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Identification of Mutation Point and Trend Analysis of Area, Production and Yield of Wheat Crop in Gujarat, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study aimed to identify mutation points and analyze trends in wheat cultivation in Gujarat from 1973-74 to 2022-23 using time series data on wheat area, production, and yield obtained from the CMIE. Non-parametric methods, including Pettitt's test, the Standard Normal Homogeneity (SNH) test, and Buishand's range test, were employed to identify mutation points. Sen's slope estimator measured trend magnitude, while the Mann-Kendall test assessed statistical significance. Results revealed 2004 as a key mutation point for wheat area, according to the Buishand range and SNH tests. The year 2002 was identified as a significant mutation point for wheat production by both the Pettitt's and Buishand range tests, and for yield by all three tests. Sen's slope analysis showed the

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highest growth in production (61.33 thousand tonnes/year, 2002-2023) and a lowest growth in the area (-3.52 thousand ha/year, 1973-2003). The analysis highlights the need to enhance agricultural practices and resource management to address the declining wheat cultivation area while capitalizing on the growth in production and yield for sustainable agricultural development in Gujarat.

Keywords: Change point; trend; wheat; M-K test; Sen's slope.

1. INTRODUCTION

"Wheat is the most consumed crop globally, next to rice and maize. It is the main grain used in Old World agriculture. Wheat belongs to Graminace family. Wheat can be consumed in a variety of ways, such as in bread, chapatti, porridge, flour, and suji The nutritional profile of wheat is fairly good: it contains 12.1% protein, 1.8% fats, 1.8% ash, 2.0% reducing sugars, 6.7% pentosans, 59.2% starch, 70% total carbohydrates, and 314 kcal per 100g of meal" [1]. "It is commonly grown in North American continent, Latin American including Europe, West Asia, North Africa, South Africa, East Africa, South Asia and Australia. In 2022, the total global production of wheat was 771 million tons. Representing over 41% of global wheat production, China, India, and Russia are the three leading producers of wheat on a per capita basis" [2]. "Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar and Gujarat are the major wheat-growing states in India. Among all the wheat growing states, Gujarat occupies 7th position in respect to area and production. In Gujarat, area under wheat is 1.06 million ha with a production of 3.46 million tonnes (2022-23) and it is mostly grown in Bhal region consisting of some parts of Kheda, Ahmedabad, Bhavnagar and Surendranagar districts" [3].

"Understanding the fluctuations in wheat production is very essential for developing countries like India. It is required to enhance the level of wheat production in the face of the rapid growth of population and declining production of wheat. There is a need to determine monotonic trends of production and it helps to know the current situation of wheat production. To meet this requirement, we need to know the status of wheat crop at the state level" [2]. Therefore, it is necessary to identify the mutation point and trend analysis of wheat crop in Gujarat state in order to inject policy innervations for sustainable growth of wheat production in the State. In view of the above facts, an attempt has been made to investigate the mutation point and trend analysis of wheat crop in Gujarat during the last five decades where a drastic change appears.

2. METHODOLOGY

Gujarat, a state on the western coast of India, is strategically located between latitudes 20°1'N and 24°7'N and longitudes 68°4'E and 74°4'E. It is bordered by the Arabian Sea to the west, providing an extensive coastline of over 1,600 kilometers, which is crucial for its maritime trade. To the northeast, Gujarat shares its boundary with Rajasthan, to the east with Madhya Pradesh, and to the southeast with Maharashtra. It has an area of 196024 km^2, majorly dominated by agriculture land use. Agriculture has historically been the primary industry in the area due to the abundance of rich land. To The present study deals with identification of mutation point and trend analysis of wheat crop in Gujarat state. To full fill the objectives of the study, a secondary data on area, production and yield of wheat crop of Gujarat state covering the period 1973-74 to 2022-23 have been obtained from CMIE (Centre for Monitoring Indian Economy). The time series data was analyzed by using XLSTAT trial version.

2.1 Identification of Mutation Point

The purpose of the mutation point analysis (also called the change point analysis) is to determine where significant changes in the wheat crop take place. To determine the change points in the time series data, multiple researchers employed a variety of methodologies. Different distribution-free statistical techniques have been used by numerous researchers to identify the change points in time series data [4]. Below are specific approaches for detecting change points in data [5,6].

2.1.1 Pettitt's test

Pettitt test's method is a non-parametric test method based on the rank to detect abrupt changes in the mean of the variables. This method is commonly applied to detect single change point in time series data.

$$U_t = \sum_{i=1}^{t}\sum_{j=t+1}^{n} sign\ (x_t - x_j)$$

$$sign\ (x_t - x_j) = \begin{bmatrix} 1, if\ (x_i - x_j) > 0 \\ 0, if\ (x_i - x_j) = 0 \\ -1, if\ (x_i - x_j) < 0 \end{bmatrix}$$

Test statistic K and the associated confidence level (ρ) for the sample length (n) may be described as

$$K = Max\ |U_t| \qquad \rho = exp\ \left(-\frac{K}{n^2 - n^3}\right)$$

When ρ is smaller than the specific confidence level, the null hypothesis is rejected. The approximate significance probability (p) for a change-point is defined as given below:

$$p = 1 - \rho$$

It is obvious that where a significant change point exists, the series is segmented at the location of the change point into two subseries. The test statistic K can also be compared with standard values at different confidence level for detection of change point in a series [7].

2.1.2 Buishand range test

The adjusted partial sum (S_k), that is the cumulative deviation from mean for kth observation of a series x_1, x_2, x_3 ….x_k…. x_n with mean $(\overline{\boldsymbol{x}})$ can be computed using following equation:

$$\boldsymbol{S_k} = \sum_{i=1}^{k}(\boldsymbol{x_i} - \overline{\boldsymbol{x}})$$

The significant breakpoint can be computed by the method of rescaled adjusted range (R) if the $\boldsymbol{S_k} \cong 0$, in this case, R is defined by

$$R = \frac{Max\ (S_k) - Min\ (S_k)}{\sqrt{n}}$$

Here, R denotes change point value [8].

2.1.3 Standard Normal Homogeneity (SNH) Test

Test statistic ($\boldsymbol{T_k}$) is used to compare the mean of first n observations with the mean of the remaining (n-k) observations with n data points.

$$T_k = kZ_1^2 + (n-k)Z_2^2$$

Z1 and Z2 can be computed as:

$$Z_1 = \frac{1}{k}\sum_{i=1}^{k}\frac{(x_i - \overline{x})}{\sigma x}$$

$$Z_2 = \frac{1}{n-k}\sum_{i=k+1}^{n}\frac{(x_i - \overline{x})}{\sigma x}$$

Where, $\bar{x}$ and σx are the mean and standard deviation of the series. The year k can be considered as change point and consist a break where the value of T_k attains the maximum value. To reject the null hypothesis, the test statistic should be greater than the critical value, which depends on the sample size (n) is given.

For confirmation of mutation point, the result of at least two tests of three tests should be same. That point was considered as the true mutation point. The significance was tested for different significant probability levels [9].

2.2 Trend Analysis

The amount of the trend in the time series data was estimated by Sen's estimator and significance of the trend in the time series was tested by Mann-Kendall (M-K) test.

2.2.1 Mann-Kendall test

The main task in trend analysis is to assess the monotonic fluctuations in long-period data sets, which can be well performed through a non-parametric linear trend test, i.e., the Mann-Kendall test. The test statistic of the Mann-Kendall test (S) is expressed as

$$\boldsymbol{S} = \sum_{i=1}^{n}\sum_{j=1}^{i=1} \boldsymbol{sign}\ (\boldsymbol{x_i} - \boldsymbol{x_j})$$

where, n is the total length of data, xi and xj are two generic sequential data values, and function sign(xi–xj) assumes the following values

$$sign(x_i - x_j) = \begin{bmatrix} 1, if\ (x_i - x_j) > 0 \\ 0, if\ (x_i - x_j) = 0 \\ -1, if\ (x_i - x_j) < 0 \end{bmatrix}$$

Under this test, the statistic S is approximately normally distributed with the mean E(S) and the variance Var(S) can be computed as follow:

$$\boldsymbol{E(S) = 0}$$

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_t (t-1)(2t+5)]$$

Where, n is the length of time series, and t is the extent of any given tie and Σt denotes the summation over all tie number of values. The standardized statistics Z for this test can be computed by the following equation:

$$Z = \begin{bmatrix} \frac{S+1}{\sqrt{Var(S)}}, if\ S > 0 \\ O, \quad\quad if\ S = 0 \\ -1, \quad\quad if\ S < 0 \end{bmatrix}$$

Here, the detection of a trend depends on the value of Z. For example, if the Z value is zero, it means that the data does not follow any trend; if the value of Z is positive, it means that the trend is in an upward direction; and if the value of Z is negative, it means that the trend is in a downward direction [10].

2.2.2 Sen's slope estimator

Assuming that the time series data exhibits a significant trend, i.e., either a positive or a negative trend, then the Sen's slope estimator can be estimated. It means the slope of the trend line or the average rate of change of the trend. The slope of the trend is estimated using the following test statistic:

$$T_i = \frac{y_{J-} y_K}{J-K} \quad \text{for i= 1,2,3… N}$$

Here, y_j and y_k are the data values at time j and k (j > k), respectively. The median of these N values of Ti is the Sen's slope estimator, which is defined as follows:

$$\beta = \begin{Bmatrix} T_{\frac{N+1}{2}} \quad N\ is\ odd, \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right)\ N\ is\ even \end{Bmatrix}$$

Here, if the value of β is positive, it means that the trend is in a rising pattern, and if the value of β is negative, it means that the trend is in a declining pattern [11].

3. RESULTS AND DISCUSSION

Data of Gujarat wheat crop obtained from the CMIE website covering the last 50 years, from 1973-1974 to 2022-23. The Table 1 presents statistical data for three agricultural variables: Area, production and yield. The area, measured in thousands of hectares, ranges from a minimum of 192.40 to a maximum of 1442.00 with an average of 758.23 and a standard deviation of 288.57. This indicates that while there is some variability in the size of the agricultural areas, it is relatively moderate. Production, also in thousands of tonnes, has a much wider range, from 351.20 to 4694.00 with a mean of 1919.26 and a high standard deviation of 1071.36 suggesting significant fluctuations in production levels. Yield, measured in kg. per hectare, varies from 1474.90 to 4694.00 with an average of 2391.50 and a standard deviation of 499.48, indicating moderate variability. Overall, the data show substantial variability in production and yield, possibly due to differing agricultural conditions and practices. (Table 1).

In the current study, the non-parametric tests Pettitt's, SNH and Buishand's range tests have been applied to identify the mutation point for year wise wheat area, production and yield from 1973-74 to 2022-23. From the Table 2. the results exhibits the significant ($p < 0.0001$) mutation points i.e., 2004 year is captured for area by two test such as Buishand range test and SNH tests while year 2002 was identified significant ($p<0.001$) mutation point by pettitt's test. Thus, year 2004 was considered as true mutation point for area. A the significant mutation points 2002 year was captured for production by two tests as Pettitt's test ($p < 0.0001$) and Buishand range test ($p < 0.0001$) while year 2004 was identified significant ($p < 0.0001$) mutation point by SNH test. Therefore, year 2002 was considered as significant ($p < 0.0001$) mutation point for production. In the case of yield of wheat crop, the significant ($p < 0.0001$) mutation points was captured as 2002 year by the all three tests such as Pettitt's test, Buishand range test and SNH test. Therefore, year 2002 was considered as significant ($p < 0.0001$) mutation point for yield. These results collectively highlight notable shifts in area, production and yield around the early 2000s, with changes in area and production showing some variation in the exact year of change among the different tests.

After, identification of mutation point, the whole time series (1973-2023) were divided into three parts i.e., first-time series (before mutation point), second-time series (after mutation point) and whole time series (1973-2023). For segmentation period of wheat area, mutation point was identified as 2004. Thus, a time series 1973-

2003 was observed as first-time series and series 2004-2023 detected as second-time series. Similarly, mutation point for both production and yield of wheat was observed as 2002. Hence, the time series 1973-2001 and 2002- 2023 were identified as first-time series and second- time series, respectively (Table 3). Using Sen's slope estimators, the degree of monotonic trends has been calculated. Further, the trend analysis was extended based on segmentation time period. In this case, the wheat crop's substantial monotonic trends have been analyzed indicator- and segmentation-wise using the M-K test. (Table 3).

From the Sen's slope estimator analysis, it is observed that statistically significant ($p < 0.0001$) highest growth of production was observed as 61.334 thousand tonnes/year during 2002-2023 i.e. second sub series time period and lowest non-significant (p= 0.292) growth was experienced as -3.52 (thousand ha/year) in the first sub-time series of area (Table 3 and Fig. 1). The whole-time series results shown the upward significant (p <0.001) trends were seen in the segment of production and yield while downward non-significant trend was observed in the area. Thus, production of wheat showed the highest increasing trend as compared to area and yield in second sub series and whole time period. A significant increasing trend was also experienced in the yield of first sub-time series (24.03 kg ha-1/year), second sub-time series (40.51 kg ha-1/year) and whole time series (30.57 kg ha-1/year) which was significant @ 1 per cent level of significance (Table 3 and Fig. 1).

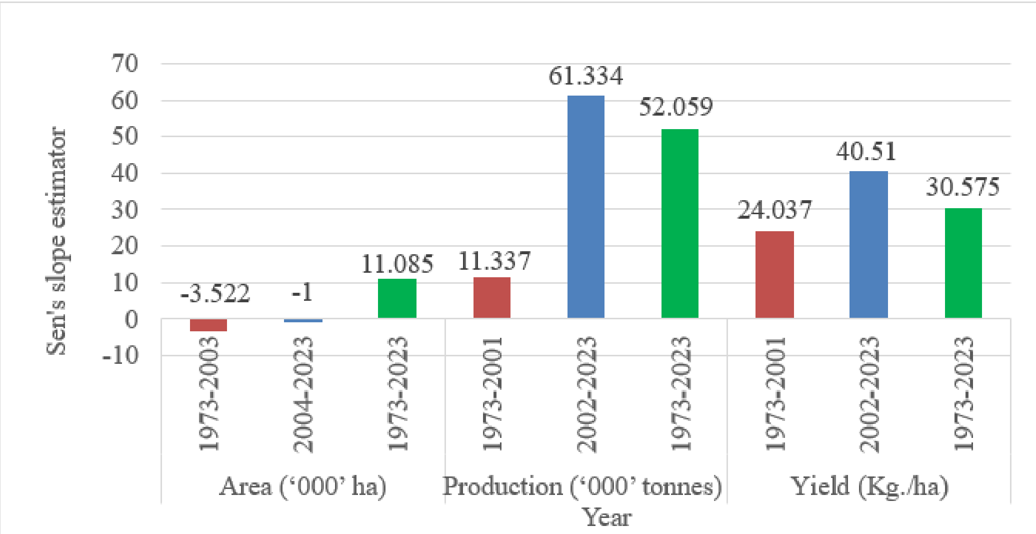

Fig. 1 Segmentation year wise Sen's slope estimators for wheat crop

Table 1. Summary statistics of wheat crop during 1973-74 to 2022-23 for Gujarat

Variable	Minimum	Maximum	Mean	Std. deviation
Area	192.40	1442.00	758.23	288.57
Production	351.20	4694.00	1919.26	1071.36
Yield	1474.900	3268.00	2391.50	499.48

Table 2. Analysis of mutation point of wheat crop during 1973-74 to 2022-23 for Gujarat

	Pettitt's test		Buishand range test		SNH test	
Variable	Change point	p-value	Change point	p-value	Change point	p-value
Area	2002***	<0.0001	2004***	<0.0001	2004***	<0.0001
Production	2002***	<0.0001	2002***	<0.0001	2004***	<0.0001
Yield	2002***	<0.0001	2002***	<0.0001	2002***	<0.0001

*Note: *, ** and *** indicate significance at 10%, 5% and 1% level of significance respectively*

Table 3. Mann-Kendall test and Sen's slope estimators of wheat crop during 1973-74 to 2022-23 for Gujarat

Variable	Segmentation year	MK-test	Kendall's tau	p-value	Sen's slope
Area	1973-2003	-63	-0.135	0.292	-3.52
	2004-2023	-6	-0.035	0.861	-1.00
	1973-2023	516	0.421***	<0.0001	11.08
Production	1973-2001	58	0.143	0.285	11.33
	2002-2023	84	0.400**	0.012	61.33
	1973-2023	701	0.572***	<0.0001	52.05
Yield	1973-2001	252	0.621***	<0.0001	24.03
	2002-2023	121	0.578***	0.000	40.51
	1973-2023	930	0.759***	<0.0001	30.57

*Note: *, ** and *** indicate significance at 10%, 5% and 1% level of significance respectively*

Overall, the results show that while the area under consideration did not exhibit significant trends in the segmented periods (1973-2003 and 2004-2023), there was a significant overall increase from 1973 to 2023. Both production and yield showed significant positive trends, particularly after 2002 suggesting improvements in productivity and efficiency.

4. CONCLUSION

The study highlights variability and long-term trends in wheat cultivation in Gujarat. Using nonparametric methods, significant changes between 2002 to 2004 were identified, influenced by climatic conditions, industrialization, and human activities. Trend analysis showed an upward trend in wheat production and yield, but a declining trend in the cultivated area. Notably, wheat production grew by 61.33 thousand tonnes/year in the second sub-time series, while the area declined by 3.52 thousand hectares/year in the first sub-time series. The study recommends improving agricultural practices and resource management to address the declining cultivation area and sustain positive growth in production and yield.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image Generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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