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Dynamics of Cropping Pattern and Water Resource Management in the Cauvery Basin: An Econometric Analysis

Y. H. Preeti[1], S. V. Suresha[2], Y. N. Shivalingaiah[3], Lalith Achoth[4], Shivashankar Tanakanakal[5]
[1,2&3]Department of Agricultural Extension, [4]Department of Agricultural Economics, [5]Department of Agricultural Statistics, Applied Mathematics and Computer Science, College of Agriculture, UAS, GKVK, Bengaluru - 560065
e-Mail : hemanthpreetiy@gmail.com

Authors Contribution

Y. H. Preeti : Conceptualization, collection and data analysis and preparation of manuscript

S. V. Suresha : Supervisor, verified the analytical approches and results interpretation

Y. N. Shivalingaiah & Lalith Achoth : Guidance, results interpretation and editing manuscript

Shivashankar Tanakanakal: Analysis of dataset

Corresponding Author :
Y. H. Preeti

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Abstract

This study investigates shifts in cropping patterns, water consumption and crop diversification within the Cauvery command area over the period 2000-01 to 2019-20, highlighting the region's adaptive responses to water scarcity. Using twenty years data, crop changes were analysed through Markov Chain Analysis and transitional probabilities were calculated using Linear Programming. Results show that rice, the most water-intensive crop, saw a decline in cultivation area from 167,018 hectares (22.86%) in 2000-03 to 139,030 hectares (17.55%) in 2017-20, signalling a gradual shift toward less water-demanding crops. Crops such as maize and coconut increased significantly with maize cultivation growing from 20,061 hectares (2.75%) to 41,984 hectares (5.30%) and coconut from 34,351 hectares (4.70%) to 72,290 hectares (9.13%). These shifts reflect a response to water scarcity, as evidenced by the Herfindahl-Hirschman Index (HHI) of 0.20 and Simpson's Diversity Index (SDI) of 0.80, which indicate substantial diversification. The findings underscore the importance of water-efficient cropping, with policymakers advised to support irrigation improvements, drought-resistant crop adoption and enhanced market access to sustain agricultural resilience in the face of environmental pressures.

Keywords : Crop diversification, Cauvery command area, Markov chain analysis, Water management

Cropping pattern refers to the proportion, arrangement and types of crops grown in a particular area over time. It represents the flexible tactics farmers use as a reaction to a range of circumstances, such as resource availability, market demands, environmental conditions and policy changes. Given its impact on crop yields, soil health, water use efficiency and income stability in farming communities, an understanding of cropping patterns is essential for agricultural sustainability (Saliu, 2023). In a country like India, where agriculture contributes around 18.00 per cent to the GDP and supports nearly 58.00 per cent of rural households, evolving cropping patterns are essential in addressing food security, economic stability and employment prospects (Anonymous, 2023). Shifts in cropping patterns allow for the optimization of water and land resources, income diversification and increased resilience against climate-induced risks. For example, transitioning to drought-resistant or low-water-use crops can help mitigate the impacts of erratic rainfall, ensuring crop stability and sustained livelihoods for farmers.

In Karnataka, agriculture remains a primary source of income for rural communities, making the monitoring and management of cropping pattern changes vital. This importance is amplified in command areas-regions equipped with irrigation infrastructure that facilitates high-output agriculture. Command areas, like the Cauvery command area, cover zones under large irrigation projects where water is actively managed to support extensive crop cultivation, impacting the agricultural output of the entire region. However, these areas face distinct challenges tied to water scarcity and crop selection. The high dependency on water-intensive crops like rice has long contributed to water scarcity issues with dry years or drought conditions amplifying water shortages. Moreover, water distribution is often unequal across the command area, with head-reach zones (closer to water sources) receiving more consistent water supply than mid- or tail-end zones. This imbalance can create disparities in productivity and economic outcomes with tail-end farmers frequently at a disadvantage. To ensure fair resource distribution and mitigate water stress, promoting a cropping pattern that aligns with water-efficient, drought-tolerant and economically viable crops is critical. Adopting recommended cropping patterns that balance water usage can help stabilize agricultural productivity, enhance equity in water access and contribute to sustainable farming practices across the entire command zone. Through strategic crop planning, these areas can bolster resilience, reduce water dependency and promote long-term agricultural viability. With this brief background the study has been conceptualize with following objective: To study the dynamic changes in the cropping pattern and water management practices in Cauvery command area

Methodology

Measurement of Dynamic Changes in Cropping Pattern in Command Areas of Karnataka

The present study was conducted at the University of Agricultural Sciences, Bangalore (UAS-B) during 2024. The dynamic changes in cropping patterns were measured using twenty years crop data (2000-2001 to 2019-2020) for principal crops grown in the Cauvery Command Areas. The Cauvery Command Area Development Authority manages 15 major and medium irrigation projects. For this study, one of the projects covering highest irrigated area was considered in the same way, the Krishnaraja Sagara Irrigation Project in Cauvery command area were considered, covering the districts of Mandya and Mysore. Crop data from both districts were collected and combined, focusing on those crops that cumulatively account for 95.00 per cent of the area. These crops were classified as major crops, while the remaining crops were grouped into an 'others' category.

Twenty years of time series data (2000-2001 to 2019-2020) were collected from the Directorate of Economics and Statistics (DES), Bengaluru and the Department of Agricultural and Cooperation Network (DACNET). The dynamic changes in cropping patterns in both command areas were analysed using crop diversification indices and Markov chain analysis.

To Analyse the Dynamic Changes in Cropping Pattern Markov Chain Analysis Tool is Applied

Markov Chain Analysis

To assess the shift in cropping pattern of area under crops during 2000-2001 to 2019-2020, transitional probabilities were calculated based on linear programming (LP) approach using LP SOLVER IDE software. Markov chain analysis develops a transitional probability matrix 'P' whose elements P_{ij} indicate the probability (share) of crop switching from the i^{ih} crop to the j^{th} crop over time. Its diagonal elements represent retention share of respective crop in terms of area under crops. This can be algebraically expressed as equation:

$$E_{jt} = \sum [E_{it} - 1] P_{ij} + e_{ij}$$

$$I = 1,\ldots\ldots,n$$

Where,

E_{jt} = Area under j^{th} crop in the year 't'

$E_{it}-1$ = Area under i^{th} crop during the year 't-1"

P_{ij} = The probability of shift in area under i^{th} crop to j^{th} crop

e_{ij} = The error-term statistically independent of $E_{it} - 1$ and

n = Number of crops

The transitional probabilities P_{ij} arranged in (m x n) matrix have the following properties:

$\sum P_{ij} = 1$ and 0 dHP_{ij}dH 1

I = 1,…..,n

The Transitional Probability Matrix (T) Based on LP Framework is Estimated Using Minimization of Mean Absolute Deviation (MAD)

Min, OP*+ Ie

Subjected to

XP* + V = Y

GP* = 1

P* > 0

Where, P* is the transitional probability matrix, '0' is the zero vector, 'I' is an appropriately dimensional vector of areas and 'e' is the vector of absolute errors.

To Forecast the Crop Area from 2020-2021 to 2029-2030 Matrix Multiplication Tool is Applied

Matrix Multiplication

This method helps in projecting future cropping patterns and understanding the inter-relationships between different crops.

Determine Coefficient Matrix (B)

Use the formula B = (X^T * X)^-1 * X^T * Y to calculate the coefficient matrix, where X^T is the transpose of the input matrix X.

Calculate Predictions (v):

Use the formula Y = X * B to forecast the dependent variable.

To Assess the Extent of Crop Diversification, the Following Indices were Used

a) Herfindahl-Hirschman Index (HHI) : It is the sum of square of the proportion of acreage under each crop to the total cropped area and is given by the equation:

$$HHI = \sum_{i=1}^{N}(MS_i)^2$$

Where MS_i represents Mean square of acreage proportion of the ith crop in total cropped area. The Herfindahl index takes the value of one when there is specialization and approaches zero when there is diversification.

b) Simpson Diversity Index (SDI) : It is the most suitable index for measuring diversification of crop in a particular geographical region and is calculated by equation

$$SI = 1 - \sum_{i=1}^{N} P_i^{2}$$

Where, $P_i = A_i/\sum A_i$ is the proportion of the ith activity in acreage. Simpson index of near zero, indicates that the zone or region is near to specialization in growing of a particular crop and if it is close to one, then the zone is fully diversified in terms of crops.

Results and Discussion

Table 1 provides a comparative analysis of average crop areas in the Cauvery command area across two periods: 2002-03 and 2017-20, illustrating shifts in cultivation patterns and increasing crop diversification. Rice remains dominant but saw a decrease from 167,018 hectares (22.86%) in 2002-03 to 1,39,030 hectares (17.55%) in 2017-20. This decline reflects a move away from water-intensive crops due to water scarcity and changing market demands. Despite Rice's continued importance, its reduced share suggests concerns about long-term sustainability. Area under Ragi also declined from 1,44,384 hectares (19.77%) to 1,12,055 hectares (14.15%), indicating a shift toward more profitable crops, though this may impact dietary diversity given Ragi's nutritional value. Similarly, Horsegram dropped from 88,562 hectares (12.12%) to 64,027 hectares (8.08%), reflecting farmers' preference for higher-value crops in response to market changes. Cotton Lint area decreased from 61,247 hectares (8.38%) to 42,620 hectares (5.38%), likely due to global market fluctuations and increased competition from synthetic fibres, raising concerns about Cotton's

TABLE 1

Cumulative change in the area of principal crops in Cauvery command area (2000-01 to 2002-03 and 2017-18 to 2019-20)

Crops	2000-01 to 2002-03		2017-18 to 2019-20	
	Average area*	Per cent	Average area*	Per cent
Rice	167018	22.86	139030	17.55
Ragi	144384	19.77	112055	14.15
Horse gram	88562	12.12	64027	8.08
Cotton Lint	61247	8.38	42620	5.38
Coconuts	34351	4.70	72290	9.13
Sugarcane	41746	5.71	38987	4.92
Maize	20061	2.75	41984	5.30
Others	173129	23.71	281025	35.49
Total cultivated area	730498	100.00	792018	100.00

*Area in hectares

viability in the region. Coconut cultivation, however, increased significantly from 34,351 hectares (4.70%) to 72,290 hectares (9.13%), signalling a shift toward cash crops with stable income potential. This trend suggests Coconut's increasing role in diversified and resilient farming systems. Sugarcane experienced a modest decline from 41,746 hectares (5.71%) to 38,987 hectares (4.92%), as high water requirements make it challenging in a water-scarce environment. Meanwhile, the 'Others' category, which includes minor crops, pulses and vegetables, expanded from 173,129 hectares (23.71%) to 281,025 hectares (35.49%), indicating a strong trend toward diversification as farmers explore alternative crops with economic and climate resilience benefits. This cumulative changes in area is graphically shown in Fig. 1 and 2, respectively. In conclusion, as farmers adjust to shifting conditions, the data highlights a move away from traditional staples like rice, ragi and cotton and toward a more

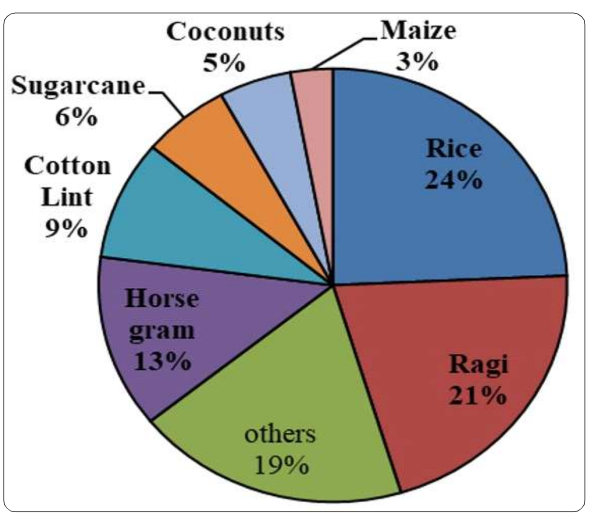

Fig. 1 : Cumulative change (2000-01 to 2002-03)

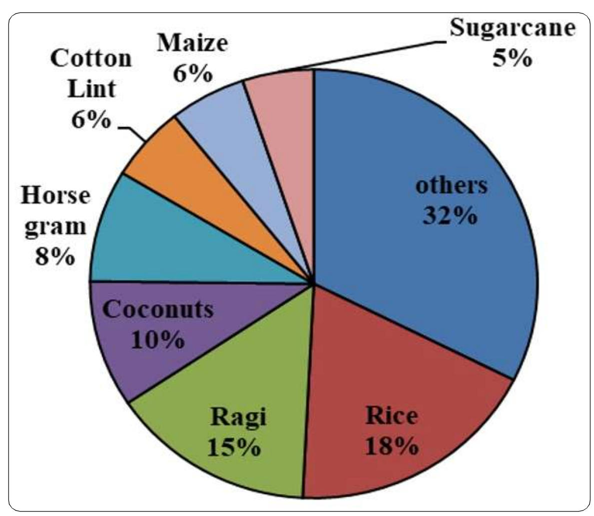

Fig. 2 : Cumulative change (2017-18 to 2019-20)

TABLE 2

Transitional probability matrix of changes in cropping pattern for Cauvery command area (2000-01 to 2019-20)

	Rice	Ragi	Horsegram	Cotton Lint	Coconuts	Sugarcane	Maize	Others
Rice	0.435	0.234	0.007	0.174	0.058	0.000	0.071	0.022
Ragi	0.297	0.286	0.178	0.000	0.053	0.072	0.000	0.114
Horse gram	0.266	0.494	0.119	0.047	0.000	0.074	0.000	0.000
Cotton Lint	0.000	0.122	0.878	0.000	0.000	0.000	0.000	0.000
Coconuts	0.000	0.000	0.000	0.000	0.331	0.161	0.034	0.474
Sugarcane	0.000	0.000	0.000	0.000	0.000	0.327	0.000	0.673
Maize	0.000	0.000	0.000	0.187	0.081	0.000	0.569	0.163
Others	0.181	0.000	0.000	0.031	0.039	0.000	0.000	0.749

varied crop base that includes coconuts and minor crops.

Table 2 shows the transitional probability matrix, outlining the likelihood of land under specific crops in the Cauvery command area shifting to other crops from 2000-01 to 2019-20. This matrix highlights farmers' responses to market conditions, water availability and climate factors. Rice has a 43.5 per cent probability of continuing as Rice, reflecting its stability, while a 23.4 per cent chance of transitioning to Ragi suggests that in unfavourable rainfall years, some land shifts towards Ragi for its nutritional benefits and lower water needs. Meanwhile, the 17.4 per cent transition to Cotton reflects diversification efforts. Ragi has a 28.6 per cent likelihood of remaining Ragi but a 29.7 per cent chance of shifting to Rice, indicating flexibility based on water availability and market prices. Horsegram shows a 49.4 per cent chance of transitioning to Ragi, as its lower market value makes it less favourable; its retention rate at 26.6 per cent highlights a reduced role in cropping choices. Cotton demonstrates strong stability with an 87.8 per cent probability of remaining as Cotton, while Coconuts show a 33.1 per cent chance of remaining and a 47.4 per cent chance of diversifying into 'Others,' reflecting a trend towards risk-spreading and economic opportunities. Sugarcane has a high probability (67.3%) of moving into 'Others,' emphasizing water resource constraints. Maize exhibits stability (56.9%) with some shift toward Cotton, indicating its dual role as a food and cash crop. Land in the 'Others' category has a 74.9 per cent likelihood of remaining diversified, demonstrating farmers' resilience through varied crop options to mitigate market and climate risks. In summary, the matrix captures a dynamic shift away from traditional staples like Rice and Ragi towards resilient options like Maize, Coconut and other minor crops. Similar results were reported by Satish and Umesh (2017). In order to validate the transition probability matrix depicted in Table 2, the actual and predicted areas under rice cultivation has been shown in Fig. 3. A perusal of the Fig. 3 shows a good fit of the model to the data.

Rice cultivation in the Cauvery command area is projected to increase slightly, from 1,54,880 hectares in 2020–21 to 1,71,935 hectares in 2029-30, maintaining its dominance as a staple crop despite its high water requirements. This trend underscores the need for sustainable water management practices and the development of water-efficient rice varieties to ensure long-term viability. Ragi cultivation is expected to grow steadily from 90,490 hectares in 2020–21 to 1,12,885 hectares in 2029–30, driven by its low water requirements and increasing recognition as a nutritious food grain. Policy support and market incentives can further enhance its contribution to food security and nutritional diversity.

Horsegram, known for its resilience in water-scarce conditions, is forecasted to grow from 54,121 hectares

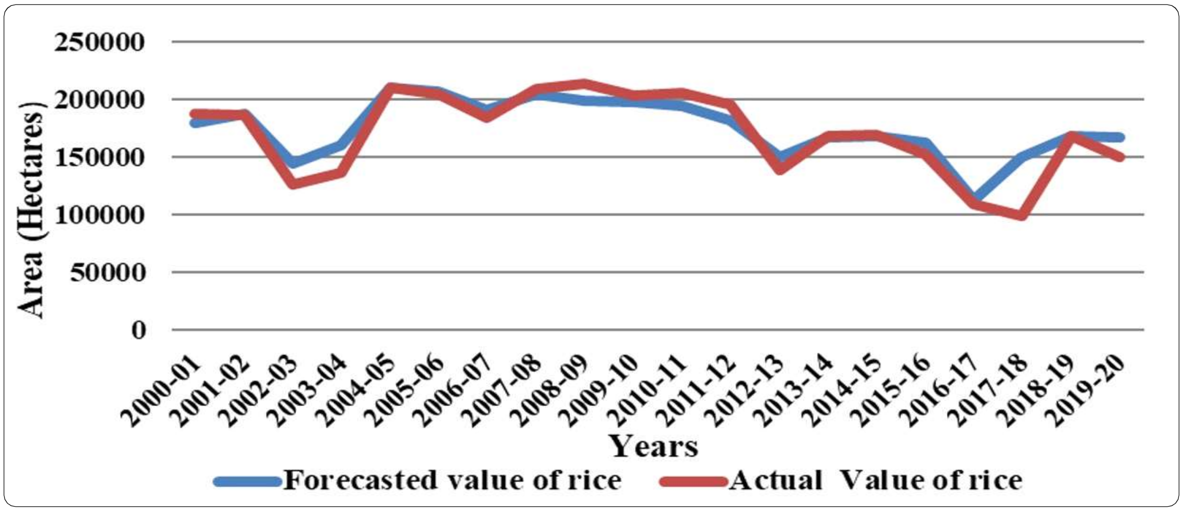

Fig: 3 : Graphical representation of Model validation

Table 3

Forecast of major crop areas in the Cauvery command area from 2020-21 to 2029-30

Year	Rice	Ragi	Horse gram	Cotton Lint	Coconuts	Sugarcane	Maize	Others	Total cultivated area*
2020-21	154880	90490	54121	41783	53428	38216	31911	299059	763888
2021-22	162951	93919	60249	44706	45677	31582	30969	293835	762613
2022-23	167604	99836	63992	45909	43330	28774	30638	281256	761337
2023-24	170376	104771	66679	46522	42689	28230	30750	270046	760062
2024-25	171728	108226	68429	46806	42469	28502	30987	261638	758787
2025-26	172283	110426	69508	46909	42348	28933	31211	255893	757512
2026-27	172423	111729	70121	46921	42251	29291	31373	252129	756237
2027-28	172351	112436	70435	46888	42162	29531	31471	249687	754962
2028-29	172170	112772	70569	46833	42078	29669	31519	248075	753686
2029-30	171935	112885	70595	46768	41999	29734	31530	246965	752411

*Area in hectares

in 2020-21 to 70,595 hectares by 2029-30. Raising awareness about its dietary and economic benefits and with standing the water stress condition could further boost its cultivation. Cotton cultivation is predicted to remain stable, ranging from 41,783 hectares in 2020-21 to 46,768 hectares by 2029-30, reflecting steady market demand. Strengthening the cotton value chain through processing and export support can improve returns for farmers.

Coconut cultivation is expected to decline from 53,428 hectares in 2020-21 to 41,999 hectares in 2029-30, due to water scarcity and market challenges. Investments in irrigation infrastructure and value-added processing facilities are necessary to counter this trend. Sugarcane is projected to decrease significantly, from 38,216 hectares in 2020-21 to 29,734 hectares in 2029-30, reflecting a shift away from water-intensive crops. Policies promoting alternative crops and supporting farmers during transitions are essential.

Maize cultivation is expected to remain stable with slight fluctuations from 31,911 hectares in 2020-21 to 31,530 hectares in 2029-30, supported by its drought tolerance and steady market demand. Improved seed varieties and marketing channels can enhance its role.The 'others' category is expected to decline from 2,99,059 hectares in 2020-21 to 2,46,965 hectares by 2029-30, reflecting a shift toward more profitable or sustainable cropping patterns. Diversification and market support for these crops are crucial for agricultural resilience.

Table 4 illustrates the water consumption (in TMC feet per hectare) for key irrigated crops in the Cauvery command area from 2000-01 to 2019-20, revealing significant variability across different crops and years (Anonymous, 2011). The water requirement for each crop is calculated by multiplying the amount of water needed for crop cultivation by the area under cultivation for that crop in a given year. Rice consistently ranks as the highest water consumer with usage fluctuating from 99.48 TMC feet/ha in 2000-01 to 57.90 TMC feet/ha in 2016-17, highlighting its substantial reliance on water resources. The pronounced variability in water consumption can be attributed to Karnataka experienced nearly 15 drought

TABLE 4

Water consumption of major crops in Cauvery command area

Year	Rice (TMC feet/ha)	Cotton (TMC feet/ha)	Coconut (TMC feet/ha)	Sugarcane (TMC feet/ha)	Total (TMC feet/ha)
2000-01	99.48	18.94	5.22	30.01	153.65
2001-02	98.95	19.43	6.32	25.90	150.6
2002-03	66.99	16.79	6.65	32.54	122.97
2003-04	72.08	10.84	6.35	30.18	119.45
2004-05	111.49	12.85	6.63	16.17	147.14
2005-06	108.41	21.90	5.70	15.45	151.46
2006-07	97.44	13.99	6.49	21.21	139.13
2007-08	110.98	16.53	7.07	23.92	158.5
2008-09	112.92	15.74	7.93	19.67	156.26
2009-10	107.86	13.10	8.38	23.15	152.49
2010-11	108.98	12.38	9.28	35.55	166.19
2011-12	103.38	11.72	9.36	29.99	154.45
2012-13	73.62	13.36	7.60	24.93	119.51
2013-14	89.03	13.86	7.64	19.39	129.92
2014-15	89.92	14.46	8.82	18.15	131.35
2015-16	80.52	14.76	7.30	24.05	126.63
2016-17	57.90	11.93	7.45	14.81	92.09
2017-18	52.43	14.42	8.17	17.72	92.74
2018-19	88.87	13.04	14.91	31.06	147.88
2019-20	79.63	10.92	15.21	33.82	139.58

1 TMC feet/ha= 2,831,680 litres of water

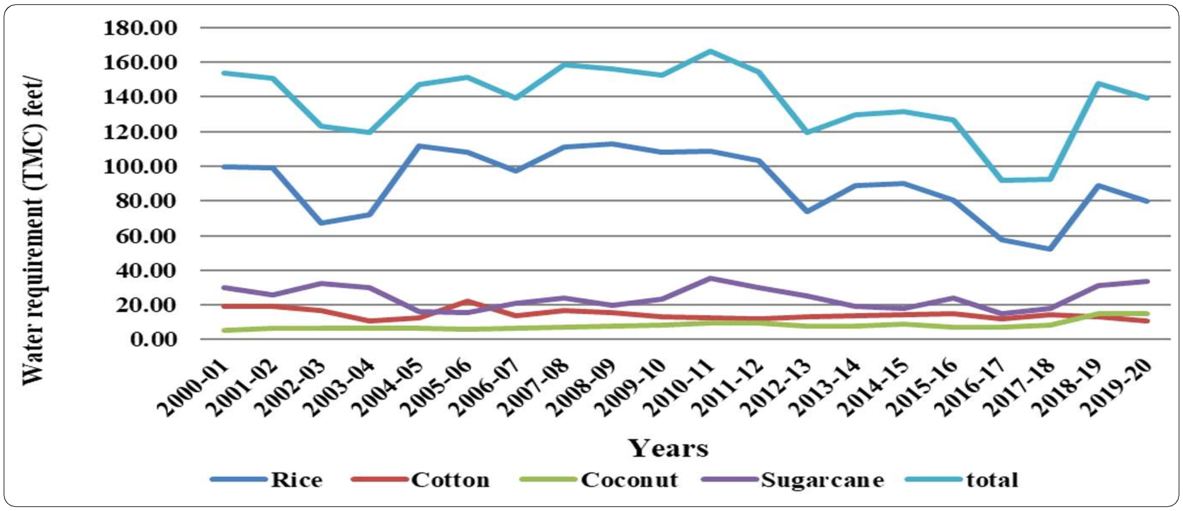

Fig: 4 : Water consumption of major crops in cauvery command area

years during this period. This situation has prompted farmers to adopt more water-efficient practices in response to the limited availability of water.

Cotton shows fluctuating yet relatively lower water consumption, starting at 18.94 TMC feet/ha and stabilizing at an average of 14.76 TMC feet/ha, indicating its potential to adapt to variable water availability better than rice, though consistent water supply is still crucial during key growth stages. Coconut, with moderate water usage between 8.73 and 9.99 TMC feet/ha, demonstrates resilience under diverse water conditions, making it a viable choice for water-scarce areas while remaining economically profitable. Sugarcane, another high water-demand crop, reached a peak usage of 35.55 TMC feet/ha in 2010-11, then declined, likely due to changing climatic and irrigation factors, highlighting the importance of careful water management in drought-prone regions. These patterns underscore the urgent need for sustainable water management, as the predominance of water-intensive crops like rice and sugarcane raises sustainability concerns. To ensure agriculture's long-term viability, policymakers should focus on efficient irrigation, promote drought-resistant crop varieties and advocate for water conservation. Table 4 underscores the importance of targeted policies supporting water-efficient cropping practices and safe guarding water resources amid intensifying climate challenges, which are critical for enduring agricultural resilience. Similar recommendations were noted by Kaur and Pardeep (2022).

Table 5 details crop diversification indices for the Cauvery command area, underscoring its agricultural diversity. The Herfindahl-Hirschman Index (HHI) for this region stands at 0.20, reflecting a relatively diverse cropping pattern. Likewise, the Simpson's Diversity Index (SDI) of 0.80 reinforces this, suggesting a well-distributed mix of cultivated crops.

These indices indicate that farmers in the Cauvery command area are embracing a variety of crops, potentially enhancing resilience to climate fluctuations and market changes. Policymakers can encourage this positive trend by supporting sustainable

TABLE 5

Crop diversification of Bhadra and Cauvery command area

Index	Cauvery
Herfindahl–Hirschman index	0.20
Simpson's Diversity Index	0.80

practices, promoting crop rotation and improving market access for diverse crops, which could bolster the economic sustainability of agriculture in the region. Similar findings were noted by Basu (2023), Bhattacharya and Sharma (2023).

The findings of this study highlight significant shifts in the cropping patterns and water usage practices in the Cauvery command area over two decades. Driven by water scarcity, farmers are gradually moving away from water-intensive crops like rice toward more water-efficient options such as maize and coconut. The Herfindahl-Hirschman Index and Simpson's Diversity Index reflect a trend toward diversification, which enhances resilience to water scarcity and market volatility. Policymakers are encouraged to prioritize initiatives that support irrigation efficiency, drought-resistant crops and broader market access to ensure sustainable agricultural practices. Overall, this study underscores the necessity for adaptive water management and crop diversification as essential strategies for maintaining agricultural sustainability in the face of environmental challenges.

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