The relationship between temperature and rainfall variability in the Levubu sub-catchment, South Africa

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Abstract: A study has been done in the Levubu sub-catchment with the aim of investigating the relationship between temperature and rainfall variability. Monthly rainfall and temperature data for the period 1964/65-2009/2010 were used for this study. Four rainfall stations located in the Levubu sub-catchment and one temperature station were used in the study. The Standardization Procedure, Pearson's correlation analysis and Cross correlation analysis techniques were employed. The latter two methods were used to establish relationships between rainfall and temperature in the study area. The study revealed the occurrence of an extremely wet period (1999/2000) and two moderately dry periods (1982/83 and 1992/93) within the study period. Wet events were predominant during the first half of the study period and mostly dry events followed thereafter. Correlation analysis was positive when rainfall and temperature were analyzed on a monthly time-scale but negative on an annual time-scale. Annual rainfall was correlated with annual maximum and minimum temperatures and the results were moderately negative $r<-0.5$. Monthly rainfall was correlated with monthly maximum and minimum temperatures and the results were positive $r>0.8$. Annual rainfall was cross correlated with annual maximum and minimum temperatures and the results were moderately positive 0.8 at 95% confidence limits. Monthly rainfall was cross correlated with monthly maximum and minimum temperatures and the results were greater than 0.85 at 95% confidence limits. A pattern in the behavior of rainfall and temperature with respect to one another was also established. During cool years, rainfall was seen to be high, while high temperatures were associated with below average rainfall. The study recommends that further studies on rainfall and temperature with more data sets need to be done before future climate predictions can be made using high resolution time scales such as daily data analysis.

Keywords: correlation; Levubu; rainfall variability; standardization; temperature

1 Introduction

The Levubu sub-catchment in the Luvuvhu River Catchment (LRC) is of significant agricultural and hydrological importance. Agriculture is the major economic driver in Limpopo Province and more so in the LRC, despite sporadic rainfall patterns. Global climate change has impacts on agriculture and water resources and there are fears that this will continue into the future. Global climate change can be manifested in different ways including change in temperature. Change in temperature may have important hydrological repercussions, both indirect and direct, through influencing potential evaporation, total evaporation, soil moisture, dryland agricultural practices, irrigation practices, increased heat waves episodes and droughts [1]. For example, an increase in temperature is likely to reduce soil moisture, moisture storage capacity and the quality of the soil, which are vital nutrients for crops.

Various studies on the climatological and meteorological variability of temperature and rainfall such as those of [2], [3] and [4] amongst others have revealed positive correlation between the two parameters. Such studies play a vital role on a catchment scale [5] and may lead to recurrent spatial and temporal variability and patterns of extreme events [6]. [7] corroborates preceding studies in finding a quasi 18 year oscillation depicted by both temperature and rainfall in the Northern Region of the Limpopo Province (NRLP). In the first quasi 18 year oscillation, temperature decreased as rainfall increased. However, in the second quasi 18 year oscillation, temperature increased with a corresponding decrease in rainfall.

The pattern and amount of rainfall are among the most important factors that affect agricultural systems. A study by [8] in the Limpopo Basin has shown that increasing temperatures experienced over the years also had adverse impacts on non-heat resistant crops. Along with temperature, the occurrence and variability of precipitation, to a large extent determine which crops can be grown in different regions throughout the world [9]. Factors that contribute to vulnerability in water systems in Limpopo include seasonal and inter-annual variation in rainfall, which are amplified by high runoff production and evaporation rates [10].

Relationship between rainfall and temperature are mostly explained meteorologically in terms of sea surface temperatures (SSTs) and El Niño Southern Oscillation (ENSO). A study by [11] revealed that rainfall variability in southern Africa can be linked to the indo-Pacific Sea Surface Temperature. Rainfall can be explained on regional scale in terms of InterTropic Convergence Zone (ITCZ) phenomenon. ENSO and SSTs can be used to represent the global climate. Thus, this study supports the use of anomalous rainfall and temperature values to explain the relationship between rainfall and temperature.

The influence of temperature on rainfall has been incorporated in an indirect, or sometimes a direct way in a number of studies [12]. Temperature influences rainfall in many ways; such that in some cases high temperatures may result in exceedingly high rates of potential evaporation and low precipitation. This results in an area being dominated by an arid or semi-arid landscape [13]. In other cases, high temperatures lead to more evaporation and consequently increased condensation leading to high rainfall.

The characteristics of rainfall are of considerable interest to farmers, water resource managers and other user groups. Rainfall is a key factor in shaping the vegetation, hydrology, and water quality throughout the earth. In view of the above, the importance of climate change on agriculture has been analysed using the relationship between two primary climatic parameters i.e. temperature and rainfall. The main objective of this study was to investigate the relationship between temperature and rainfall variability. This is in addition to determination of drought and wet spells for the study area.

2 Study Area

The Luvubu sub-catchment is located within the LRC in the Limpopo Province of South Africa (Fig.1). The LRC is located between the longitudes 30°15’05.6’’E and 30°18’00’’E and latitudes 23°02’33.5’’S and 23°06’40.10’’S. The study area is drained by the Luvuvhu River and one of its major tributaries, Latonyanda River. It receives fairly high amount of rainfall as compared to the rest of the catchment.

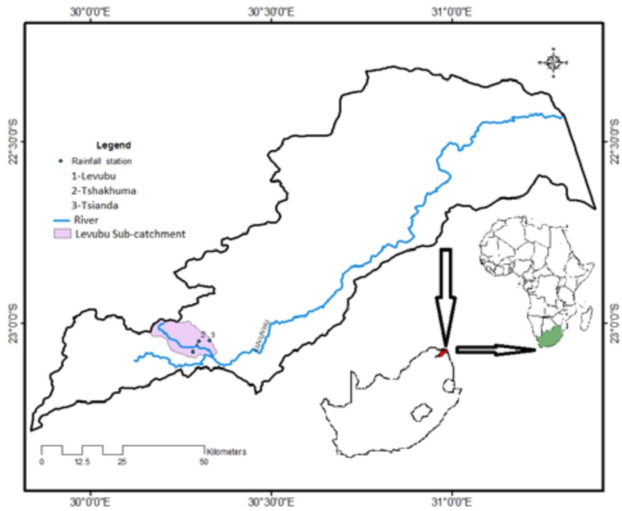

Fig.1: A map of the Levubu sub-catchment within the LRC and the location of the weather stations

3 Data

The data used in this study consists of monthly rainfall data from three stations, monthly maximum temperature data and monthly minimum temperature data from one station within the LRC (Fig. 1). Monthly rainfall and temperature data were provided by the South African Weather Service (SAWS) for a period of 46 hydrological years (1964/65-2009/10). Table 1 show the stations used in this study. The rainfall stations were chosen because they are located within the farming areas in Levubu as agriculture forms the basis for this study's motivation.

Table 1: Description of weather stations used in the study

Station Name	Station Number	Data Type	Latitude (°E)	Longitude (°S)	Height (m)	Start Year	End Year
Levubu	0723485AO	Temperature	23.08	30.283	670	1964	2010
Levubu	0723485AO	Rainfall	23.08	30.283	670	1964	2010
Tshakuma	0723513X	Rainfall	23.050	30.300	716	1964	2010
Tsianda	0723603O	Rainfall	23.050	30.366	659	1964	2010

The data period is in agreement with the World Meteorological Organization (WMO) condition that states that a period of 30 years or longer is ideal for climatic changes of significance to take place (WMO, 1976). The temperature records for this study had no missing data. Artificial neural networks were employed to fill missing data in the rainfall records provided by SAWS. Stations that did not have data recorded within the stipulated period, i.e. 1964 to 2010, were not considered in this study.

4 Methods

4.1 Standardization procedure

The standardization procedure was used to transform rainfall and temperature data in order to come up with standardized anomalies. The data was standardised using the following formula as defined by [15]:

$$Z = \frac{x_i - \bar{x}}{\sigma} \tag{1}$$

Where, $\bar{x}$ = sample mean, Z = normalized standardised departure, x_i = raw value

σ = sample standard deviation

The advantage of using the standardization procedure is that it aids in discerning normal and typical values and is symmetrical for the occurrence of wet and dry events [16]. Another advantage of this method is that a number of statistical means such as correlation analysis, which were employed in this study (See section below), required according to [15] that the data be normally distributed.

4.2 Pearson's Correlation

The Pearson Correlation Coefficient (PCC) is a statistical measure of the strength of a linear relationship between two data sets. PCC was employed to measure the linear dependence between temperature and rainfall. Monthly averages of rainfall for each year (from October to September) were correlated with monthly average temperatures for each year (from October to September). In this study annual average temperature and rainfall for the period under study was used. The relationship can be positive (large values of X (rainfall) tend to be associated with large values of Y (temperature) and small values of X tend to be associated with small values of Y), negative (large values of X tend to be associated with small values of Y and vice versa), linear or non-linear. PCC is expressed by the following statistic:

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum X^2 - \frac{\left(\sum X\right)^2}{N}\right)}\sqrt{\left(\sum Y^2 - \frac{\left(\sum Y\right)^2}{N}\right)}} \tag{2}$$

Where, N = represents the number of pairs of data, X = x-score, Y = y-score

A key mathematical property of the PCC is that it is invariant to changes in location and scale. The PCC also takes into account magnitude and direction.

4.3 Cross Correlation

Cross correlation was used to determine the strength of the relationship between the dependent time series and the independent time series at various lags [17]. Cross correlation function (CCF) provides information on the causal and non-causal relationships between rainfall and temperature as well as the significance of these relationships.

The advantage of using CCF is that it allows the investigation of statistical relationships between two variables through time and detects associations between variables that may not be obvious because of strong trends in the data [18]. The following formula was used to determine CCF;

$$r_{(d)} = \frac{\sum_{i=0}^{n-1}\left(x_i - \bar{x}\right)\left[\left(y_{i-d} - \bar{y}\right)\right]}{\sqrt{\sum_{i=0}^{n-1}\left(x_i - \bar{x}\right)^2 \left[\left(y_{i-d} - \bar{y}\right)\right]^2}} \tag{3}$$

Where: r_d = cross correlation coefficient, d = delay, $\bar{x}$ = mean of rainfall series, $\bar{y}$ = mean of temperature series, x_i = raw rainfall value,

y_{i-d} =delayed raw temperature value

n = total number of values, i = i^{th} term in series.

4.4 Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is an index based on the probability of precipitation for any time scale. The SPI calculation for any location is based on the long-term precipitation record for a desired period. The SPI classification values from [19] were used to discern between wet and dry spells/events. In this study annual average precipitation for the three stations considered in this study were used.

5 Results and discussion

5.1 Analysis of Rainfall and Temperature Data

5.1.1 Monthly Data Analysis

Maximum and minimum temperatures in the Levubu sub-catchment are both at their highest from October to April (summer) whilst they are at their lowest from May to August (winter) (Fig. 2). The preceding graph is in agreement with studies by [20] and [7].

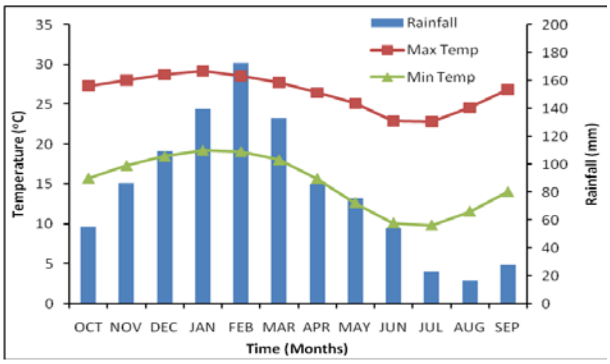

Fig.2: Average monthly maximum and minimum temperatures and rainfall for the study area for the period 1964/65 to 2009/10

The rainy season occurs mostly in summer starting from October and ending in March. The peak rainfall month in this study is February and the least amount of rainfall is experienced in winter (Fig. 2). The period from May to September is a dry season.

5.1.2 Temporal Data Analysis

Comparison of rainfall and temperature (minimum and maximum) time series data (Fig. 3) showed a consistent temporal pattern of rainfall compared to minimum and maximum temperatures. The cooler years tend to be associated with more rainfall and vice versa, mainly in terms of the frequency of occurrence and its abundance. Observation of the behaviour of rainfall peaks in relation to the behaviour of the corresponding temperature peaks confirms this. In terms of potential future global warming, according to [21], if the current temperature/rainfall relationships remain unchanged in the study area, then warmer years will most likely be linked to a decrease in rainfall.

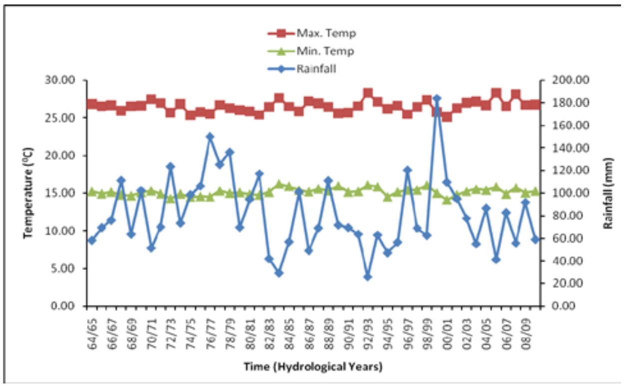

Fig.3: Temporal behaviour of rainfall in relation to minimum and maximum temperatures in the study area.

This study's findings are in line with the rainfall-temperature relationships that were summarized by [22] when they computed correlations between temperature and rainfall in the contiguous United States, Europe and southern Africa for 64 years i.e. 1897 to 1960. They found that cold years were mostly wet and warm years were drier than normal. There has been considerable interest on variability and trends in rainfall and surface temperature since then with expectations that cooler temperatures result in high rainfall totals, while heat waves often accompany droughts inland. The same association and manner in peak occurrence can be seen in relation to rainfall and maximum temperature.

Generally, southern Africa experiences one major rainfall season centred on December-January-February associated with the extreme southward position of the ITCZ [23]. This explains the peak of rainfall during the month of February as depicted in Fig. 2. The three month period (i.e. December, January and February) is an important season because the atmospheric circulation over southern Africa is dominated by tropical circulation features [24]. The ITCZ follows distinct seasonal meridional propagation across the region, and is often associated with rainfall because of extensive convection and cloud development that occur at the location of the ITCZ. The high temperatures centred in November to February are thought as precursors of seasonal rains since they provide ample energy for convective activities that enhance rainfall to Levubu sub-catchment [25]. Thus, it can also be assumed that this heat feeds and maintains the ITCZ across Levubu sub-catchment.

5.2 Analysis of Anomalous Years

5.2.1 Mean maximum temperature

Fig. 3 shows that the mean maximum temperature is 26.5°C while Fig. 4 shows appreciable variation of maximum temperatures. The hottest season in the study period recorded an anomaly of 2.4 and this value coincides with the 1991/92 season. This finding is in accordance with literature by [26], which highlighted a severe drought during the same period. The lowest mean maximum temperature experienced during the 1999/00 season correlated to an anomaly of -1.9, and was associated with the 1999/00 extreme floods. In addition to the above, hydrological years 76/77 and 95/96 had low mean maximum temperature of -1.4 and -1.3 respectively. This is in agreement with studies such as those of [22]; [2] and [21] among others that showed that cooler years are linked to wetness.

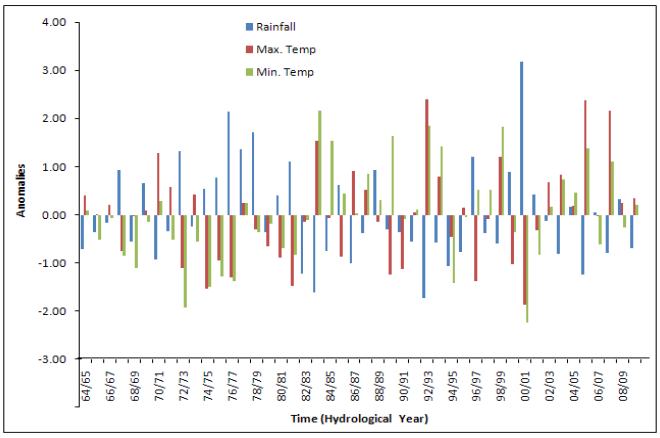

Fig.4: Maximum and minimum temperatures, and rainfall anomalies from 1964/65 to 2007/10.

Fig. 4, other than displaying extreme events, also shows different anomalous years. The first five years experienced near normal conditions with little deviation from the average maximum temperature. The seventies and early eighties i.e. between 1969/70 and 1981/82 were predominantly characterized by below average maximum temperatures. From 1982/83, maximum temperatures fluctuated above and below the average maximum temperature. This shows much variation in the mean maximum temperature time series. Most of the peaks in the time series were sparsely distributed with clusters of one or two peaks experienced in adjacent years.

As a result of the high average maximum temperature, the study area experiences high levels of evapotranspiration. This negatively affects surface water resources availability in the study area that farmers utilise for irrigation.

5.2.2 Mean Minimum Temperature

The mean minimum temperature was found to be 15.2°C with a standard deviation of 0.5°C. Fig. 4 revealed much distinguishable variation in mean minimum temperature. The coolest season of the study period recorded an average minimum temperature of 14°C in 99/00 year (Fig. 3). This low minimum temperature resulted in a -2.2 temperature anomaly. In addition to the above, hydrological years 76/77 and 95/96 had low mean minimum temperature of -1.4 and -1.3 respectively. The warmest mean minimum temperature was 21°C during the 1991/92 drought. This finding was coupled with a 1.9 temperature anomaly (Fig. 4).

Two distinct phases in the pattern of the anomalies were identified. The latter shows the trend and the manner in which minimum temperatures behave during the study period. Firstly, from 1964/65 to 1981/82, the average minimum temperature anomaly was rarely exceeded (Fig. 4). These low minimum temperatures correspond to flooding in the study area during the same period. The second and longer phase in the time series was characterized by high minimum temperatures. The anomalies from 1982/83 onwards show that above average minimum temperatures dominated the trend. However, two peak anomalies that were below average were highly conspicuous (Fig. 4). The behaviour of the minimum temperature standardized departures show the variation suggested by this study.

5.2.3 Rainfall Anomalies

Table 2 shows the classification of the hydrological years in relation to SPI values. SPI is related to temperature in that when temperature is low, rainfall is high and vice-versa. Wet and dry events were distinguished from the rainfall anomalies (Fig 4). In the 46 year period, 19 years were classified as wet i.e. years that had anomalies above the average and 27 seasons were categorized as dry seasons i.e. years that had anomalies below the average.

Table 2: The classification of the seasons in relation to SPI

SPI values	Description	Season(s)
2+	Extremely wet	99/00, 76/77
1.5 to 1.99	Very wet	71/72, 95/96
1.0 to 1.49	Moderately wet	75/76, 77/78, 80/81,
-0.99 to 0.99	Near normal	64/65, 65/66, 66/67, 67/68, 68/69, 70/71, 72/73, 73/74, 74/75, 78/79, 79/80, 83/84, 84/85, 86/87, 87/88, 88/89, 89/90, 90/91, 92/93, 94/95, 96/97, 97/98, 98/99, 00/01, 01/02, 02/03, 03/04, 04/05, 06/07, 08/09, 09/10
-1 to -1.49	Moderately dry	69/70, 81/82, 85/86, 93/94
-1.5 to -1.99	Severely dry	82/83, 91/92
-2 and less	Extremely dry	

According to SPI classification by [27], there were only two extremely wet events. The latter were found to occur during the 1976/77 and 1999/00 season and had anomalies of 2.1 and 3.27, respectively (Fig. 4). These indices were associated with average rainfall totals of 150mm and 184mm, respectively (Fig. 3). Severely dry events were also experienced. Within those however were periods of severe dryness. The 1982/83 and 1991/92 rainfall seasons recorded -1.5 and -1.7 on the SPI scale respectively. The most frequent condition was near-normal with very few of these departures exceeding the median value and most of the values in this classification fell below the median throughout the 1980's and 1990's. This study found out that temperature has influence on rainfall variability. This is significant in the sense that planners can base their designs on temperature data. In addition farmers can plan their farming seasons based on the available temperature information.

5.3 Correlation Analysis

5.3.1 Pearson's Correlation Coefficient Analysis (PCC)

The correlation of annual rainfall and maximum temperature gave Pearson's Correlation Coefficient was $r = -0.71$. The correlation of annual rainfall with minimum temperature gave $r = -0.61$. The correlation of annual data for the study period revealed negative and significant association between rainfall and maximum and minimum temperatures. The results of the correlation analysis confirm studies by [28] and [29] that identified and forecasted a reduction in rainfall and an increase in temperature in South Africa.

Strong and positive correlation coefficients were found when the monthly averages for rainfall were correlated with the monthly averages for maximum and minimum temperatures. The result for the correlation of monthly data for rainfall and maximum temperature was $r = 0.81$. Strong relationship of $r = 0.90$ was found to exist between annual monthly rainfall and minimum temperature. These results show that as rainfall increases, temperature increases. This is in contradiction to studies mentioned earlier i.e. [28] and [29]. This is so because rainfall and temperature on a monthly time frame behave in the same manner in relation to the summer and winter seasons. The nature of the relationship of rainfall and temperature on an annual time scale is in sharp contrast to the relationship of rainfall and temperature on a monthly time scale.

5.3.2 Cross Correlation Function Analysis (CCF)

Cross correlation was applied to annual averages of rainfall and temperature data for a suspected leading indicator to find out how it influences the dependent variable at various lags. The lag with the greatest correlation was shown as having the highest bar in the correlation plots. The CCFs for annual rainfall and annual maximum and minimum temperatures at 95% confidence limit are shown in Appendix A.

Appendix A1 and A2 both display negative and significant correlation coefficients. The expected leading parameter in the cross correlation analysis was temperature while rainfall was seen to be the dependent parameter. The results, however, show negative correlation, hence, rainfall is seen to be the leading variable. A high negative correlation indicates a high correlation but of the inverse of one of the parameters [30].

This study also subjected the monthly averages for rainfall and temperature data to CCF. This short time frame produced contrasting results to the annual rainfall and temperature analysis (Appendices A3 and A4), as did PCC. The cross correlation plot for monthly rainfall and maximum temperature averages showed three peaks out of the 95% upper confidence limit (Appendix A3). The major peak, however, was found to have a 0 lag and a correlation coefficient of $r_d = 0.81$ which is a statistically significant correlation. A statistically significant correlation was also found when monthly rainfall was correlated with monthly minimum temperature. The correlation coefficient plot (Appendix A4) exhibited three peaks that fell out of the 95% upper confidence limit. The correlation function was found to be $r_d = 0.92$ at 0 lag. The results from the cross correlation of monthly averages showed statistically significant correlation between rainfall and temperature. The behaviour of the correlation plots i.e. positive peaks; suggest that temperature on short time scale, does influence rainfall but at 0 lag.

Analysis of the data on a long time scale i.e. annual data shows negative correlation while analysis on a short time scale shows positive correlation. The relationships established for the monthly data are robust during the study period and should apply on multiple small time scales, including trends[22]. Relationships between rainfall and temperature are strong and weak varying on different time scales from multi-decadal, inter-annual, monthly and daily [30]. [31] confirmed negative correlations for inter-annual rainfall over parts of Europe and the Middle East and positive correlation coefficients for daily data time series. Results from [31] are in harmony with the conclusions drawn in this study.

6 Conclusion and recommendations

The results of this study suggest that annual (long) time scale correlation of rainfall and temperature results in a negative correlation. This can be explained on the basis of the fact that during cool years, in which the standardized departures of maximum and minimum temperatures infrequently exceeded the long-term average, rainfall was high. Therefore, when temperature decreases rainfall is high, hence a negative correlation. When warm years were apparent the resulting effect was a reduction in rainfall. The positive correlation coefficients were found to result from correlation on a monthly (short) time scale. This could be explained from the fact that monthly data for temperature and rainfall behave in the same manner, for example, in January when the highest temperatures are experienced, the highest amounts of rainfall are recorded. The study has revealed that temperature increases when rainfall decreases which is likely to impact on water resources availability in the study area. As the study area experiences a high degree of annual rainfall variability with drought and wet years alternating frequently, careful management of water resources is a high priority. The latter is due to the fact that the region is prone to devastating floods and droughts. Further studies on rainfall and temperature with more data sets need to be done for more certain future understanding of rainfall variability with temperature changes.

In addition, due to uncertainties arising from the variability of temperature and rainfall, water and municipal managers, farmers and communities should come up with alternative and sustainable sources of water. For example, developing groundwater sources, which will assist in averting the negative impact associated with water shortage.

Acknowledgement
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Appendix A: Cross correlation plots

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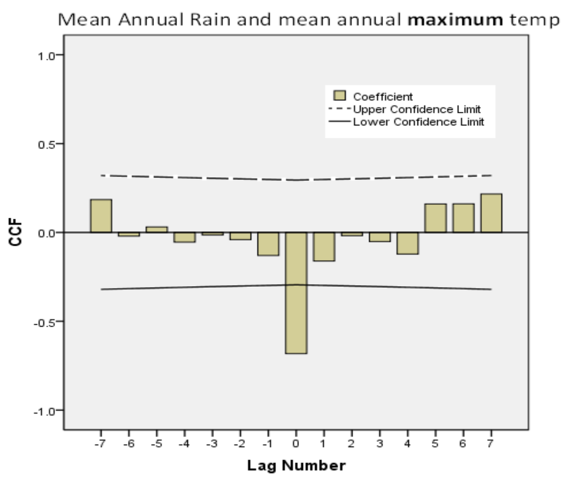

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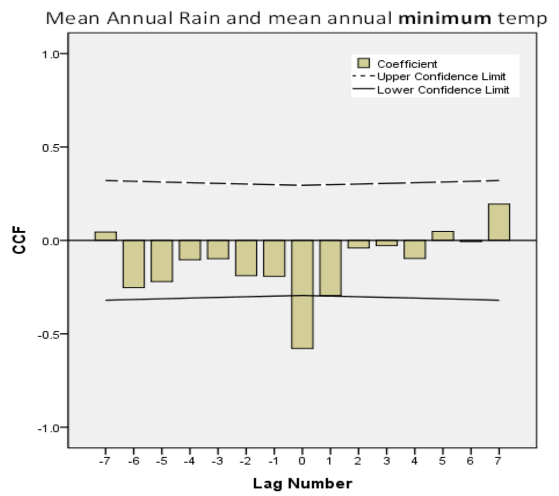

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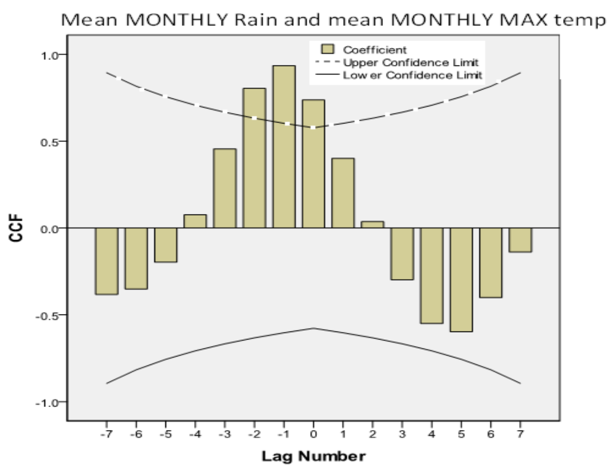

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