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Piecewise regression analysis of rice yield trends in Manipur

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Abstract

Rice is the main crop, and its cultivation serves as the primary source of livelihood for the people of Manipur. The primary objective of this study is to formally analyze the patterns and characteristics of paddy production. This paper includes a statistical model for the data analysis. Time series secondary data for the period 1981-2022, obtained from the department of Economic & Statistics, Govt. of Manipur were used for the analysis. Piecewise regression analysis is followed, and the model fits the data well. Out of the total variation of dependent variable, 73.5% of the variation can be explained by independent variables of rice production and 73.9% for cultivated area.

Keywords: Piecewise regression analysis, Time series data, variation, rice production.

Introduction

Rice (*Oryza Sativa*) is the third most significant crop in the World after sugarcane and corn [World Population Review, 2024 ^[1], Saha *et al.*, 2021] ^[2]. It is a staple food of our region Manipur with the state ranking second only to Assam in rice production among the Northeastern states of India. Consequently, half of the valley's total area, which is home to 67% of the state's population, is dedicated to agricultural activities [Singh *et al.*, 2023] ^[3]. Owing to the intensive cultivation of rice in Manipur, a systematic study and a proper analysis as well as a critical observation on the trend of production of rice is highly relevant. Due to lack of reliable data, the existing studies are not directly utilized to this region, and therefore, they should be modified to suit the specific socio-economic, agro-climatic, and different topographical conditions of Manipur. In this regard, a scientific report with statistical analysis of rice crops, based on available data, will be highly valuable for the state's socio-economic development and future planning initiatives [Mog *et al.*, 2017] ^[4].

Materials and Methods

1. Time series secondary data from the year 1980 to 2022 were collected from the Department of Economic & Statistics, Govt. of Manipur [Anonymous, 2022] ^[5].
2. Statistical model [Montgomery *et al.*, 2012] ^[6]

The piecewise linear regression model is used for this analysis and is defined as

$$Y_i = b_0 + b_1X_{i1} + b_2(X_{i1} - X^{(k)})X_{i2} + \varepsilon_i$$

This may also be written as

$$Y_i = b_0 + b_1X_{i1} + b_2X_{i2}^* + \varepsilon_i$$

Where,

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Y_i	=	production for i^{th} year
X_{i1}	=	i^{th} year
$X^{(k)}$	=	breaking point(knot value)
X_{i2}	=	a dummy variable $\begin{cases} 0, \text{if } X_{i1} \leq X^{(k)} \\ 1, \text{if } X_{i1} \geq X^{(k)} \end{cases}$
X_{i2}^*	=	$(X_{i1} - X^{(k)})X_{i2}$
ε_i	=	error term

The above model simplifies to:

If $X_{i1} \leq X^{(k)}$, the model can be written as

$$Y_i = b_0 + b_1 X_{i1} + \varepsilon_i$$

If $X_{i1} \geq X^{(k)}$, the model can be written as

$$Y_i = b_0 + b_1 X_{i1} + b_2 X_{i2}^* + \varepsilon_i$$

Results and Discussion

The findings indicated that the breaking point revealed a prominent change in the rate change of variation in the trend values of rice production and area. The "Knot value 2015" indicates that increased in production up to the year 2015 and decreased from there onwards. In the area of rice cultivation, the breaking point is 1994, where a decreasing trend was observed up to 1994 with an increasing trend thereafter (Table 1).

Table 1: Breaking points of rice yield and area

Crop	Aspects	Knot values
Rice	Production	2015
	Area	1994

It was observed that the positive regression coefficient b_1 (5.361) indicates increased in rice production until 2015. But there was a decrease in rice production from 2015 onward, as indicated by the negative coefficient b_2 (-3.616). The small p-value (< 0.05) indicates that the coefficient b_0 and the b_1 are statistically significant, revealing a meaningful impact on rice production. However, the b_2 coefficient is not statistically significant (Table 2).

Table 2: Regression coefficients of Piecewise regression model for rice yield

Coefficients	Estimate	Std. error	t	p
Constant(b_0)	-10360	1841	-5.626	0.00000 ***
$b_1(X_{i1})$	5.361	9.213	5.819	0.000000 ***
$b_2(X_{i2}^*)$	-3.616	6.794	-0.532	0.598

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The value of RSE (60.4) was acceptable as compare to the range of rice production. The R value of 0.734 reveals that 73.4% of the variation in rice production is explained by the independent variable. Independent variables effectively explain the variation in the dependent variable (Y_i) as indicated by the significant F-

value (Table 3).

Table 3: Summary Statistics of the Piecewise Regression Model for Rice Production

RSE	R	Multiple R^2	Adj. R^2	F	p
60.4	0.734	0.54	0.517	23.48	0.00000***

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The significant value of F revealed that the amount of information supplied by the independent variable about the dependent variable is effective (Table 4). It confirmed that the independent variables collectively have a statistically significant influence on the dependent variable of rice production.

Table 4: ANOVA table for rice yield

Source	Df	Sum sq	Mean Sq	F	p
Regression	2	171280.5	85640.267	23.47756	0.00000***
Residual	40	145910.0	3647.749		
Total	42	317190.5			

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The cultivated area under rice decreased until 1994 as indicated by the negative regression coefficient b_1 (-1.1966). However, from the year 1994 onwards, the positive coefficient b_2 (2.0937) shows an increased in cultivated area. The small p-value (< 0.05) revealed that the coefficients b_0 , b_1 and b_2 are statistically significant, demonstrating a meaningful impact on cultivated area (Table 5).

Table 5: Estimated Piecewise regression model for cultivated area (1980-2022)

Coefficients	Estimate	Std. error	t	p
Constant(b_0)	2541.387	581.562	4.370	0.00008 ***
$b_1(X_{i1})$	-1.1966	0.3819	-4.093	0.00020 ***
$b_2(X_{i2}^*)$	2.0937	0.04011	5.482	0.00000 ***

Significant. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The value of RSE (6.572) was acceptable given the range of the cultivated area. An R value of 0.735 indicates 73.5% of the variation in rice area explained by the independent variable. The significant value of F indicates that the independent variables accurately explain the dependent variable (Y_i) (Table 6).

Table 6: Model Evaluation Statistics for rice cultivated area

RSE	R	Multiple R^2	Adj. R^2	F	p
6.572	0.735	0.546	0.524	24.09	0.000000***

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The ANOVA table revealed that the significant value of F illustrates the effectiveness of the information provided by the independent variables (past value of cultivated area) in explaining the dependent variable of cultivated area. The result also confirms that the independent variables collectively have a statistically significant impact on the dependent variable [Montgomery *et al.*, 2012] ^[6] (Table 7) (Fig.1, Fig.2).

Table 7: ANOVA for rice cultivated area

Sorce	Df	Sum sq	Mean Sq	F	p
Regression	2	2080.953	1040.476	24.088	0.00000***
Residual	40	1727.787	43.194		
Total	42	3808.740			

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

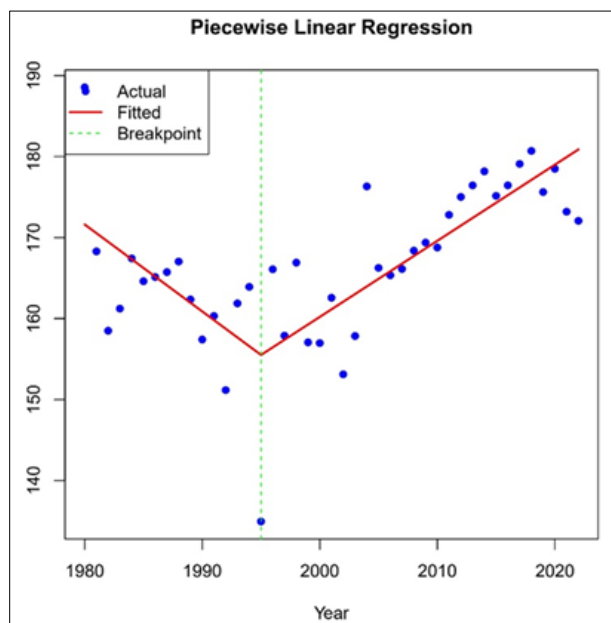


Fig 1: Piecewise regression trend of rice yield of Manipur

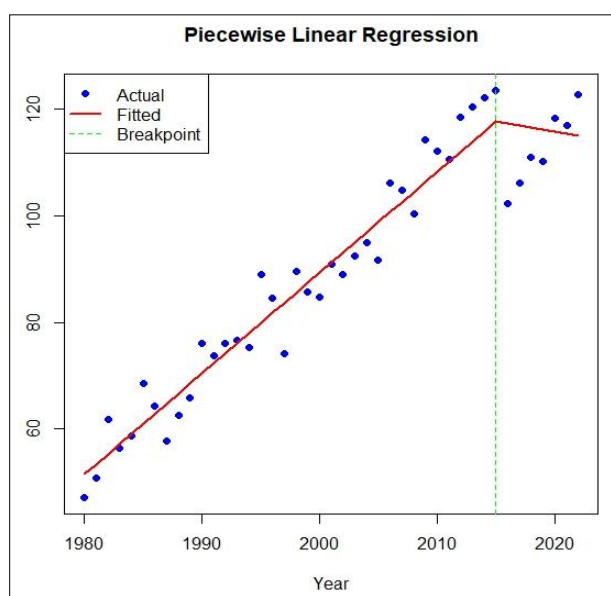


Fig 2: Piecewise regression trend for cultivated land area of Manipur

The above figures indicate trend values of rice yield and cultivated land area respectively.

Conclusion

The final piecewise linear regression model for rice yield and cultivated area are given below

$$Y_i = -10360 + 5.361X_{i1} - 3.616(X_{i1} - 2015)X_{i2}^* + \varepsilon_i$$

and $Y_i = 254.387 - 1.966X_{i1} + 2.0937(X_{i1} - 1994)X_{i2}^* + \varepsilon_i$ respectively.

The present investigation showed that the significant value of F due to rice production and the cultivated area respectively indicates that the amount of information supplied by the independent variable is effective.

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