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Original Research Article

Forecasting Wheat Productivity and Production of Madhya Pradesh, India, Using Autoregressive Integrated Moving Average Models

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A B S T R A C T

Forecasting of wheat area, production, and productivity of Madhya Pradesh was made of historical data of 1981-82 to 2015-16 by using univariate autoregressive integrated moving average (ARIMA) Models and was compared with the forecasted all India data. The autoregressive (p) and moving average (q) parameters were identified based on the significant spike in the plot of partial autocorrelation function (PACF) and autocorrelation function (ACF) of the different time series. ARIMA (0,1,0) & (0,1,1) model was found suitable for all India and Madhya Pradesh area (million hectare), whereas ARIMA (O,1,1) & (0,1,0) was best fitted for forecasting of wheat productivity (yield kg ha^{-1}), in India and Madhya Pradesh. ARIMA (1,1,0) & (3,1,0) model was found production (million ton) in India and Madhya Pradesh. Projection was made for the immediate next 10 year that is 2017-18 to 2026-27, using the best fitted ARIMA models based on minimum values of the selection criterion, that is Akaike information criteria (AIC) and Schwarz-Bayesian Information criteria (SBC/BIC). The performance of model was validated by comparing with percentage deviation from the values and mean absolute percent error (MAPE).

Keywords

Autoregressive Integrated Moving Average Models, Wheat productivity

Introduction

Wheat is one of the most important cereal crops of India occupying an area of 30.32 million hectare with an annual production of 93.50 million tones with an average productivity of 3093 kgha^{-1} (2015-16) (http://www.agricoop.nic.in/). It play a vital role in the national food security and would continue to remain so because of its wider adaptability continue to remain so because of its wider adaptability to grow under diverse ecosystem. Wheat contribute 37.07 % (93.50 million tones) of total food grain (252.22 million tones) and remains the principal source of livelihood for more than 58% of the population. With the stabilization of area under wheat at around weather like rainfall, lake of irrigation, declining productivity trend.

A proper trend analysis and forecast of production of such an important crop in the potential central region is having significance on many accounts. Critical analysis of production and productivity is a prerequisite for proper knowledge base on the ecology and appropriate research /development efforts for harvesting maximum possible potential. Trend analysis has been attempted for crops like papaya and garlic by several authors [2-4]. An unexpected unexpected decrease in production reduces marketable surplus and income of the farmers and leads to price rise. Similarly, an increase in production can lead to a sharp decrease in prices and has adverse effect on farmer's income. Impact on price of an essential commodity has a significant role in determining the inflation rate, wages, salaries and various polices in an economy. The proper forecast would pave way for appropriate surplus and deficit management to stabilize the price and ensure profits for the farmers.

Several techniques like simulation modeling and remote sensing are largely being used for forecasting of the crops yield and area. But sometimes, forecasting in needed much before the crop harvest or even before the crop planting. This can be achieved only by modeling the past data and getting the predictions. Autoregressive integrated moving average (ARIMA) has been used for model building based on the past data and predictions are made. ARIMA models have been developed to forecast the cultivable area, production and productivity of various crops of Tamil Nadu [5,6] and wheat production in Canada[8]. Univariate forecasting of state level agricultural production was also made by various authors using ARIMA models [9-12].

Keeping the above requirement in view, the present study was carried out to (i) analyze the trend of production, productivity, and area under in Madhya Pradesh and compare with all Indian scenarios and (ii) forecast and validate the wheat area, production, and productivity using ARIMA models.

Materials and Methods

Data collection

The data on cultivable area, production and productivity of the wheat in Madhya Pradesh was collected from the Annual Report on "Area, Productivity and Production ", Directorate of Agriculture, Madhya Pradesh, Bhopal. The same data for India was obtained form Directorate of Economics and Statistics, Department of Agriculture and Cooperation, India. The data pertaining to the agriculture years 1981 to 2016 was used for the model building and forecasting. The data of 2017, 2018 and 2019 was used for validation of the model.

Trend Analysis

The time series data pertaining to wheat area, productivity and production in Madhya Pradesh as well as India were analyzed using the Mann-Kendall trend test for assessing the trend present in the data. Initially, this test was used by Mann [13] and Kendall [14] and subsequently derived the test statistics distribution [15, 16]. This hypothesis test is a nonparametric, rank-based method for evaluating the presence of trends in time series data.

The data are ranked according to time and then each data point is successively treated as a reference data point and is compared to all data points that follow in time. Compared with parametric statistical tests, nonparametric test are thought to be move suitable for nonnormally distributed data [17]. Since the time series data used in the study is mostly nonnormally distributed as evident from the skewness and kurtosis values given in Table no.1 the nonparametric test were used in the study.

The Mann-Kendall test statistics is given by

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

Where x_i and x_j are the sequential data values, n is the data set record length, and

$$sgn(\theta) = \begin{cases} +1, if\ \theta > 0 \\ 0 \quad if\ \theta = 1 \\ -1, if \theta < 0 \end{cases}$$

The Mann-Kendall test has two parameters that are of importance to the trend detection. These parameters are the significance level that indicated the trend's strength and the slope magnitude estimate which indicates the direction as well as the magnitude of the trend.

For independent, identically distributed random variables with no tied data values, we have E(S) = O;

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

When some data value are tied, the correction to Var(S) is

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i)(i-1)(2i+5)}{18}$$

Where t_i denotes the number of ties of extent i. For n larger than 10, the test statistic.

$$Z_s = \begin{cases} \frac{S-1}{[Var(S)]^{0.5}}, if\ S > 0 \\ 0 \quad if\ S = 0 \\ \frac{S+1}{[Var(S)]^{0.5}}, if S < 0 \end{cases}$$

Z_s follows the standard normal distribution [14]. The magnitude of trend slopes can be also calculated (Sen, 1968). Sen's estimate for slope is associated with the Mann-Kendall test as follows:

$$\beta = Median\left(\frac{x_j - x_i}{j - i}\right)$$

Where x_j and x_i are considered data value at time j and I (j>i), correspondingly. The median of these N values of β_i is represented as Sen's estimator of slope which is given as

$$Q_i = \begin{cases} \beta_{(N+1)/2}\ when\ N\ is\ odd \\ \frac{1}{2}\left(\beta_{N/2} + \beta_{(N+2)/2}\right)\ when\ N\ is\ even \end{cases}$$

A positive value of Q indicates an upward trend, whereas a negative value represents a downward trend.

ARIMA model

The ARIMA model analyzes and forecast equally spaced univariate series data. An ARIMA model predicts a value in a response time series as a linear combination of its own past values.

The ARIMA approach was first popularized by Box and Jenkins [18], and ARIMA models are often referred to as Box-Jenkins model. In this study, the analysis performed by ARIMA is divided into three stage [19].

Notation for ARIMA Models.

$$W_t = \mu + \frac{\theta(B)}{\phi(B)}\ a_t$$

Where t indexes time, W_t is the response series Y_t or a difference of the response series, μ is the mean term, B is the backshift operator, that is, $BX_t = X_{t-1}$, ϕB is the autoregressive operator, represented as a polynomial in the backshift operator, ϕB = 1- $\phi_1 B$ -... $\phi_p B^p$, θB is the moving average operator, represent as a polynomial in the backshift operator θB = 1- $\theta_1 B$-.... $\theta_p B^p$, and a_t is the independent disturbance, also called the random error. For simple differencing, also called the random error. For simple differencing, $W_t = (1-B)^d Y_t$, where d is the order of differencing.

Identification stage

The stationary check of time series data was performed, which revealed that wheat area, production, and productivity for India as well as Madhya Pradesh were nonstationary except for the area under wheat in Madhya Pradesh. The nonstationary time series data were made stationary by first order differencing and best fit ARIMA models were developed using the data from 1981 to 2016 and used to forecast the cultivable area, production and productivity of wheat for Madhya Pradesh and India for the next three years, which is 2017, 2018 and 2019.

Candidate ARIMA models were identified by finding the initial values for the orders of nonseasonal parameter "p" and "q". they were obtained by looking for significant spikes in autocorrelation and partial autocorrelation functions. At the identification stage, one or more models were tentatively chosen which seem to provide statistically adequate representation of the available data. Then precise estimate of parameter of the model were obtained by least squares.

Estimation Stage: ARIMA models are fitted and accuracy of the model was tested on the basis of diagnostics statistics.

Diagnostic Checking: the best fit model was selected based on the following diagnostics

Low Akaike Information Criteria (AIC):- AIC [20] is estimated by AIC =(-2 log L + 2m), where m = p + q and L is the likelihood function.

Sometimes, SBC [21] is also used and estimated by SBC = $\log\sigma^2 + (m \log n)/n$.

Insignificance of Autocorrelation for Residuals. If a model as an adequate representation of a time series, it should capture all the correlation in the series, and the white noise residuals should be independent of each other.

Significance of the parameters: - Significance test for parameter estimate indicate whether some terms in the model might be unnecessary.

Forecasting stage. Future values of the time series are forecasted.

Model Evaluation: the mean absolute present error (MAPE) as defined below was used as a measure of accuracy of the model:

$$MAPE = 100 \times \left(\frac{\sum_{i=1}^{n} (|Y_F - Y|) / Y}{N} \right)$$

Y_F is forecasted variable, Y is actual variable and n is number of variables.

SPSS software was used for time series analysis and developing ARIMA models and forecasting.

Results and Discussion

Trend Analysis

Descriptive statistics for the time series data of wheat area, production and productivity for both Madhya Pradesh and India is given in Table no.1.The time series data is plotted in Figure 1. The time series data for wheat area, production and productivity density plot and values of skewness and kurtosis. Hence nonparametric Mann-Kendall test for trend analysis was performed to test the significance of trend. As evident form the values of Mann-Kendall's Z statistics and Sen's slope estimate (Q), the time series data for all the parameters selected for analysis showed significant and positive trend. The Mann-Kendall Z value as well as magnitude of slope indicated that the rate of increase was less for area, production and high for productivity in Madhya Pradesh as compared to all Indian scenarios.

The trend analysis of long term time series data (1981 -2016) for the area under wheat was found positive with a Q value of 0.04 and 0.23 for both Madhya Pradesh and India respectively. The low Q values can be explained by the fact that the area under wheat remained more or less constant for the least 10 years due to competition from weather like rainfall, irrigation facility, urbanization and industrialization. Area under wheat in India was 26.48 million hectare and 30.42 million hectare, respectively, for this years 2006 to 2016, while during the same period area under wheat in Madhya Pradesh 3.69 to 5.91 million hectare. It is evident that there is plateauing in the area under wheat in the last decade.

Trend analysis also showed a considerable increase in all Indian average productivity of wheat from 1630 kgha^{-1} in 1981 to 3034 kgha^{-1} in 2016 and during the same period, wheat productivity in Madhya Pradesh increased from 934 kgha^{-1} to 2993 kgha^{-1}. The rate of increase of productivity in Madhya Pradesh is similar than all Indian average as evident from Sen's slope estimate of 39.68 kgha^{-1} year^{-1} and 38.70 kgha^{-1} for India and Madhya Pradesh, respectively, indicating an untapped growth potential for wheat in Madhya Pradesh.

Building ARIMA Models

The autoregressive (p) and moving average (q) parameters were identified based on the significant spikes in the plots of PACF and ACF of the different time series. While identifying the best fit ARIMA models, appropriate values of p, d and q were chosen corresponding to minimum value of the selection criterion, that is AIC and SBC. While identifying the best fit ARIMA models, appropriate values of p, d and q were chosen, that is AIC and SBC. The appropriate best fit models for wheat area, production and productivity of Madhya Pradesh and India along with AIC and SBC are given in Table 2.

The estimate of the autoregressive and moving average parameters along with the constant term are presented in Table.3.

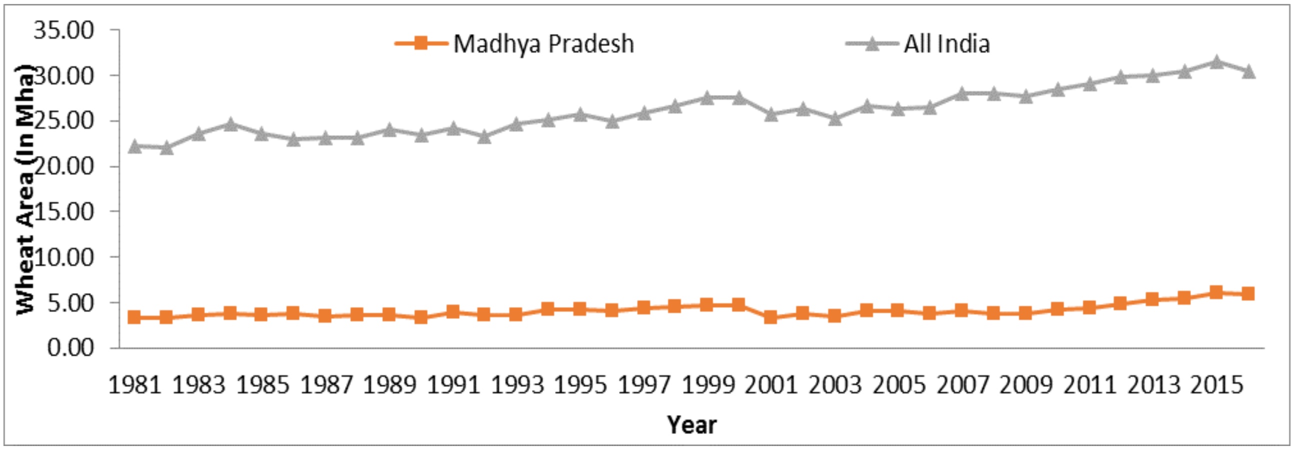
It is clear from the "t" value that the entire parameters estimate were significant which is an essential criteria for the ARIMA models.

It is evident from Figure 2(a) that ACF of area under wheat for India has a significant spike at lag 1 and PACF declines gradually (Figure 3(a)), which indicated a moving average model of first order.

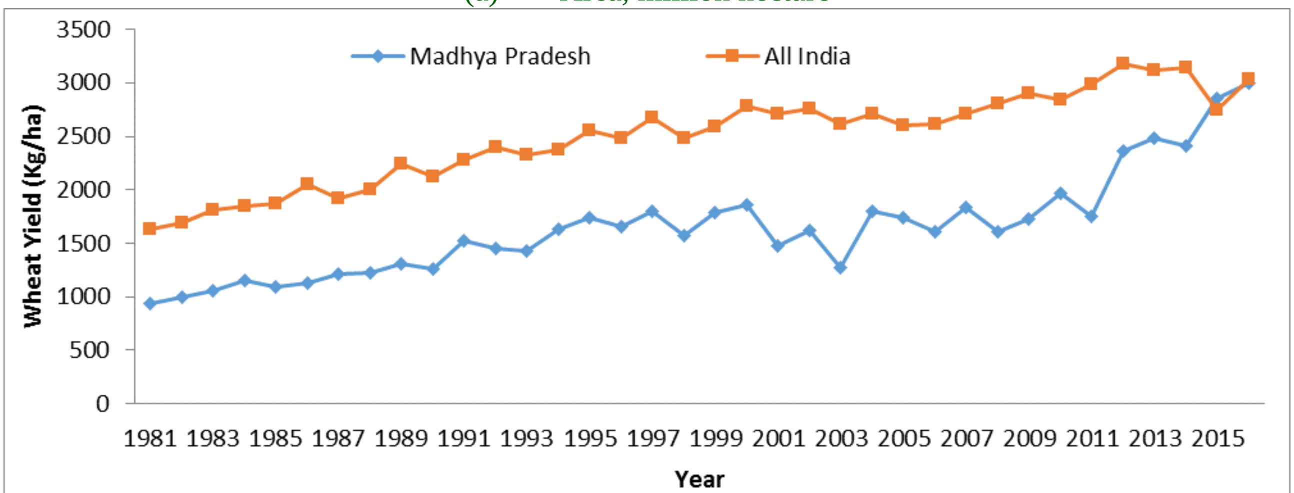
Similarly significant spike at leg 2 for the PACF of wheat productivity and production of India indicate a second order autoregressive model of ARIMA (0,1,1) and (1,1,0) which was found to be best fit model. Significant spike at lag of PACF 1 (Figure 3 (d) and gradually decaling ACF (Figure 2(d)) for area under wheat for Madhya Pradesh indicated a pure autoregressive model of order ARIMA (0,1,1) was fond to be best fitted. Significant spike at lag 1 in Figures 2 (e) and 2 (f) and Figures 3(e) and 3(f), for both ACF and PACF, indicated a first order autoregressive as well as moving average model for both productivity and production of Madhya Pradesh.

The ACF and PACF were plotted for residual of the fitted model and were lying within the limits, which showed that ARIMA model fitted well.

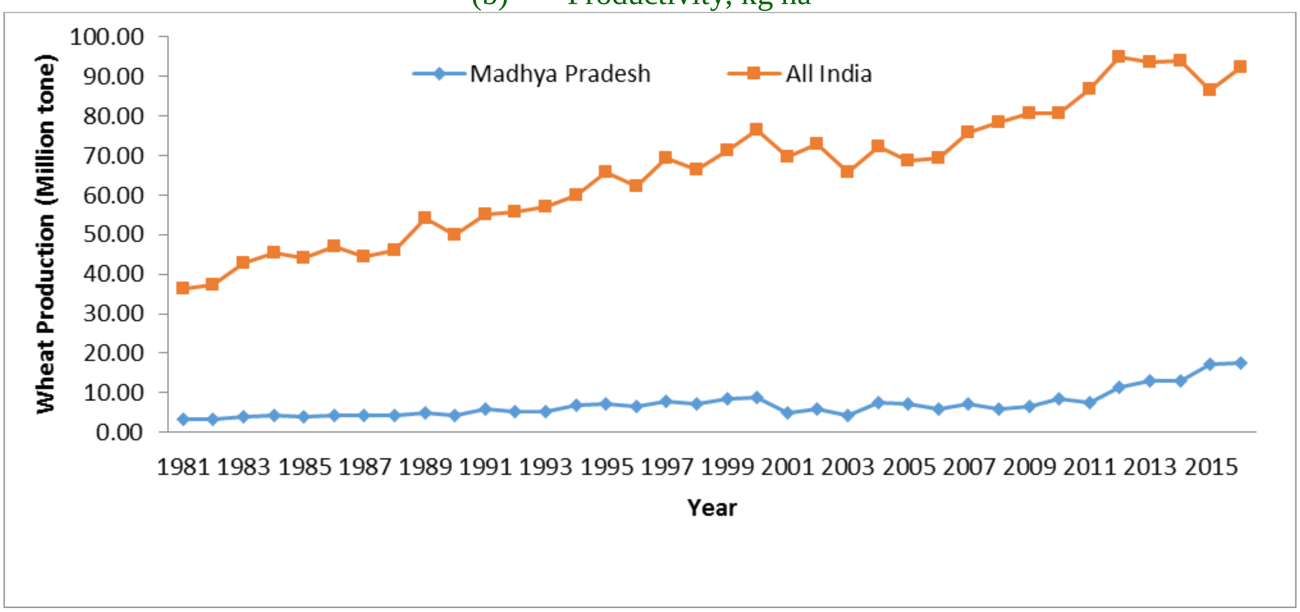
Fig.1 Trend of area, productivity and production of wheat in Madhya Pradesh and India



(a) Area, million hectare



(b) Productivity, kg ha^{-1}



(c) Production, Million tones.

Fig.2 Autocorrelation function (ACF) of area, productivity and production in Madhya Pradesh and India

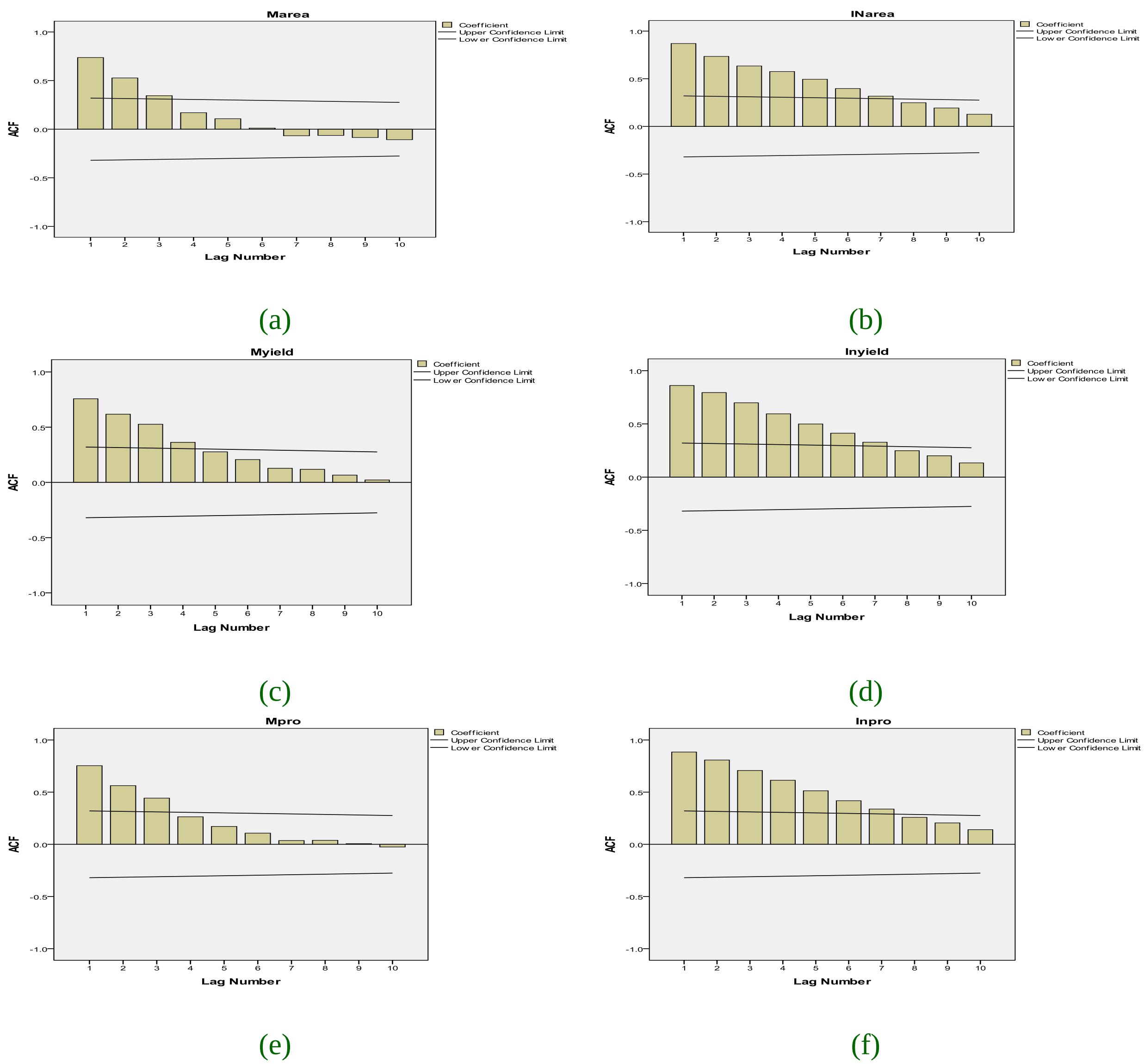
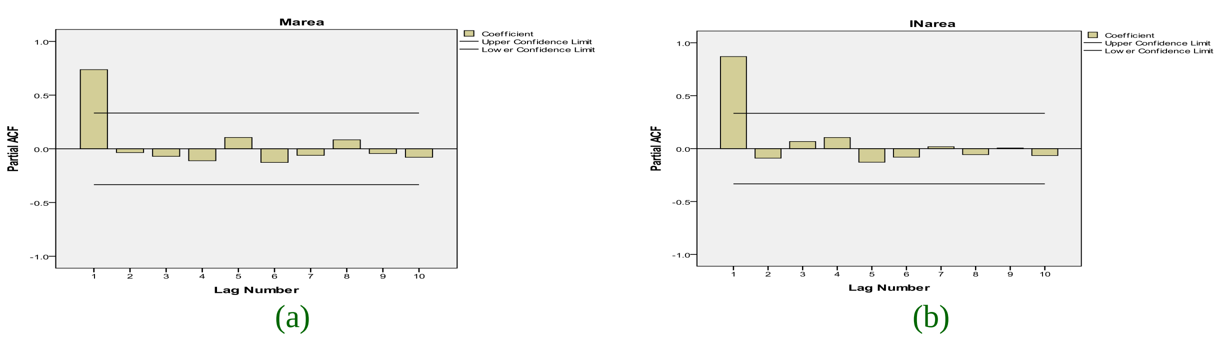
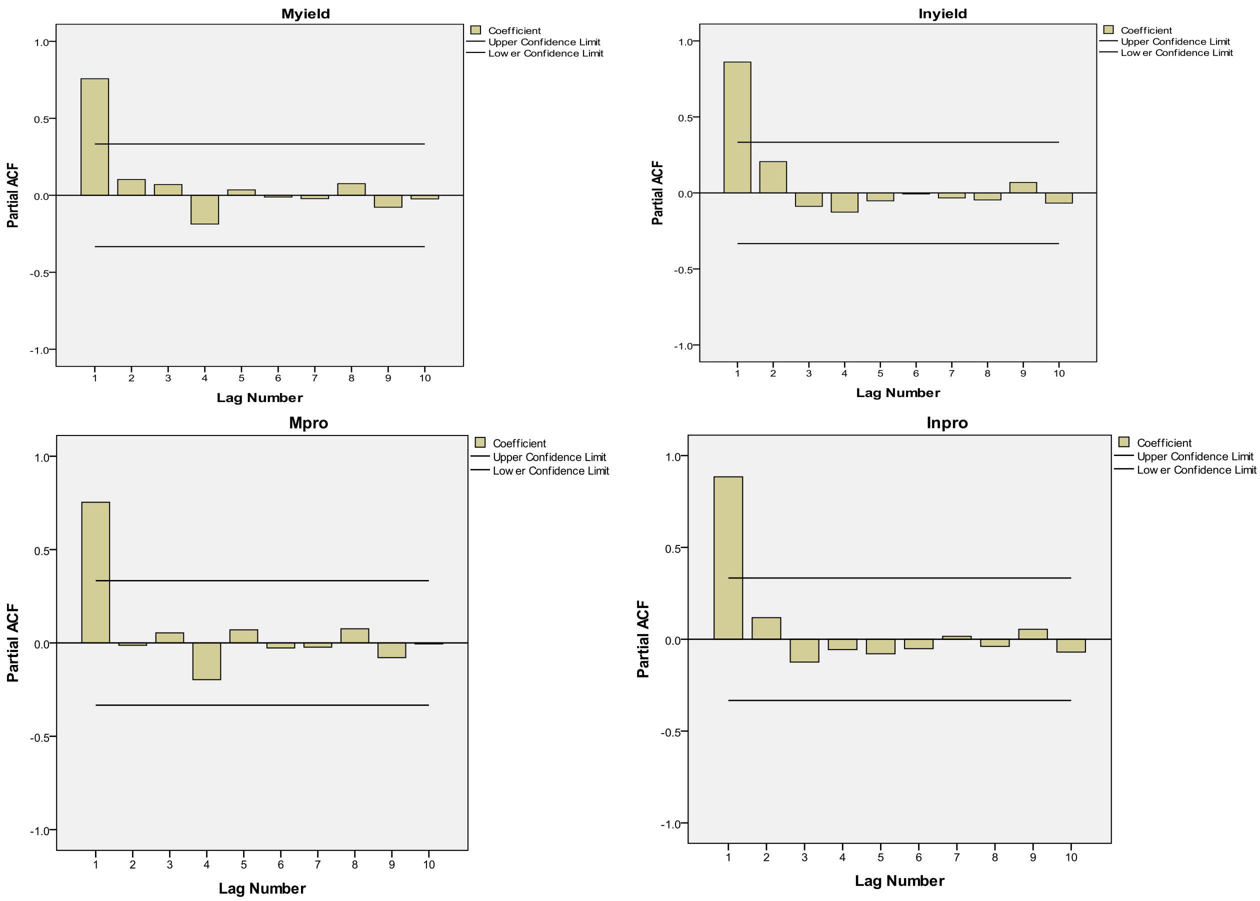


Fig.3 Partial Autocorrelation function (ACF) of area, productivity and production in Madhya Pradesh and India





(e) (f)

Fig.4 ARIMA Model Observed value, forecast value, upper limit of forecast and lower limit of forecast, wheat area, production and productivity in India and Madhya Pradesh

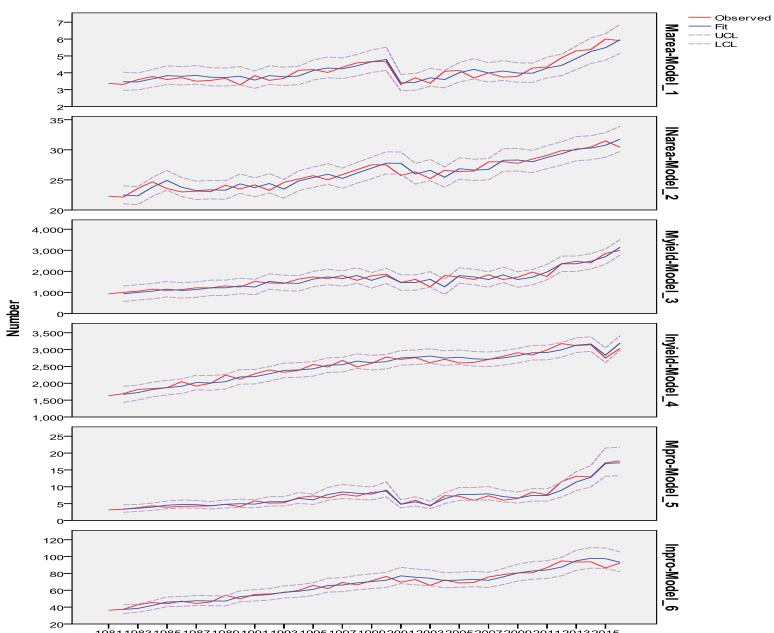


Table.1 Descriptive statistics and Mann-Kendall trend analysis test for the time series data of wheat cultivation in Madhya Pradesh and India from 1981 to 2016

Parameter	Mean	Median	Standard Deviation	Kurtosis	Skewness	Mann-Kendall trend (Z value)	Sen's slope (Q)
All India							
Area (million hectare)	26.08	25.81	2.54	-0.76	0.39	6.99	0.23
Productivity (kg ha^{-1})	2489.36	2596.00	427.08	-0.72	-0.40	7.30	39.68
Production (million tons)	65.80	67.50	16.89	-0.93	0.03	7.46	1.57
Madhya Pradesh							
Area (million hectare)	4.08	3.81	0.70	1.25	1.30	4.60	0.04
Productivity (kg ha^{-1})	1647.61	1616.50	487.56	1.14	1.05	6.36	38.70
Production (million tons)	7.03	6.28	3.51	2.80	1.69	5.95	0.22

Table.2 Autoregressive integrated moving average (ARIMA) Models fitted for time series data on wheat area, productivity, and corresponding selection criterion, that is, Akaike information criteria (AIC) and Schwarz-Bayesian information criteria (SBC/BIC)

Parameter	ARIMA model	AIC	SBC /BIC	RMSE	MAPE
All India					
Area (million hectare)	ARIMA(0,1,0)	88.40	93.07	0.838	2.69
Productivity (kg ha^{-1})	ARIMA(0,1,1)	442.14	446.81	106.21	3.28
Production (million tons)	ARIMA(1,1,0)	200.06	204.73	4.14	4.77
Madhya Pradesh					
Area (million hectare)	ARIMA(0,1,1)	34.96	36.51	0.285	5.61
Productivity (kg ha^{-1})	ARIMA(0,1,0)	472.95	477.62	179.37	8.18
Production (million tons)	ARIMA(3,1,0)	130.35	135.01	0.89	9.13

RMSE= Root Mean Square Error, MAPE: Mean absolute percent error.

Table.4 Performance of autoregressive integrated moving average (ARIMA) models for wheat area, productivity and production for All India and Madhya Pradesh

Year	All India								
	Projected Area ('000 hectare			Projected yield (kg/ha)			Projected production ('000 MT)		
	Point forecast	W.C.L*		Point forecast	W.C.L*		Point forecast	W.C.L*	
		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
2017-18	31.01	29.43	32.59	3067.75	2820.81	3314.70	92.02	84.23	99.81
2018-19	31.25	29.37	33.13	3106.64	2834.54	3378.75	94.39	85.45	103.32
2019-20	31.49	29.36	33.63	3145.54	2850.40	3440.67	95.60	84.91	106.29
2020-21	31.74	29.37	34.10	3184.43	2867.94	3500.91	97.32	85.42	109.22
2021-22	31.98	29.41	34.55	3223.32	2886.83	3559.81	98.82	85.71	111.93
2022-23	32.22	29.46	34.98	3262.21	2906.84	3617.58	100.42	86.25	114.59
2023-24	32.46	29.52	35.40	3301.10	2927.81	3674.39	101.97	86.79	117.15
2024-25	32.70	29.59	35.81	3339.99	2949.60	3730.39	103.54	87.43	119.66
2025-26	32.95	29.67	36.22	3378.88	2972.11	3785.66	105.11	88.11	122.11
2026-27	33.19	29.76	36.61	3417.78	2995.25	3840.30	106.68	88.83	124.52

*With confidence interval (95%)

Year	Madhya Pradesh								
	Projected Area ('000 hectare)			Projected yield (kg/ha)			Project production ('000 MT)		
	Point forecast	W.C.L*		Point forecast	W.C.L*		Point forecast	W.C.L*	
		Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
2017-18	5.91	5.15	6.66	3013.28	2629.12	3397.44	18.05	15.17	20.93
2018-19	5.91	4.84	6.98	3088.00	2648.38	3527.63	18.48	14.94	22.03
2019-20	5.91	4.59	7.22	3138.58	2612.28	3664.88	18.89	14.67	23.12
2020-21	5.91	4.39	7.42	3199.86	2614.69	3785.04	19.31	14.54	24.09
2021-22	5.91	4.21	7.60	3256.40	2611.65	3901.15	19.73	14.45	25.00
2022-23	5.91	4.04	7.77	3315.04	2618.30	4011.79	20.14	14.41	25.88
2023-24	5.91	3.90	7.91	3372.75	2626.59	4118.91	20.56	14.40	26.72
2024-25	5.91	3.76	8.05	3430.87	2638.81	4222.93	20.98	14.42	27.53
2025-26	5.91	3.63	8.18	3488.81	2653.18	4324.44	21.39	14.47	28.32
2026-27	5.91	3.50	8.31	3546.83	2669.87	4423.78	21.81	14.53	29.09

*With confidence interval (95%)

Table.3 Final estimate of parameter of autoregressive integrated moving average (ARIMA) models fitted for time series data on wheat area, productivity and production for Madhya Pradesh and India

Parameter	ARIMA Parameter	Estimate	Standard error	t-value	Sing.
All India					
Area (million hectare)	Constant	0.009	0.006	1.615	0.116
	Difference	1	--	-	-
Productivity (kg ha^{-1})	Constant	41.521	9.589	4.330	0.000
	Difference	1	-	-	-
	MA Lag 1	0.484	0.167	2.895	0.007
Production (million tons)	Constant	0.026	0.007	3.602	0.001
	AR Leg 1	-0.434	0.157	-2.773	0.009
	Difference	1	-	-	-
Madhya Pradesh					
Area (million hectare)	Constant	0.027	0.008	3.426	0.002
	Difference	1	--	-	-
	MA Lag 1	0.383	0.165	2.320	0.027
Productivity (kg ha^{-1})	Difference	1	-	-	-
Production (million tons)	Constant	0.070	0.019	3.673	0.001
	AR Leg 1	-0.494	0.138	-3.586	0.001
	AR Leg 1	0.434	0.143	3.032	0.005
	Difference	1	-	-	-

Forecast Using ARIMA models

The projected values for wheat area, production and productivity

Area Projections

ARIMA model projected that area under wheat cultivation will increase form 31.01 million hectares in 2017-18 to 33.19 million hectares in 2026-27 in India and in the Madhya Pradesh area under wheat cultivation will increase 5.90 million hectares in 2017-18 to 5.91 million hectares in 2026-27. This nominal increase may be due to land reclamations and government policy towards wheat production. With 95 per cent confidence interval, the maximum area under wheat would increase form 32.59 million hectare to 36.61 million hectare in India and Madhya Pradesh the maximum area under wheat would increase from 6.66 million hectare to 8.31 million hectare. The increase in maximum area under wheat is due to increasing irrigation facilities and increasing population pressure of India. On the other hand, decrease in minimum area under wheat production may be due to adverse climatic conditions and land degradation due to changing climatic pattern.

Yield projections

Point of forecast for yield (kg ha-1) of wheat crop register an increase of ---- pre cent by the end of following decade. From 2071-18 to 2026-27 point froecast yield per hectare would increase from 3067.75 to 3417.78 (kg ha-1) in India and 3013.28 to 3546.83 (kg ha-1) in Madhya Pradesh (Table no.4). Considerable increase in wheat yield can be achieved in spite of climate change by the policy interventions to encourage cultivation. At 5 per cent probability the increase in minimum and maximum yield is due to better technology availability, suitable government policies and irrigation facilities.

Production projections

Using ARIMA the 10 year advance production projection and their 95 per cent confidence interval are calculated and presented in Table.4. The projected result in wheat production indicated trends in production in the coming year in India and Madhya Pradesh. A considerable increase of about 15.3 per cent in India and 15.3 per cent Madhya Pradesh can be achieved by 2026-27. On the basis of model output an increase in the production from 92.02 million tones 2017-18 to 106.68 million those in 2026-27 is expected in India and same year Madhya Pradesh point of forecast production 18.05 to 21.81 million tones in the year 2017-18 to 2026-27 (Table No. 4). the minimum production projection with 95 per cent confidence shoed that wheat production may decrease in the coming years and will reach 88.83 million tones in India and Madhya Pradesh 14.53 million tones which is at par with the current production level. This may occur due to adverse effect of temperature rise, government attention to the crop and decrease in cultivable land. However, maximum production projection registered a significant increase in production levels which may reach upto 124.52 million tons in India and 29.09 million tons in Madhya Pradesh.

The trend analysis of the wheat data showed an increasing area, productivity and production trend for both Madhya Pradesh and India. The rate of increase was lees in Madhya Pradesh than all India average. This may be attributed to uderexploitation of the potential of the state due to low input in agriculture operations and other biotic and abiotic factors. To bridge the gap between existing and potential productivity, wheat varieties suitable to different ecologies can be introduced in farmer's field along with the nutrient and agronomic management practices. Based on the forecasting and validation results, it may be concluded that ARIMA model could be successfully used for forecasting wheat area, production and productivity of Madhya Pradesh as well as India for the immediate subsequent years.

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