Development of a Time-Series Model to Forecast Climatic Data in the Batticaloa District, Sri Lanka

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Abstract

Climate variations more or less decide the environmental dynamics of an area. Extreme rainfall causes problems in Batticaloa district, especially to the agricultural sector. In this respect, knowledge of the likely climate and its impact could add value to Agro-environmental management. A forecasting approach that incorporates climatic variability of the Batticaloa district is presented in this study. Rainfall time series and their corresponding extreme event processes are analyzed using statistical models in order to study the annual climatic trend, evolution and variability. Incorporation of long-term monthly rainfall and temperature data in the ARIMA model analysis proved to be a very valuable technique in forecasting climatic trends for Agro-environmental planning.

Keywords: ARIMA, forecasting, rainfall, temperature

Introduction

Scientific interest in climatic variations has significantly increased in recent years due to important economic and social consequences connected with extreme climatic events. Most of the studies regarding climate change only seek to detect potential trends or fluctuations in the long term mean of climatic signals, but the study of variability changes and extreme event behaviour are also essential (Manobavan, 2003). This approach has become popular due to the fact that some recent climate models indicated that climate changes in the 21^{st} century would result in an increase of extreme events.

In the Batticaloa district, rainfall variability causes heavy damages to paddy production. Drought and flood not only affect the paddy but also are also responsible for famine, outbreak of various diseases and economic crisis (e.g. extreme rainfall conditions in December 2004 and the associated floods in Batticaloa). Therefore, a study of rainfall patterns in an agro-climatological perspective has an immense value for the paddy sector development and Agro-environmental planning of this district.

In these regards, the erratic nature of the rainfall in Batticaloa is worth mentioning. Even under highly erratic rainfall regimes, years with favorable rainfall distribution could occur and it is necessary to strive for product maximizing strategies in such times. Hence, early identification of the potential of seasonal variability is important in designing appropriate strategies for the environmental consequences in the Batticaloa district.

Due to its location in Sri Lanka, Batticaloa has very strong influences from the North East monsoon (NEM), which accounts for a major portion of the rainfall. Pattern of rainfall prevailing, during the inter-monsoonal months are clear while, random thunderstorms occur in the evenings (Partheepan, 2005). Tropical cyclonic activity is part of the second inter-monsoonal period however, Batticaloa lies outside the main cyclone belt (Demores, 1978). Cyclones are not frequent in this district (the last major cyclone was reported in 1978) and some times highest recorded rainfall events are experienced due to depression related perturbations. Seasonal rainfall events have been combined with other forms of rainfall (Thambyahpillay, 1958).

By considering the situation in the Batticaloa district, a study was conducted to evaluate the dynamics of such situations and to model the environmental consequences in accordance to the changing weather patterns.

The objectives of this study are;

- To forecast monthly rainfall and temperature of Batticaloa district up to 7 years.
- To explore the trend and pattern of seasonal rainfalls in Batticaloa district.

Methodology

Econometric time-series modeling techniques were applied to the time series data obtained for the Batticaloa District. The monthly rainfall records used in this study are for the Batticaloa (1900-2003). The continuous records were split into four sub-series to perform the following: preliminary and homogeneity tests, and the basic statistical properties (i.e. means, co-variance, standard deviation).

Finally, to test the outputs of the time-series analysis in respect to rainfall response, simulations were generated using stochastic Auto Regressive Integrated Moving Average (ARIMA) models. ARIMA models are an established (forecasting) technique in econometrics (Box *et al.*, 1994) and are used as a complement to the 'trend regression approach'. A detailed description of the ARIMA modeling approach adapted in this study is given in Manobavan (2003), and Meyler (1998).

It should be noted that the final phases of the analysis routine, namely the forecast the rainfall, temperature pattern are joined using dashed lines to the main body of the investigation methods. This is mainly due to the fact that there is no direct statistical approach to finalize this, yet a combination of the analysis routines and their results are used to make this judgment.

ARIMA Modeling

There are four stages in the modelling process, i.e. identification, estimation, diagnostic checking, and forecasting Janacek & Swift (1993).

Identification

The first step is to plot the data for the annual rainfall, temperature time series for 103 years. Data for 100 years are used for constructing the ARIMA model and the remaining 5 years are reserved for evaluation. A simple linear regression model is used to characterize the trend component. Further illustration of the time series is obtained from the estimated autocorrelation function (ACF) and partial autocorrelation function (PACF). Using an autocorrelation model calibrated on annual time scales, rainfall fluctuations; interannual monthly rainfall fluctuations were estimated to be 10-11 year units, 19month units respectively. Estimations using the re-parameterized autocorrelation model indicate that rainfall fluctuations have a well-pronounced seasonality of 18-19 months (Figure 01). This suggests that the rainfall pattern exhibits an annual rhythmic (seasonal) behaviour as shown by Partheepan (2005).

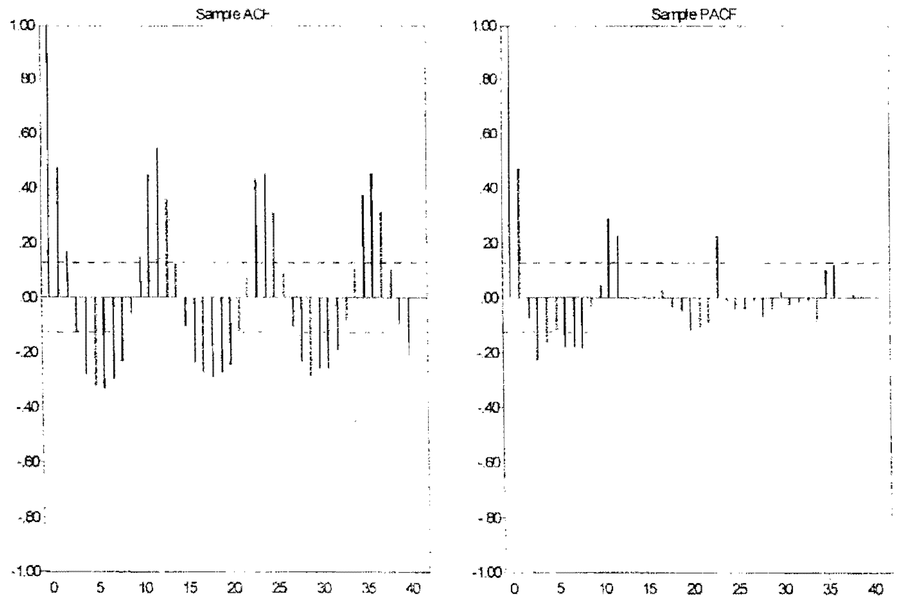

Figure 01: Autocorrelations (ACF) and Partial Autocorrelations (PACF) for monthly rainfall

Estimation

The parameter of each model is estimated with the ARIMA module of MINITAB. The results are summarized. The constant terms of all classes are negligibly small since the modeled differencing series has a nearly zero mean. All coefficients are significantly greater than zero and satisfy the stationary conditions. Absolute values for all coefficients are also significantly different from 1. Various seasonal ARIMA models were tried in this respect and the bivariate ARIMA version P, D, Q = 1, 1, 0 and p, d, q = 0, 1, 1 at S = 12 was found to be the best fitting model to analyze the rainfall time-series data.

Diagnostic Checking

The statistical adequacy of the estimated model was then verified. The ACF function for the residuals resulting from a good ARIMA model has statistically zero autocorrelation coefficients. Last 5 years also forecasted and compared to confirm the hypothesis.

The hypothesis: As inferred from the results (Table 01), the following hypothesis can be stated: *"There is no difference between measured data and forecasted data at 95 % confidence level"*

Table .01: Diagnostic checking (t test results, $P<0.05$)

Forecasted component	t value
Annual rainfall	0.0056
Northeast monsoonal rain	0.0058
Maha season rain	0.04
Yala season rain	0.014
Maximum average temperature	0.002
Minimum average annual temperature	0.0001

Forecasting:

Using the selected ARIMA model a forward forecast was first generated to predict five future years. Then taking the five predicted values, a next forecast was generated for another five years. Likewise, using this moving window methodology (Manobavan, 2003), forecasts for 7 future years were generated.

Results and Discussion

Forecast Simulation

Each model was applied for each parameter such as monthly rainfall, annual rainfall, annual maximum temperature and minimum temperature. The forecasts are then compared with the actual data obtained from the Meteorological Department, for Batticaloa meteorology station. The forecasted time series and the actual rainfall (on an annual scale) are compared in Figure 02. This shows 82%

accuracy (at 95 % confidence level). It is observed the values fall within the error bound (95%), and the forecasts track the seasonal pattern reasonably well.

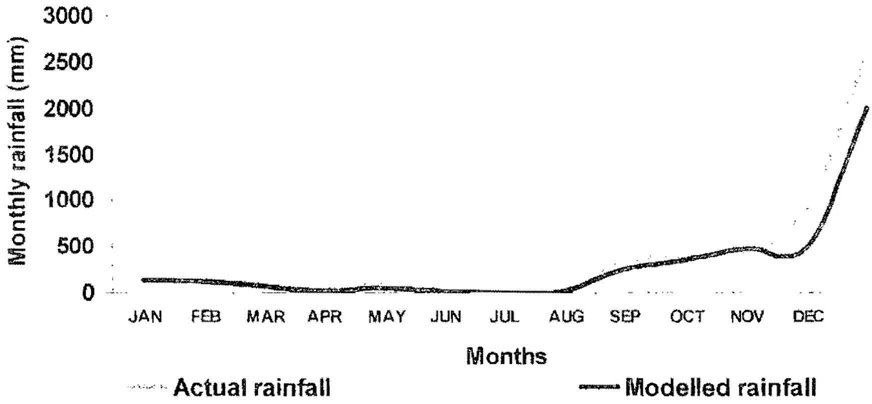

Figure 02: Correlation graph for actual rainfall data and modeled rainfall data in 2004, on a monthly scale. This shows the high accuracy of the model (83% fit with actual rainfall).

Forecasted Annual Rainfall

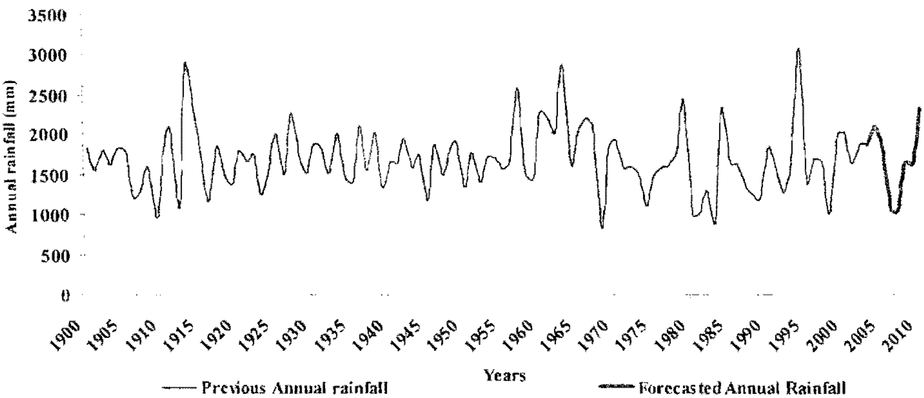

Figure 03: Forecasted annual rainfall (with past data) of Batticaloa district through ARIMA analysis.

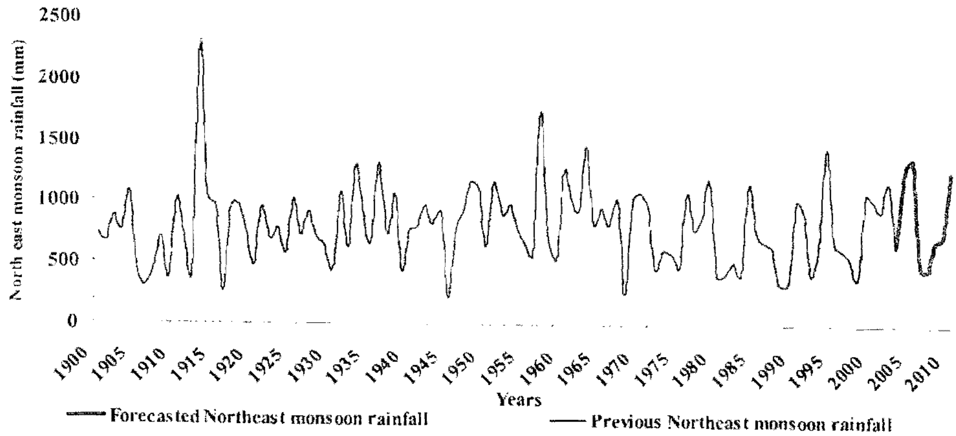

Figure 04: Forecasted Northeast monsoon rainfall (with past data) of Batticaloa district through ARIMA analysis.

ARIMA forecasts of annual rainfall were done for the period of 2004 to 2010. Figure 03 shows a compilation of the rainfall data for 1900 to 2004 with the forecasted values from 2004 to 2010. It is clearly seen the trend of annual rainfall is slightly decreased. The frequent fluctuations can be seen from 1950 can be attribute to the global climate change due to of industrialization, urbanization and heavy consumption of petroleum fuels.

Forecasted Annual Temperature

The annual maximum average temperature for Batticaloa district is 31.07°C. Temperature greatly increased from 2004 to 2010. Now the mean annual maximum temperature is 31.07°C but in 2010 it will be 31.78°C nearly 1°Cwill increase with in 7 years. This is due to green house effect and increase population heavy consumption of vehicles and machinery.

Maximum Annual Temperature

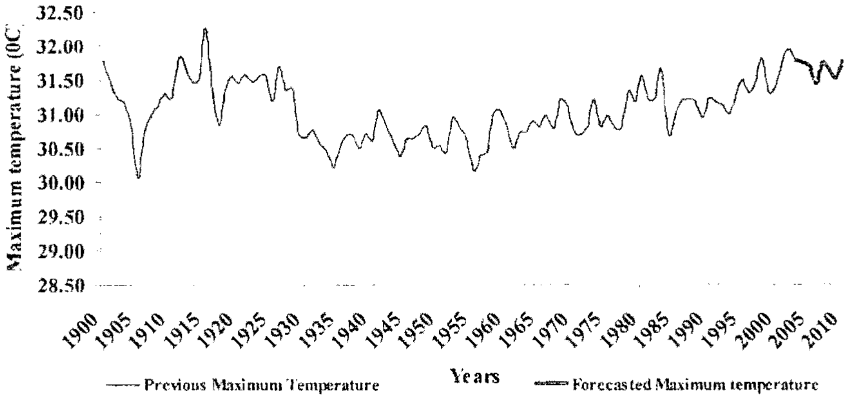

Figure 05: Forecasted annual maximum temperature (with past data) of Batticaloa district through ARIMA analysis.

Minimum Annual Temperature

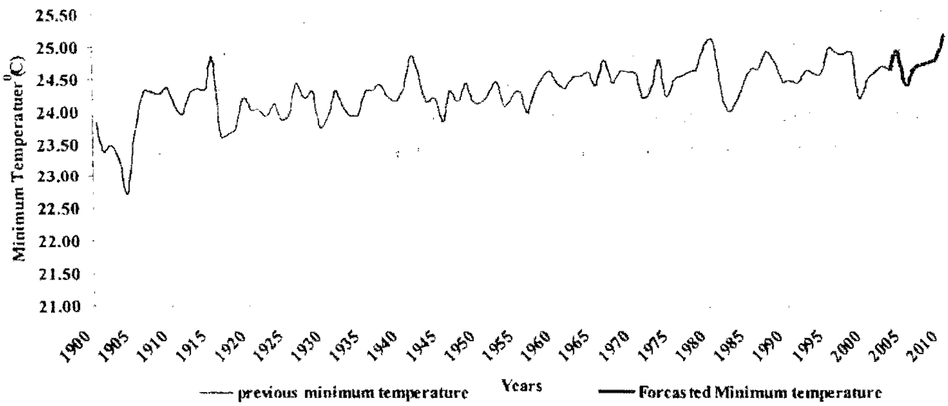

Figure 06: Forecasted annual minimum temperature (with past data) of Batticaloa district through ARIMA analysis

Correlation between Annual Rainfall and Annual Temperature

It was found that there are weak correlations for annual rainfall ~ maximum annual temperature (r = -0.1311) and annual rainfall ~ minimum temperature (r = 0.1919) at s = 95%.

The weak correlation might be due to the influence of annual rainfall at sub continental scale via the monsoon mechanism, where as temperature is mostly a product of local conditions. The inland air temperature does not depend on annual rainfall in Batticaloa district.

Drought Index for Batticaloa District

There is an ambiguity in forecasting annual rainfall, (that inherent in the ARIMA methodology), so, that a Drought index was created to know about the future climatic scenarios in the Batticaloa District. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms.

A drought index value is defined as a single number, useful for decision making (definition developed by authors).

Drought index = $\left(R - \overline{R}\right) / \overline{R}$

R = Annual Rainfall

$\overline{R}$ = Mean Annual Rainfall

In the drought index optimum years, drought index is ranging from 2.8 to -2.8. According to this drought index the forecasted data in the 2004, 2010, years, severe floods are to be expected and drought will be expected in the 2007 and 2008 years in Batticaloa. According to past inference, every decade flood can cause in Batticaloa E.g., 1963, 1984 and 1994. The rainfall coincides with the deforestation of the coastal area for low land agriculture, at this fact alone cannot explain a decline 1-2% in 100 years. It was now been established, reasonably well, that this decline is primarily associated with the decrease in North East monsoon rains and that it may be related to the global climate changes in the Indian Ocean.

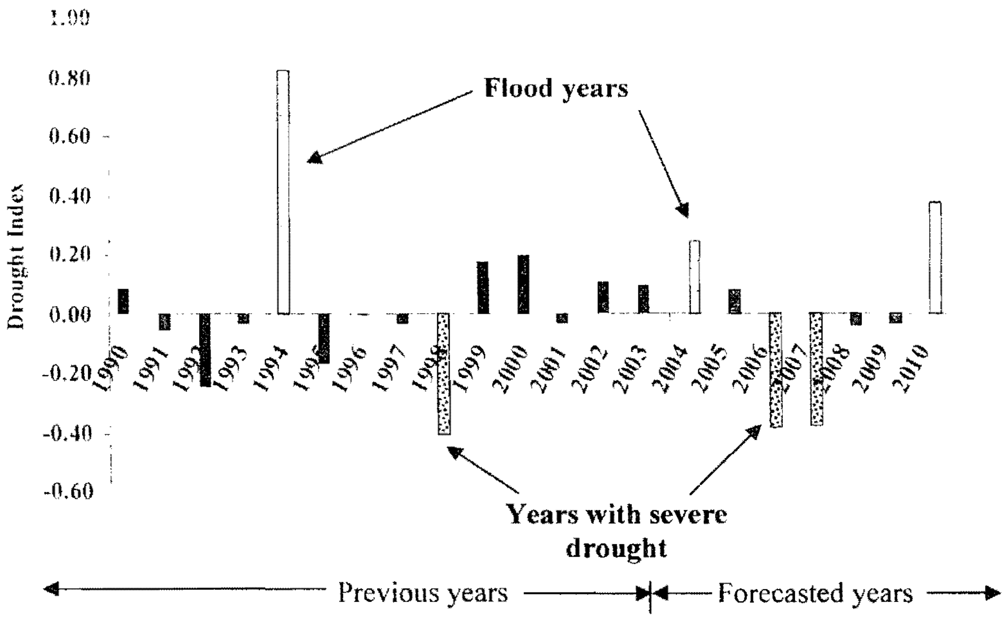

Figure 07: Past and forecasted drought and flood years for Batticaloa district on the basis of drought index, ash bars: forecasted flood years, dotted bars: years with severe drought and black bars optimum years

Conclusions

The use of the ARIMA model as a tool of analysis in an Agriculture based research, which is arguably the unique aspect of this research.

The results show that the rainfall becomes more elastic to the inter-annual climatic perturbations over time. Furthermore, it was also shown that forecasted drought and flood years can be identified with the help of the drought index. Patterns of several seasonal rainfall and temperature patterns are identified up to year 2010. This issue was promptly addressed which details the further analysis that was performed using an ARIMA forecasting simulation model.

This research has established the following aspects:

1) Forecasted how annual rainfall behaves on a 10 year cyclic pattern (north east monsoon rain also responds to this pattern), and that,

2) The forecasted trend of rainfall shows a slightly increasing trend up to year 2010.

3) Maximum mean annual temperature will increase by nearly 1°C after next 7 years but, the minimum mean annual temperature is not likely to change considerably.

4) There is no correlation between Maximum annual temperature and Annual rainfall in the Batticaloa district.

However, the model does not account for variations in precipitation due to cyclonic activity, which is a significant factor of variation in the local climate. This shortcoming should be addressed in the future research projects of this nature to enable a much cleaner picture of climatic changes in the Batticaloa district.

Further, this modeling approach could be refined using the black box approach. However, this is beyond the scope of this project.

This paper is not a hardcore hydro analysis, where the spatial perspective is paramountly necessary. Rather, this is about inferring pattern on the temporal domain. Hence, the use of econometric techniques on rainfall data becomes necessary. The findings of this work can be applied in decision making for paddy cultivation and related water resources management. The objectives are better agricultural decision making (using the techniques freely available) and not re-defining or developing an extremely comprehensive (and complex) mathematical model.

As Lovelock (1995) states: "there is no such thing as a perfect comprehensive model which is mathematically or spatially perfect; even if there was one it will be completely useless." Further, Lenton (1998) observed that the modeling is a 'mimicking' exercise and should never be confused with reality. Models can be used as general guidelines to understand probable future conditions that may occur.

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