millet-based climate resilience strategies in India.

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Data availability: Data on area under cultivation, production, productivity, and total cultivable area of sorghum (2001–2020) were obtained from the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.

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