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Comparison and Forecasting for Indian Rainfall Using Proposed and Time Series Models

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ABSTRACT

The experiment was conducted using rainfall data for the period from 1968 to 2022 in India. The aim of this study was to evaluate and compare the effectiveness of time series and proposed models in accurately predicting seasonal and annual rainfall trends in India. Since Indian agriculture was highly dependent on rainfall, this study attempted to propose a method for forecasting rainfall in India. Firstly, the initial step-1 involves specifying both the linear and multiplicative regression models with available independent variables with and without one time period log dependent variable as one of the independent variables and select one of the above four specifications having maximum $\bar{R}^2$ for forecasting purpose. In step-2 that all of the model's independent variables, such as linear, exponential, and power functions, are correlated with a time variable. Estimate these relationships for every independent variable, choose the best one based on $\bar{R}^2$ values, and predict the future values for all independent variables. As a step-3 substitute the future values of the independent variables obtained from step-2 in the selected model obtained from step-1. The obtained values are called forecasted values through proposed method. As a step-4, the dependent variable was related to time as linear, exponential and power functions; select one of these estimated relations with maximum $\bar{R}^2$ for forecasting. Finally, to compare the forecasted values through proposed and time series models using $\bar{R}^2$ criteria. The results show that the proposed forecasting model was better than a time series forecasting model. Since the proposed models are the best models.

KEYWORDS: Rainfall, forecasting, regression, time series models, $\bar{R}^2$

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

India is an agricultural country and a large part of its economy is based on agriculture. Rainfall is the main source of water for agricultural activities in all tropical countries, including India, where agriculture plays a crucial role in driving the country's economy. Weather forecasts are crucial for various catchment management applications, especially flood warning systems. A weather condition is the state of the atmosphere at a given time in terms of weather variables like rainfall, cloud conditions, temperature, etc. These exogenous variables are out of farmers' control, though they determine production. Especially the outcome of rainfall fluctuation is quite natural, and it often brings instability to the production of agricultural commodities, which in-turn leads to fluctuations in the price of every commodity. Due to the importance of rainfall in determining agricultural production and prices, attempts have been made to forecast monthly rainfall in India using various data mining techniques, like time series analysis and gathering monthly rainfall data (Basistha et al., 2009; Prabakaran et al., 2017; Manohar et al., 2018; Nikhilkumar et al., 2019; Debasis et al., 2020). The changing precipitation pattern and its impact on surface water resources are important climatic problems facing society today. Associated with global warming, there are strong indications that rainfall changes on both the global and regional scales (Sahai et al., 2003; Goswami et al., 2006). A mathematical method called Linear Regression is generally used to predict the rainfall in various districts in the southern states of India. For analyzing series of data, the regression analysis especially multiple regression analysis has been commonly used to establish the statistical relations between one dependent variable and one or more independent variables (Kumar et al., 2010; Jeyarami, 2013; Ankita et al., 2023). Multiple linear regressions were widely applied because; it easily depicts the relationship of multiple influential variables to form a statistically significant rainfall (Amiri et al., 2015). In the case of non-linear regression analysis, the observational data is modeled by a function that is a non-linear combination of the model parameters and depends on one or more independent variables (Bilgili, 2010). One of the most significant phenomena in the climate system is rainfall. It is commonly recognised that the environmental, agricultural, human, and even entire biological systems are impacted by the fluctuations and intensity of rainfall (Arvind et al., 2017). The annual rainfall of 1476 rain gauge stations for the period of 100 years from 1901 to 2000 in India has been studied and suggested various tests to approximate the best suitable trend for the rainfall time series (Stella, 2012). In addition to being a difficult scientific task, forecasting rainfall on a monthly and seasonal basis is crucial for agricultural planning and strategy development. Rainfall on a monthly basis is predicted using the Box-Jenkins time series seasonal auto-regression integrated moving average technique (ARIMA). The most accurate model to predict rainfall over the next five years with a 95% confidence level is the seasonal ARIMA model (Avinash et al., 2019). In India, a new multiple linear regression model has also been evaluated for accurate rainfall prediction utilizing a collection of meteorological data that includes monthly rainfall information (Swain et al., 2017; Gnanasankaran et al., 2020). The present investigation was undertaken with the main objective of comparing time series and proposedmodels for forecasting the seasonal and annual trends of rainfall in India by collecting rainfall data series for 55 years from 1968 to 2022. The secondary data wastaken from the Seasonal and Annual Rainfall Time Series for All-India (Kothawale et al., 2017) and Rainfall in India, Open Government Data.

2. MATERIALS AND METHODS

The aim of the present study was to propose a method to predict the annual rainfall of different seasons in India such as winter (January+February: JF), pre-monsoon (March+April+May: MAM), southwest monsoon (June+July+August+September: JJAS) and post-monsoon (October+November+December: OND) by using Indian rainfall data series for 55 years from 1968 to 2022. To fit linear and multiplicative models to Indian rainfall as the initial step in the forecasting process, both with and without the one-time period log dependent variable as one of the independent variables. If all the four proposed models one is selected based on maximum value ofadjusted R^2 value. First, projected India's future seasonal rainfall using the selected model. To fit the various time series models, choose a model with the highest value of adjusted R^2 and forecast the future rainfall by using the yearly rainfall as the dependent variable and the time period as the independent variable. At end, to compare the forecasted values obtained with respect to proposed models and time series models.

In this study, an attempt is made to propose a method of forecasting technique with reference to linear and multiplicative regression models with and without a onetime log-dependent variable as one of the independent variables. The procedure is given below. As a first step consider the following specifications (Draper and Smith, 1998).

$$Y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i X_{it} + \varepsilon_{1t} \quad (1)$$

$$Y_t = \beta_0 + \sum_{i=1}^{k} \beta_i X_{it} + \beta_{k+1} Y_{t-1} + \varepsilon_{2t} \quad (2)$$

$$Y_t = \gamma_0 \prod_{i=1}^{k} (X_i^{\gamma_{it}}) e^{\varepsilon_{3t}} \quad (3)$$

$$Y_t = \delta_0 \prod_{i=1}^{k} (X_i^{\delta_{it}}) Y_{t-1}^{\delta_{(k+1)t}} e^{\varepsilon_{4t}} \quad (4)$$

one of the above four specifications (1)– (4) with maximum adjusted R^2 may be selected for forecasting purpose.In the second step assume that the dependent variable Y_t and each of the independent variables [X_{it} (i= 1, 2…k), Y_{t-1}] involved in the model is a function of time and specified as

Y_t, X_{it}& Y_{t-1} = a + bt (5)

=ae^{bt} (6)

=at^{b} (7)

=ab^{t} (8)

Select the linear specification (5) and one of the three non–linear specifications (6)– (8) with maximum adjusted $R^2$for each of X_{it} (i= 1, 2…k) and Y_{t-1}; and for Y_t, select one specification from (5) – (8) With maximum adjusted R^2. To Compute the forecasted values of dependent variable Y_t, independent variables X_{it} (i=1, 2…., k) and Y_{t-1} from the above selected models.

Substitute the predicted values of each independent variable in the selected model from step one as the third step.The obtained values of dependent variable are called forecasted values through proposed method. To compare the forecasted values of dependent variable obtained through proposed method from step three with that of obtained from step two using adjusted R^2 or MSE criteria.

2.1. Proposed models/variable estimation methods

The linear and multiplicative regression models with Annual Rainfalland four seasons as

$$Y_t = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 X_{2t} + \alpha_3 X_{3t} + \alpha_4 X_{4t} + \varepsilon_{1t} \quad (9)$$

$$Y_t = \beta_0 + \beta_1 X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \beta_4 X_{4t} + \beta_5 Y_{t-1} + \varepsilon_{2t} \quad (10)$$

$$Y_t = \gamma_0 X_{1t}^{\gamma_1} X_{2t}^{\gamma_2} X_{3t}^{\gamma_3} X_{4t}^{\gamma_4} e^{\varepsilon_{3t}} \quad 11)$$

$$Y_t = \delta_0 X_{1t}^{\delta_1} X_{2t}^{\delta_2} X_{3t}^{\delta_3} X_{4t}^{\delta_4} Y_{t-1}^{\delta_5} e^{\varepsilon_{4t}} \quad (12)$$

Y_t=Annual Rainfall

Y_{t-1}=Annual Rainfall with one period time log

X_{it}= Winter, Pre-monsoon, Southwest Monsoon and Post Monsoon (i = 1, 2, 3, 4)

α_i(i = 0, 1, 2, 3, 4), β_j (j = 0, 1, 2, 3, 4, 5), γ_k= (k = 0, 1, 2, 3, 4) and δ_l=(l=0, 1, 2, 3, 4, 5) are parameters

ε_{it}=error variable (i=1, 2, 3, 4).

After converting the non–linear models (11) and (12) into linear using natural logarithms, and may apply ordinary least square method to estimate the unknown parameters.

2.2. Time series models

(i) Linear trend: Y = a + bt

$$\hat{b} = \frac{\sum tY - \frac{(\sum t)(\sum Y)}{n}}{\sum t^2 - \frac{(\sum t)^2}{n}} \quad \text{and} \quad \hat{a} = \overline{Y} - \hat{b}\overline{t}$$

(ii) Exponential curve trend

i. Y=a e^{bt}

Ln Y =Ln a+bt

Y=A+bt

$$\hat{b} = \frac{\sum tY - \frac{(\sum t)(\sum Y)}{n}}{\sum t^2 - \frac{(\sum t)^2}{n}} \quad \text{and} \quad \hat{A} = \overline{y} - \hat{b}\overline{t}$$

$\hat{a}$ =Antilog ($\hat{A}$)

ii. Y=a b^{t}

Ln Y=Ln a + t Ln b

y =A+B t

$$\hat{B} = \frac{\sum tY - \frac{(\sum t)(\sum Y)}{n}}{\sum t^2 - \frac{(\sum t)^2}{n}} \quad \text{and} \quad \hat{A} = \overline{y} - \hat{B}\overline{t}$$

$\hat{a}$ =Antilog ($\hat{A}$), $\hat{b}$ = Antilog ($\hat{B}$)

iii. Power curve : Y= a t^{b}

Log Y=Log a+b Log t

Y=A+B t, where Log Y=y, T=Log t, Log a=A

$$\hat{b} = \frac{\sum TY - \frac{(\sum T)(\sum Y)}{n}}{\sum T^2 - \frac{(\sum T)^2}{n}} \text{and } \hat{A} = \overline{y} - \hat{b}\overline{T} \rightarrow \hat{a} = \text{Antilog}(\hat{A})$$

Here $R^2 = \frac{\hat{\beta}' X' Y}{Y' Y}$, $\overline{R}^2 = 1 - (1 - R^2)\left(\frac{n-1}{n-k}\right)$

3. RESULTS AND DISCUSSION

The seasonal and annual rainfall of India for the period from 1968 to 2022 was presented in Figure 1.

In this section described, (i). The estimated modelsof proposed linear and multiplicative regression models with and without one time period log annual rainfall which were intended initially to forecast the annual rainfall; (ii). The estimated modelsof different independent variables in terms of linear, exponential and power curve trends; (iii). The estimated models of selected time series models for forecasting of annual rainfall and (iv). The annual rainfall

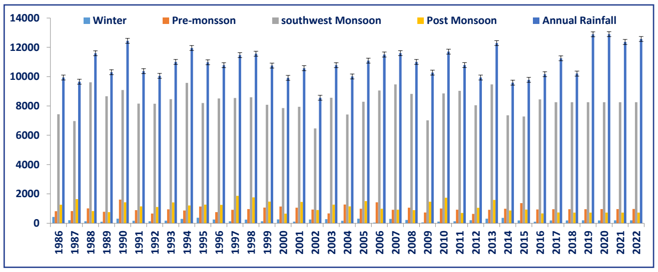

Figure 1: Seasonal and annual rainfall of India for the period from 1968 to 2022

forecasts obtained through (i) and (iii) and the relevant interpretations with respect to India and various seasons.

3.1. Estimation of annual rainfall by using proposed models

To estimate the annual rainfall to various seasons in India and presented the results with the data available on the study variables using the methodology given. The variables under study are;

Y_t: Annual Rainfall

$X_{1t}, X_{2t}, X_{3t}, X_{4t}$:Winter, Pre-monsoon, southwest monsoon and post monsoon respectively

Y_{t-1}: Annual rainfall with one period time log.

Model (i):

$\hat{Y}_t$=0.1846+1.0001X_1+1.0000X_2+0.9999X_3+1.0004X_4

R^2= 0.9999997129, $\bar{R}^2$=0.9999996874

Model (ii): Selected for rainfall foresting

$\hat{Y}_t$=1.5185+1.0003X_1+1.0000X_2+0.9999X_3+1.0003X_4-0.0001Y_{t-1}

R^2= 0.9999997227, $\bar{R}^2$=0.9999996911

Model (iii)

$\hat{Y}_t$=0.8351+0.0155lnX_1+0.0910lnX_2+0.7744lnX_3+0.1060lnX_4

R^2= 0.9968591567, $\bar{R}^2$=0.9965799706

Model (iv)

$\hat{Y}_t$=0.8704+0.0156lnX_1+0.0911lnX_2+0.7739lnX_3+0.1058lnX_4-0.0032lnY_{t-1}

R^2= 0.9968683383, $\bar{R}^2$=0.9965124676

In the above estimated models, based on the selected models of linear or multiplicative models with respect to Indianannual rainfall, the model (ii) contains maximum adjusted R^2value and it was selected for Rainfall Forestingand the corresponding values of R^2 was observed 0.9999997227 (~0.99) and $\bar{R}^2$was observed 0.9999996911 (~0.99), it washighly significant in India Rainfall. It indicates that 99% of the total variation in the annual rainfall wasexplained by the four seasons, such as winter, pre-monsoon, southwest monsoon, and post-monsoon, respectively.

3.2. Estimation of various seasons by using time series models

The estimated equations for the second step, which uses linear, exponential, and power curve trends to predict India's yearly rainfall and various seasons, are as follows:

i. Winter (X_1)

Model (i): Selected for forecast

Ln(X_1)=5.09552+0.04005Ln(t); R^2=0.0040597955, $\bar{R}^2$ =-0.0166889588

Model (ii):

Ln(X_1)=185.02740 -0.00024 t; R^2=0.0000382520, $\bar{R}^2$ = -0.020794284

Model (iii):

Ln(X_1)= 195.02740 *(0.00024)^ t; R^2=0.0000023825, $\bar{R}^2$ = -0.0207123942

ii. Pre-monsoon (X_2)

Model (i): Selected for forecast

Ln(X_2)= 6.77773+0.02115Ln(t); R^2= 0.0880053110, $\bar{R}^2$ = -0.012661245

Model (ii):

Ln (X_2)= 889.15271 *(1.00197)^t ; R^2= 0.01869791 , $\bar{R}^2$=-0.001749067

Model(iii):

Ln (X_2)= 889.15271*e^(1.00197*t ; R^2= 0.01869791, $\bar{R}^2$ =-0.001749067

iii. Southwest Monsoon (X_3)

Model (i):

Ln (X_3) =8369.22030 *(0.99641)^t ; R^2=0.002637, $\bar{R}^2$ =-0.00245689

Model(ii**)**:

Ln (X_3)=8369.22030*e^(0.99641)*t ; R^2=0.002637, $\bar{R}^2$ = -0.00245689

Model (iii): Selected for forecast

Ln(X_3)=9.03563-0.00421Ln(t); R^2= 0.004339, $\bar{R}^2$ = -0.019466400

iv. Post monsoon (X_4)

Model (i):

Ln X_4=1233.12890 *(0.99759)^t; R^2=0.017541, $\bar{R}^2$ = -0.000246112

Model (ii):

Ln X_4=1233.12890*e^(0.99759)*t ; R^2 = 0.017541, $\bar{R}^2$ =-0.000246112

Model (iii): Selected for forecast

LnX_4=7.09356-0.12690Ln(t); R^2 = 0.018108, $\bar{R}^2$ =-0.01898481

v. Annual rainfall with one period time log (Y_{t-1})

Model (i):

Ln Y_{t-1}=10629.62300 *(1.02653)^t; R^2 = 0.00013, $\bar{R}^2$ = -0.000458

Model (ii):

Ln Y_{t-1}=10629.62300*e^(1.02653)*t ; R^2 = 0.00013, $\bar{R}^2$ =-0.000458

Model (iii): Selected for forecast

LnY_{t-1}=9.25004-0.00780 Ln(t); R^2=0.007799, $\bar{R}^2$ =-0.01480709

The models of linear, exponential, and power curve trends selected from the above estimated models were observed with respect to different Indian seasons, and the values are shown in Table 1. At the 5% level of significance, the R^2 values for the different seasons are significant.

Table 1: Selected Specification Models for Forecasting in various Seasons in India

Selected specification model	R^2-value	Adjusted R^2-value
Ln(X1)=5.09552+ 0.04005Ln(t)	0.0040597955	-0.0166889588
Ln(X2)=6.777734+ 0.021151 Ln(t)	0.0880053110	-0.012661245
Ln(X3)=9.03563- 0.00421 Ln(t)	0.004339	-0.019466400
Ln(X4)=7.093555- 0.1269 Ln(t)	0.018108	-0.01898481
Ln(Yt-1)=9.25004 -0.007799 Ln(t)	0.007799	-0.01480709

3.3. Estimation of annual rainfall by using time series models

The time series models were used to forecast the annual rainfall in India. The estimated specifications of the linear, exponential, and power curves, as well as the corresponding values of R^2 and adjusted R^2, were noted below:

Model (i): Selected for forecast

Y_t=10778.74041-3.08394t, R^2= 0.0022771986, $\bar{R}^2$ = -0.0185086931

Model (ii):

Ln(Y_t)= 9.274988672-0.00028963 Ln(t), R^2= 0.000008276, $\bar{R}^2$ = -0.020824885

Model (iii):

Ln(Y_t)=9.280957-0.00027t, R^2=0.0019015790, $\bar{R}^2$ = -0.0180921381

The model (i) contains maximum $\bar{R}^2$ values, so that model (i) was the selected model for Rainfall Foresting. This indicates that the annual rainfall was linearly associated with the time variable. i.e, the growth that occurring yearly in the all Indian rainfall was in the linear trend.

3.4. Comparison

The best estimate can be determined by conducting a Comparison by using the corresponding adjusted R^2 values as shown in the below table.

Table 2: Adjusted R^2 values obtained for India annual rainfall w.r.to selected specifications of proposed and Time series Models

Selected proposed model*		Selected time series model**	
Multiplicative regression with one time log period		Linear model	
R^2	Adjusted R^2	R^2	Adjusted R^2
0.99999-97227	0.99999-96911	0.00227-71986	-0.01850-86931

*: obtained with reference to Proposed models can be observed under section 3.1; **: obtained with reference to Time series Model can be observed under section 3.3

The adjusted R^2 values for the proposed models are better than those of the time series models. It can be understood that the proposed models provide a good estimate (Table 2). The predicted values of various seasonal variables are substituted in the selected model of linear or multiplicative models and obtained in predicted values of annual rainfall in India for the next 10 years 2023–2032.These rainfall forecasts are to be compared with the annual rainfall forecasted obtained, from selected time series models. The annual rainfall forecasts which are obtained based on the selected proposed and time series models are presented in Table 3.

The proposed multiplicative model with a one-time period log of annual rainfall was observed to be the to be the best fit compared to the time series linear model. The forecasts of rainfall for the next 10 years, i.e., from 2023 to 2032, with reference to the above-selected proposed model, were observed to increase in annual rainfall from 10685.44 in 2023 to 10711.43 in 2032.

Table 3: Annual rainfall forecasts for India on the bases of selected proposed and time series model

Sl. No.	Year	Proposed model	Time series model
1.	2023	10685.44	10127.26
2.	2024	10688.32	10125.25
3.	2025	10691.21	10123.25
4.	2026	10694.10	10122.24
5.	2027	10696.98	10121.24
6.	2028	10699.87	10118.23
7.	2029	10702.76	10118.23
8.	2030	10705.65	10115.22
9.	2031	10708.54	10114.21
10.	2032	10711.43	10112.21

4. CONCLUSION

The values of adjusted R^2 for the selected models of linear and multiplicative models with one time period log models are larger than those of selected models of time series models. It indicated that the proposed forecasting model showed better rainfall prediction performance than the time series forecasting model. The results obtained clearly ensured that the proposed model offered a superior outcome over the compared time series models.

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