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Statistical analysis for trend and change point detection of sugarcane production in India

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ABSTRACT

Sugarcane is the one of the most dominant industrial crops for sugar and bio-energy. It is extremely essential to be acquainted with the trend of variability in sugarcane production for proper planning and maintaining balanced demand and supply system. The present study explored the statistical analysis for trend and change point detection for sugarcane production of major sugarcane producing states of India. Several well-known non-parametric methods viz. Pettitt's test, Standard normal homogeneity test and Buishand's range test were applied. The objectives of these methods were to find out the mutation point in time series data related to sugarcane production during the period 1990-2019. Accordingly, Sen's slope estimator was applied to determine the magnitude of the trend and their significances were evaluated by the Mann Kendall test for sugarcane production. It was seen that the most of the states observed significant change points in different time periods say Uttar Pradesh at 2009, Maharashtra at 2005, Karnataka at 2009, Tamil Nadu at 2013, Bihar at 2009, Andhra Pradesh at 2012, Gujrat at 1997 and Madhya Pradesh at 2004, except Haryana and Punjab. In addition, the change point (1997) was firstly detected in Gujarat state and Tamil Nadu (2013) was identified at the last. The majority of the states appeared the raising trends in sugarcane production. The significant rising trend of sugarcane production was observed in Uttar Pradesh and found maximum Sen's slope estimator (5912.714/year) in the second segmentation period (2010-2019). Currently, the production of sugarcane in Uttar Pradesh was extremely enhanced as compared to other states from 2009. Thus, the production of sugarcane has been increased significantly in Uttar Pradesh compared to preceding years and also Uttar Pradesh maintained top rank in production of sugarcane in the country.

Keywords: Change point, coefficient of variation, MK-trend test, Sen's slope, sugarcane, trend analysis

Sugarcane *(Saccharum officinarum* L.*)* is the most important commercial crops and it is cultivated for sweetener and bio-energy worldwide. Sugarcane is the largest crop by volume of production (FAO, 2019). Sugarcane crop is grown comprehensively to tropical and sub-tropical regions. Sugarcane is also one of the most significant profitable crop of India. Sugarcane is the main resource of raw material not only for sugar manufacturing but also other allied industries. Sugarcane is the backbone of farming community and providing employment opportunities to large number of people (Rahman and Bee, 2019). Sugarcane is flexible crop which is sufficient source of food, fiber, fodder and energy. By products and co-products of sugarcane have played a crucial role in the taste of human being as well as in the economy of the country. In India, cultivation of sugarcane and its processing is a main source of livelihood and employment generation. More than 50 millions of farmers and labourers are involved in the cultivation of sugarcane and also more than 0.3 million of skilled and unskilled workers are engaged in its related industries (Krishnakant *et al.,* 2015). Cultivation of sugarcane is done very well in the whole country except some part of hilly areas such as Kashmir valley and Arunachal Pradesh. Sugarcane crop is cultivated in several types of soils like loams, brown or reddish loams, clayey loams, black cotton soils and also laterites. Climate of India is a tropical and it is much more favourable for the cultivation of sugarcane crops. India is the second major sugarcane producer after Brazil as a major producer followed by China, Thailand, Pakistan, and Mexico (FAO Stat Database, 2019).India contributed about 20% of total world's sugarcane production (Medar *et al.*, 2019). In India, major sugarcane producing states are Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Bihar, Andhra Pradesh, Haryana, Gujarat, Punjab and Madhya Pradesh where more than 92 % of sugarcane production comes

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from these ten states. In India, sugarcane occupies an area of 5.11 million hectares, production is of 400.16 million tonnes and cane productivity is of 78.25 tonnes per hectare (Anonymous, 2020). In the current study, trend and change point detection (CPD) for sugarcane production in India has been studied. In order to identify CPD for time series of sugarcane production data, the more dominant and commonly used distribution free approach like Pettitt's test, Standard Normal Homogeneity test and Buishand's range tests were studied. Trend analyses were investigated by the Sen's slope estimation method and test of significances of trends were tested by the Mann-Kendall test.

MATERIALS AND METHODS

The secondary time series data on sugarcane production has been utilized for the present investigation. Various states like Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Bihar, Andhra Pradesh, Haryana, Gujarat, Punjab and Madhya Pradesh have been selected for the study. Time series of sugarcane production has been obtained from ICAR-Sugarcane Breeding Institute, Coimbatore website sugarcane-statistics as secondary sources of these top ten states from 1990 to 2019.

Methods for Change Point and Trend Detection

The analysis of change point and trend detection (CPTD) attempts to find those points where significant changes occur in the sugarcane time series data. Various techniques were applied to find out change points in the time series data by the several researchers (Buishand, 1982; Bryson *et al.*, 2012; Li and Lund, 2012; Sharma *et al.*, 2016; Polisetty and Paidipati, 2020).The Pettitt's test, a distribution-free test, developed by Pettitt (1979), is valuable for estimating the happening of sudden changes in the time series data (Mu *et al.*, 2007). Several research workers had applied different distribution-free statistical tools to find the change points in the several types of time series (Sharma *et al.*, 2016; Kalpana *et al.*, 2019; Polisetty and Paidipati, 2020). In the present study, various non-parametric tests such as Pettitt'sTest (Pettitt, 1979), Buishand's Range Test (Buishand, 1982) Standard Normal Homogeneity (SNH) Test (Alexandersson,1986) have been used to identify the change point and their trends in the time series data of sugarcane production. The details of these tests were described by Polisetty and Paidipati (2020).

Test for Trend Analysis and Sen's Slope Estimator

Non-linear trends in time series of yield data often hinder risk analysis for crop production.The pattern of trend in long term time series data of sugarcane has been analysed.The amount of the trend in the time series data were driven by Sen's estimator (Sen, 1968) and significance of the trend in the time series was tested by Mann-Kendall (M-K) test (Mann, 1945; Kendall, 1975). Sen's slope estimator is a non-parametric technique frequently used for ecological study because it is robust to missing data and outliers (Gilbert, 1987) and also provides a robust estimation of the trends (Yue *et al.*, 2002). The Mann-Kendall test played a crucial job to identify the nature of linear trends in the time series (Polisetty and Paidipati, 2020). The test statistic (S) of M-K test is defined as Salas (1993):-

$$S = \sum_{i=1}^{N-1} \sum_{ij=i+1}^{N} \text{sgn}(y_j - y_i)$$

where N is number of data points. It was assumed $(y_j - y_i) = \theta$, the value of sgn(θ) was calculated by the following expressions:

$$\text{sgn}(\theta) = \begin{cases} 1 & if\theta > 0 \\ 0 & if\theta = 0 \\ -1 & if\theta < 0 \end{cases}$$

This statistic represents the differences of positive and negative sign of their values for all the differences measured. For large samples (N>10), the test is facilitated using a normal distribution (Helsel and Hirsch, 1992) with the subsequent equations:

$$E[S] = 0$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k}^{n} t_k (t_k - 1)(2t_k + 5)}{18}$$

Here, N represents number of tied groups in the observations and t_k is data points in the k^{th} tied groups in the observations. The standard normal deviate (Z-statistics) was then calculated as suggested by Hirsch *et al.* (1993) by the following expression:

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

If the calculated value of $Z > Z_{\alpha/2}$, the null hypothesis (H_0) is rejected at α level of significance in a two-tailed test. The sign of 'S' represents upward or downward trends of time series. If 'S' has positive sign, it represents the upward trend and if 'S' observed negative sign, it indicates downward trend.

A non-parametric test has been applied to calculate the value of trends in the sugarcane production data. Sen's slope estimator (Sen, 1968) has the sufficient procedure to evaluate the trend in time series data. The details of Sen's slope estimator were given by Polisetty and Paidipati (2020).

RESULTS AND DISCUSSION

The crop production is determined by various agro-climatic factors such as soil type, temperature and rainfall pattern. Besides, other factors such as relative prices of crops, expansion of irrigation facility, provision of technological inputs, institutional facility, etc., are also responsible for crop production (Choudhari *et al.,* 2013). It is clear that Uttar Pradesh had first position in the production of sugarcane in India (Table 1).The sugarcane production was recorded highest in Uttar Pradesh (179715 thousand tonnes) with a standard deviation (S.D.) of 20351.42 thousand tonnes and a coefficient of variation (C.V.) of 16.13% followed by Maharashtra (92443 thousand tonnes) with S.D. of 21450.16 thousand tonnes and C.V. of 38.13%. The highest and lowest C.V. was recorded in Madhya Pradesh (54.83%) and Gujarat (13.60), respectively.This means that the instability in Madhya Pradesh was highest as compared to other states in sugarcane production. Gujarat has more stable in the production of sugarcane in India. Also, Uttar Pradesh and Haryana contributed stable sugarcane production.The contributions of both states (Uttar Pradesh and Maharashtra) were more than 60% of total sugarcane production of the country. The minimum sugarcane production was observed in Madhya Pradesh (1084 thousand tonnes). Further, on an average Uttar Pradesh and Madhya Pradesh were acknowledged as highest and lowest sugarcane producers during 1990-2019.

For change point detection, test statistic of Pettitt's, Standard Normal Homogeneity and Buishand's range tests were computed to capture the year from which drastically changes occured drastically in the production of sugarcane from 1990-2019. It was observed that the majority of the states have experienced statistically significant change point at different time points such as Uttar Pradesh at 2009, Maharashtra at 2005, Karnataka

Table 1: Summary statistics for sugarcane production ('000 tonnes) in different states of India

State	Minimum	Maximum	Average	S.D.	C.V. (%)
Uttar Pradesh	102929	179715	126201.83	20351.42	16.13
Maharashtra	20475	92443	56252.50	21450.16	38.13
Karnataka	14276	43776	30461.67	8194.64	26.90
Tamil Nadu	16208	41124	29002.97	6839.62	23.58
Bihar	3855	14034	7688.73	3792.56	49.33
Andhra Pradesh	7830	21692	14308.97	3588.20	25.08
Haryana	5130	9633	7751.13	1207.40	15.58
Gujarat	9198	15630	12544.23	1705.97	13.60
Punjab	3700	11040	6660.60	1623.44	24.37
Madhya Pradesh	1084	6956	2763.40	1515.05	54.83

Table 2: Analysis of change point for sugarcane production in different states of India

State	Pettitt's Test		Buishand's Range Test		Standard Normal Homogeneity test	
	p-value	Change Point	p-value	Change Point	p-value	Change Point
Uttar Pradesh	0.000	2009**	<0.0001	2009**	0.000	2016**
Maharashtra	<0.0001	2005**	<0.0001	2005**	<0.0001	2005**
Karnataka	0.013	2008*	0.007	2009**	0.008	2009**
Tamil Nadu	0.123	2013	0.036	2013*	0.003	2015**
Bihar	<0.0001	2009**	<0.0001	2009**	<0.0001	2009**
Andhra Pradesh	0.004	2012**	0.001	2012**	<0.0001	2012**
Haryana	0.750	2007	0.286	2007	0.547	2007
Gujarat	0.005	1997**	0.008	1997**	0.003	1997**
Punjab	0.803	2002	0.198	2002	0.408	2002
Madhya Pradesh	<0.0001	2004**	<0.0001	2004**	<0.0001	2013**

*Level of significance (p = 0.05), **Level of significance (p = 0.01)

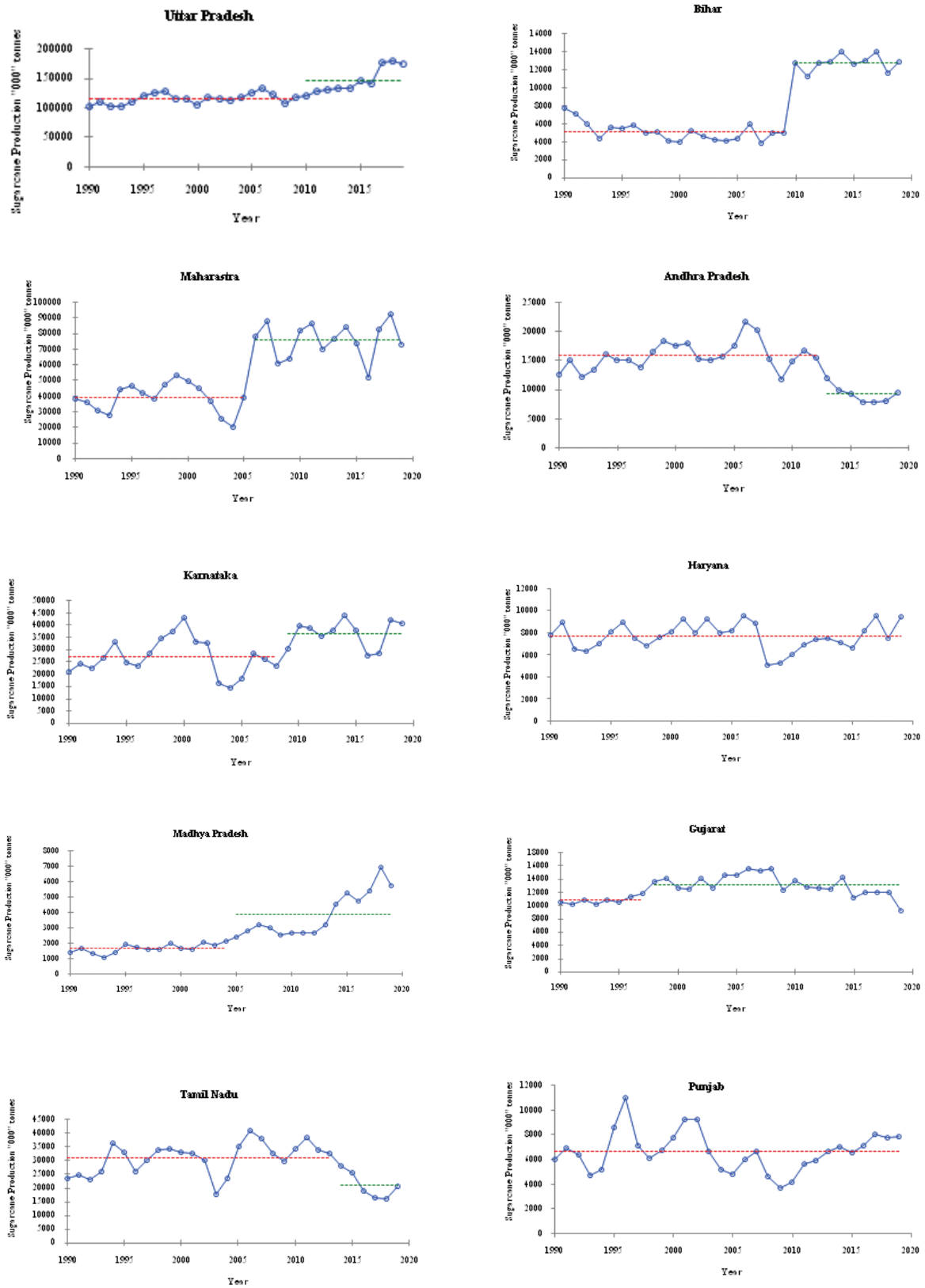

Fig. 1: Identified change points for sugarcane production in India

Table 3: Mann-Kendall test and Sen's slope estimators for sugarcane production

State	Division year	Kendall's tau	p-value	Sen's slope
Uttar Pradesh	1990-2009	0.337	0.040	764.955
	2010-2019	0.822	0.000	5912.714
	1990-2019	0.651	<0.0001	1447.700
Maharashtra	1990-2005	0.000	0.965	-2.719
	2006-2019	0.033	0.914	364.182
	1990-2019	0.517	<0.0001	1741.500
Karnataka	1990-2009	0.042	0.823	132.010
	2010-2019	-0.067	0.862	-243.500
	1990-2019	0.352	0.006	510.500
Tamil Nadu	1990-2013	0.297	0.044	391.616
	2014-2019	-0.600	0.136	-2452.000
	1990-2019	-0.099	0.457	-114.692
Bihar	1990-2009	-0.417	0.010	-120.799
	2010-2019	0.156	0.601	45.333
	1990-2019	0.295	0.022	232.208
Andhra Pradesh	1990-2012	0.257	0.092	129.545
	2013-2019	-0.333	0.381	-474.000
	1990-2019	-0.232	0.075	-176.167
Haryana	1990-2007	0.425	0.014	106.364
	2008-2019	0.727	0.000	365.150
	1990-2019	0.080	0.548	15.929
Gujarat	1990-1997	0.429	0.179	158.036
	1998-2019	-0.359	0.020	-109.000
	1990-2019	0.195	0.135	67.412
Punjab	1990-2002	0.436	0.042	258.333
	2003-2019	0.500	0.005	186.450
	1990-2019	0.057	0.671	16.250
Madhya Pradesh	1990-2004	0.467	0.016	43.125
	2005-2019	0.657	0.000	250.727
	1990-2019	0.789	<0.0001	116.429

at 2009, Tamil Nadu at 2013, Bihar at 2009, Andhra Pradesh at 2012, Gujarat at 1997 and Madhya Pradesh at 2004, except Haryana and Punjab. Furthermore, for first time Gujarat had experienced the change point as 1997 and lastly change point detection was seen in Tamil Nadu (2013). Now, on the basis of significant change point, the entire data (1990-2019) were separated into two parts viz. before the change point (first sub-division) and after the change point (second sub-division) of the time series data. These turning points played a very crucial role to analyse the monotonic trends in the production of sugarcane. For analysis of trend point detection, M-K test was applied to analyse the significant monotonic trends of these two parts and entire time series. Further, the Sen's slope estimators had been used to compute the degree of monotonic trends. A noteworthy point had been observed that most of the states had increased in the trends of for the year wise division (Table 3 and Fig. 1) and it was statistically significant. A noteworthy point had been seen that the increasing trends in sugarcane production were observed in Uttar Pradesh, Maharashtra, Karnataka, Bihar and Madhya Pradesh whereas decreasing trend were found in Tamil Nadu and Andhra Pradesh which were statistically significance 5% level of significant by M-Ktest (Table 3 and Fig. 1). Non-significant stable trends were observed in Haryana,Punjab and Gujarat.Using Sen's slope analysis, statistically significant highest growth trend was observed in Uttar Pradesh (764.955/year) and lowest negative growth trends was seen in Bihar (-120.799/year) state in the first sub-division of the series. Also, Uttar Pradesh has experienced statistically significant highest growth trend (5912.714/year) and lowest growth trend was seen in Tamil Nadu (-2452.00/year) in the second sub-division of the sugarcane production. In the entire time series data of sugarcane production, Maharashtra (1741.500/year) had experienced highest statistically significant growth trend and lowest negative trend was observed in Andhra Pradesh (-176.167/year). In Uttar Pradesh, the surge

production of sugarcane had been started from the year 2010 as area was also increased.This indicates that the performance of Uttar Pradesh was excellent in the production of sugarcane in the country. Uttar Pradesh had witnessed extraordinary changes due to the adoption of new varieties, soil testing, expansion of field cultivation, other enterprises, etc. while in Maharashtra, production of sugarcane had been raised by about 1800 tonnes in the last decade and still Uttar Pradesh is the top dominant sugarcane producing state in the country. The results of the analysis of entire-time series of sugarcane production displayed the maximum growing and lowest descending significant trend have seen in the states of Maharashtra (1741.500/year) and Andhra Pradesh (-176.167/year) respectively. Therefore, it is clear that Uttar Pradesh showed the highest trend ratio compared to Maharashtra in second sub-division of time series. Also, on an average the magnitude of the trends were increased in second sub-division series as compared to the first sub-division series in most of the states like Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Haryana and Madhya Pradesh whereas deceasing trends were observed in Bihar, Gujarat and Punjab. Overall, theses result showed that the production of sugarcane was positively increased during the study period in the country. Thus, the growth in the population of the country is increased with the increasing in the production of sugarcane.This indicates that the high production of sugarcane evolve full sufficient on food security and along with economy of the country.

The present paper deals with the variability, instability, trends and change point in the long-term time series data on sugarcane production of mainsugarcane producing states of India. Several non-parametric tools were applied to find the abrupt change point and their variability.The change point analysis captured significant change points from 1997 to 2013. The increasing trends were experienced in most of the states and this showed the production of sugarcane was raised in long term time series. Moreover, majority of the states has been increased in the amount of trends of first sub-time series except Maharashtra and Bihar. Also,for second sub-division time series, the increasing trends were observed except Gujarat and Punjab. The significant observation from the trend analysis was seen that the magnitude of trends for majority of thestates were increased in first sub-time series except Maharashtra and Bihar and the same results were obtained in second sub-division of time series except Bihar, Gujarat and Punjab. The highest and lowest significant growth rates in sugarcane production were observed in Uttar Pradesh (764.955/year) and Bihar (-120.799/year) respectively in the first sub-division of time series and also the same results were observed in Uttar Pradesh (5912.714/year) and Tamil Nadu (-2452.00/year), respectively in the second sub-division of time series. Also, the highest significant growth trend was observed in Maharashtra (1741.500/year) and lowest significant growth trend was experienced in Andhra Pradesh (-176.167/year) of the entire of the period of time.

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