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MODELLING AND FORECASTING RAINFALL FOR BULAWAYO PROVINCE (ZIMBABWE) USING TIME SERIES ANALYSIS

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ABSTRACT

Rainfall modelling is important to all farmers in the world, therefore modelling and forecasting rainfall is vital. The first difference of the monthly average rainfall data obtained from the Bulawayo Meterological Office is stationary and is used in the fitting of an ARIMA model. The Box Jenkins approach is used in the fitting of the ARIMA model. The ACF and PACF of the differenced rainfall data is used to determine the lags. An ARIMA (2,1,1) model fits well to the Bulawayo rainfall data. RMSE, MAE and MAPE supported this model. Future forecasts for 7 months from the model indicate that Bulawayo province will receive an average rainfall. The Ministry of Agriculture may advise farmers to plant crops which require low rainfall such as sorghum.

1. INTRODUCTION

The climate of Africa is warmer than it was before and this changing climate place additional stress on rainfall and water resources, (Clover, 2003). According to Cooper (2004), a large fraction of Africas crop production depends directly on rainfall, for example, 89% of cereals in sub-Sahara are rain -fed. Rainfall is highly variable in Africa and so in Zimbabwe. It is widely recognised that Africa is one of the most vulnerable region in the world due to widespread poverty and its highly variable climate (Madzwamuse, 2010). Zimbabwe is particularly highly vulnerable due to its dependence on rain-fed agriculture and climate sensitive resources, (Chaguta, 2010).

Like any other developing country, Zimbabwe highly depends on agriculture. High rainfall variability cause frequent droughts in Zimbabwe, particularly in the Bulawayo province. According to Sithole (2012), nearly 80% of the households in the Bulawayo high density suburb are food insecure. This means that something has to be done to address this problem. The rainfall for the province is normally referred as being above normal, below normal or near normal. This information might not be very useful to the people in Bulawayo because it does not have a statistical basis, thus the researcher thought of scientific methods in analysing the rainfall in the province in order to help the Bulawayo residents.

According to Chifurira and Chikobvu (2010), Zimbabwe had in the past years been affected by erratic rainfall patterns and sometimes droughts. During 1991 to 1992 rainy season, Zimbabwe experienced the worst drought in the living memory (Zimbabwe Central Statistical Office Report, 1994). In the year 2000, Zimbabwe was ravaged by cyclone Eline. From 2001 to 2003 Zimbabwe had rainfall in the first half of the rainfall season and dry spell in the second half of the resulting in severe drought in some parts of the country such as Bulawayo province. 2004 to 2008, Bulawayo province received little rainfall. In the 2009 to 2010 rainfall season Zimbabwe received below average rainfall in the first half and above average rainfall in the second half of the rainfall season, (Zimbabwe Central Statistical Office Report, 2010).

Accurate rainfall forecast increase preparedness and leads to better social, economic, environmental outcomes with agricultural production systems. There are several decisions made by farmers, such as choice of crops, whether to invest in fertilizers and the choice of period for planting. All these depend on the nature of rainfall variability (Githungo et al, 2009). Climate forecasts provide farmers with the opportunity to adopt improved technology, intensify production and replenish soil nutrient and invest in more profitable enterprises when the climatic conditions are favourable and to effectively protect their families and farms against the long term consequences of extremes, (Vermuel et al, 2010).

Crop production in Zimbabwe is predominantly rain fed and seasonal rainfall is highly variable, making crop failure due to rainfall extreme common (Martin et al, 2000). Improvements of the advance warning system of rainfall extreme events should be of high priority, especially considering the resources of poor farmers, who are the most vulnerable group of the Southern African region, (Manatsa et al, 2012). Rainfall is a primary determinant of agriculture productivity, (Adams et al, 1998). In most parts of Africa climate is already the driver of food security, (Clover, 2003), so is it to Bulawayo province.

Zimbabwe lies in the semi-arid region with limited and unreliable rainfall. Due to this rainfall variability it is very important to have reliable forecasts so as to enable farmers to plan on the types of crops that will produce a good yield under the forecasted conditions. Manatsa (2012) notes that in Zimbabwe, forecast are issued by the meteorological service department through the Southern African Regional Outlook Forum (SARCOP). The process generally had limited value to the concerned stakeholders. According to Manatsa (2002), Zimbabwe‘s rainy season is from October to March with December and January being the wettest month and most provinces receive above 120mm of rain during this period. Planting of crops is usually done in October in the Bulawayo province like any other province in Zimbabwe and November while harvesting is done in April and May depending on the types of crops.

Zimbabwe has ten provinces (Harare Metropolitan, Bulawayo Metropolitan, Midland, Manicaland, Masvingo, Mashonaland Central, Mashonaland East, Mashonaland West, Matebeleland North, Matebeleland South). Zimbabwe is divided into five agricultural regions (Region 1, Region 2, Region 3, Region 4 and Region 5) and Bulawayo province is under Region 5 which is part of the dry land in Zimbabwe. These regions were given on the basis of rainfall, soil quality and vegetation among other factors. Bulawayo is also the second largest city in Zimbabwe. Region 1 and 2 has reliable rainfall and good soil, Region 3 is characterised by high temperature, dry spell and is suitable for the production of groundnuts and sunflowers as cash crops. Region 4 is located in the low lying areas in the north and south of the country and is suitable for cattle production and wildlife, while Region 5 covers the lowland areas and is suitable for cattle production and game ranching.

Rainfall is a scarce resource and an important hydrological variable in dry land areas. Rainfall is important for human beings, plants and animals. There is a need for water increases daily in Bulawayo province due to population growth, economic developments and urbanisation. It is therefore vital to understand the climate and variation of rainfall in space, time and amounts and their effects on the ecosystem for the province. Most rainwater is used in agriculture for crop production, hence the prediction of rainfall is important for proper management of droughts, environmental flows and maintaining reservoir levels. An analysis of rainfall data is important for many agricultural, ecological engineering activities for example, designing of irrigation and drainage systems in the province. There is a need for each and every farmer in the province to know the rainfall patterns associated with the province for planning purposes.

Zimbabwe's land reform programme empowered citizens with agricultural land and most farmers in Bulawayo province benefited from this land reform programme. Several families in Bulawayo rely on agriculture since different social and economics groups are into farming. Furthermore, commercial urban agriculture is being undertaken largely in some parts of Bulawayo province where dairy production, poultry, market gardening and horticulture is being carried out. Peri-urban areas such as Umguza and the low density suburbs such as Trenance and Burnside produce crops such as maize, wheat, vegetables, fruits, feeder crops, poultry piggery, goats and dairy cows. All these products and produce are marketed at wholesale markets in the central business district in Bulawayo and they rely on rainfall. The production and successfulness of these farmers depend on accurate rainfall forecasts.

The Bulawayo council has two most productive farms, namely Aisleby which specialises in livestock production and Goodhope which deals with crops such as maize and wheat. There are also 12 garden allotments scattered throughout the high density suburbs, for example Mpopoma, Njube, Makokoba, Mzilikazi and Mabutweni to mention just a few. These gardens were created for the underprivileged people such as widows and the elderly and they rely on rainfall or borehole water for all the farming activities. A gum plantation and agro forestry bee keeping located in the northwest of the Bulawayo city are some of the projects initiated by the Bulawayo city council which also requires rainfall. There is also Khami school leaver and co-operatives located near the southern areas of Bulawayo which is a center that offers general agriculture training, practice and theory in both livestock and agronomy. All their activities and operations are water based.

Frequent droughts, severe dry spell, reduced yields and increased food insecurity are common features of the Bulawayo province due to high rainfall variability and unavailability of time series model that can be used to forecast future rainfall patterns in the province. There is need for statistical methods that produce accurate rainfall forecasts in order to inform farmers about the likely weather patterns they will experience. Autoregressive Integrated Moving Average (ARIMA) and Seasonal Autoregressive Integrated Moving Average (SARIMA) are capable of providing farmers with an insight of future rainfall patterns that help farmers in planning purposes and choosing suitable crops. According to Chiew (1993), time series models can provide adequate estimates of monthly or annual rainfall amounts. Crop selection and the adoption of irrigation schemes in the province will be based on these scientific models and their forecasts.

Mahsin et al (2012) used Box Jenkins methodology to build a seasonal ARIMA model using monthly rainfall taken from Dhaka station, Bangladesh for the period 1981 to 2010 and they concluded that the ARIMA(0, 0, 1)(0, 1, 1)12 model was adequate. Ansari et al (2003) dealt with the statistical analysis of rainfall measurements for three meteorological stations in Jordan, Amman Airport, which is central Jordan, Irbid which is northern Jordan and Mafraq which is eastern Jordan. An ARIMA model was fitted was used to forecast the annual rainfall values for five years for the three stations and gave better forecasts. Seyed et al (2011) applied time series to predict monthly rainfall to Iran at Abadeh station and concluded that the ARIMA (0, 0, 1)(1, 1, 1)12 model as the best. Soltani et al (2006) through the International Journal of Climatology used time series models to forecast the rainfall of 28 main cities in Iran. Their results from the time series models showed a high variation of the temporal pattern of the monthly rainfall over Iran. Weesakul and Lowanichchai (2005) used an ARIMA model to fit the time series of annual rainfall during 1951 to 1990 of 31 stations distributed in all regions of Thailand and concluded that the ARIMA model was more suitable in describe the international variation of annual rainfall in Thailand. Nail and Momani (2009) used ARIMA to model monthly rainfall data for Amman and Jordan and they concluded that the model can be used for forecasting monthly rainfall for the next 10 years.

Abdul-Aziz et al (2013) used a time series ARIMA process to model and forecast rainfall pattern in Ghana, Ashanti region and their results indicated that rainfall pattern in Ashanti, Ghana significantly changes over time. Ampaw et al (2013), used time series to model rainfall in New Juaben municipality of the Eastern region in Ghana. A SARIMA (0, 0, 1)(1, 1, 1)$_{12}$ model fitted well to the rainfall data of Ghana.

2.0 Methods and Data

A time series approach is adopted in this study with the Box Jenkins methodology being applied in building the appropriate ARIMA/SARIMA model. The historical mean monthly summer rainfall data for the Bulawayo province for the period of 2006 to 2017 obtained from the Bulawayo Meteorological service is used. The R software package is used in the data analysis. In order to determine the monthly rainfall pattern for the Bulawayo province, time series plots are used.

2.1 Stationarity test

A stationarity test is a prerequisite in most time series modelling hence the Augmented Dickey-Fuller (ADF) test introduced by Dickey and Fuller in 1979 is used to test the presence of a unit root on the series.

2.2 ARIMA

ARIMA models are specific subset of univariate models that consists of an autoregressive (AR) polynomial, an order of integration and a moving average (MA) polynomial. A process X_t is said to be an ARIMA process, denoted by ARIMA (p,d,q) where p is the order of the AR component of the model, d is the level of differencing to achieve to a stationary series and q represents the order of the moving average component. The ARIMA can be expressed as:

$$\phi_p(B)\nabla^d X_t = \alpha + \theta_q(B)W_t \qquad (1)$$

Where α is the parameter related to the mean of the process X_t, B is the backward shift operator, X_t is the mean monthly rainfall, W_t is the white noise term, ∇^d is the difference operator, θ_q and ϕ_p are the MA and AR component of the ARIMA model respectively.

2.3 Model identification and selection

ACF and PACF will are used to determine the order of the lags of the tentative ARIMA model. The Akaike Information Creterion (AIC) and Bayesian Information Creterion (BIC) are used to pick the best model, the one with the lowest AIC and BIC, (Sakamoto, 1986). The AIC and BIC are given by the following formulas.

$$AIC = 2k - 2\log(L) \qquad (2)$$

and

$$BIC = -2\log(L) + k\log(n) \qquad (3)$$

where k is the number of parameters in the model, L is the maximized value of the likelihood function for the estimated model and n is the number of observations.

2.4 Diagnostics checking

According to Smart (2013), one assumption of the ARIMA model is for the residuals to be a white noise. This means the residuals should be uncorrelated and normally distributed. The Jarque-Bera test and Ljung-Box tests are used to check normality and serial correlation on model residuals respectively. Forecasting accuracy of the model is measured by the Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE). RMSE is given by the formula:

$$RMSE = \sqrt{(f - o)^2} \quad (4)$$

where f represents the forecasted values and o are the observed values.

3.0 Data analysis

3.1 Descriptive statistics

The general characteristics of the original mean monthly rainfall data denoted by ($\boldsymbol{X_t}$) are summarised in Table 4.1

Table 4.1: Descriptive statistics for X_t.

Statistics	$\boldsymbol{X_t}$
Mean	82.61818
Median	62.10000
Maximum	316.6000
Minimum	0.100000
Std.Dev	77.05282
Skewness	1.2466950
Kurtosis	3.966950
Jarque-Bera	22.94573
Probability	0.000010

It is observed from Table 4.1 that Bulawayo province recorded the highest rainfall of 316,6mm and the lowest amount of 0.1 mm. The rainfall data is positively skewed because of the skewness value. The Anderson test's p-value is less than 0.05 supporting the rejection of the null hypothesis which states that the rainfall series is normally distributed.

3.2 Time Series Plots

The rainfall patterns for Bulawayo province are determined through a time series plot.

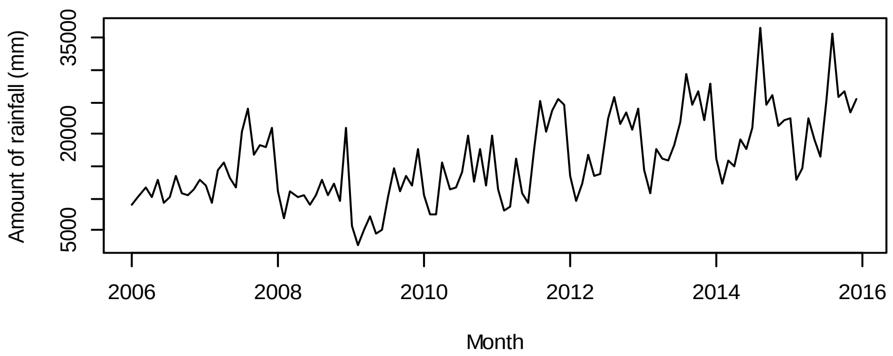
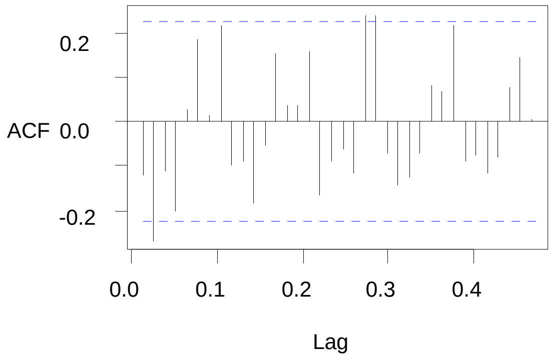


Figure 4.1: Time series plot for rainfall

Figure 4.1 shows some fluctuations in the mean rainfall data for the Bulawayo province indicating a non-stationary series. The plot shows a lot of variation in the province's rainfall suggesting a need of help, especially during those periods with major drops.

An ADF test for the mean rainfall series is done to see if the series is stationary. The ADF test statistic of -4.6253 and the p-value of 0.071 supports the acceptance of the null hypothesis of the presence of a unit root at 5% level of significance. A first difference in the series achieved stationarity because of the ADF test statistic of -8.317090 and p-value of 0.012 at 5%. The ACF and PACF of rainfall series are used to identify the tentative models.



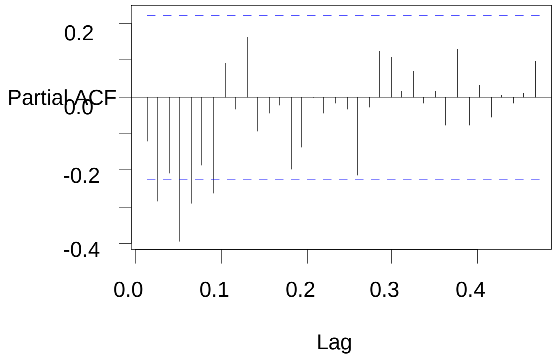


Figure 4.2: ACF and PACF of first difference of rainfall data

The ACF and PACF in Figure 4.2 suggest an ARIMA (2,0,1) model which is ARIMA (2,1,1) when using original series. This model fitted along with various models.

Table 4.2: AIC and BIC of ARIMA models

ARIMA Model	**AIC**	**BIC**
ARIMA(0,1,1) with non-zero mean	891.1746	898.1668
ARIMA(1,1,1) with non-zero mean	889.0723	989.3952
ARIMA$(1,1,0)_{12}$ with non-zero mean	903.8065	910.7987
ARIMA(2,1,1) with non-zero mean	874.1572	884.4541
ARIMA(2,1,0) with non-zero mean	896.6408	894.4051

From the Table 4.2 it is obvious that ARIMA (2,1,1) has the lowest AIC and BIC. The ARIMA (2,1,1) is considered the best for the mean rainfall data and the optimal parameters are summarised in Table 4.3.

Table 4.3 ARIMA(2,1,1) model parameters

Variable	**Parameter**	**t-statistic**	**Probability**
ar1	0.3427	3.1498	0.0037
ar2	-0.2754	-2.2838	0.0250
ma1	-0.9333	-17.9827	0.0000

In Table 4.3, it is observed that all the parameters are statistically significant at 5% level of significance.

3.3 Residual analysis.

Normality and serial correlation on the ARIMA(2,1,1) model is being examined. The Box-Ljung test statistic of 35.6077 and the probability value of 0.0171 suggest that residuals are not correlated at 1%. The Jarque Bera test statistic of 13.4017 and the probability value of

0.0123 suggest normality of residuals at 1%. The ARIMA (2,1,1) model satisfied all the model adequacy test therefore it can be used to forecast future rainfall patterns.

3.4 Forecasting

ARIMA(2,1,1) model is used to come up with out-of-sample forecasts for the next 7 months.

Table 4.4: Rainfall forecasts

Month	Amount
October 2017	72.19
November 2017	83.85
December 2017	90.66
January 2018	90.66
February 2018	91.16
March 2018	91.21
April 2018	91.22

Table 4.4 shows that for the next 7 months, Bulawayo province will receive an average amount of rainfall that will be increasing at a slow rate. This means that the Bulawayo province residence and farmers should use the available water wisely. Farmers have to resort to irrigation schemes and choose drought resistant crops or those crops that need less amount of rainfall.

5.0 CONCLUSIONS

A time series model for the mean monthly rainfall of Bulawayo province indicated variations in rainfall patterns. A first difference of the average monthly rainfall leads to a stationary series. The Box Jenkins methodology was used in the fitting of the appropriate model and an ARIMA (2,1,1) proved to be the best for the Bulawayo province data and future rainfall forecasts from the model indicated an increase in the rainfall amounts for the next 7 months. It is recommended that the Ministry of Agriculture, in partnership with the government advice the farmers about the predicted rainfall amounts so that they plan wisely and resort to drought resistant crops. The Government should also consider the construction of dams and mobilise resources so that they give farmers, irrigation equipment and avoid food insecurity in the province.

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