International Journal of Intelligent Computing and Technology

ISSN: 2457-0249 (Online)

Website: https://www.ijict.com June (2020) - Vol.4, Iss.1 Pages:01-17

Simultaneous Trend Analysis of Seasonal Rainfall Pattern in Zimbabwe

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Article History- Received: May 2020; Published: June 2020

Abstract

This study analyses seasonal rainfall pattern in Zimbabwe using a simultaneous trend analysis approach over a 30 year period (1986-2016). Most studies in the country have used one source of climatic data from the Zimbabwe Meteorological Services Department (ZMSD) to show how climate is changing in Zimbabwe , which may not provide a comprehensive picture on how climate change have resulted in the decline of seasonal precipitation in the country . This study analysed 3 seasonal precipitation related bio-climatic variable trends i.e. the seasonal minimum precipitation (SMP), seasonal maximum precipitation (SMXT), and seasonal total precipitation (STP) from two sources of climatic data at the same time . Climate data were obtained for the National Climate Data Centre (NCDC) and the World Bank. Time series analysis of climatic variables was performed in XLSTAT using the Mann-Kendall trend tests. Results show that the SMP from NCDC has a non- significant declining trend (p=0.586; α= 0.05.), whilst SMP from the World Bank showed a significant trend (p=0.017; α=0.05). SMXP from the NCDC revealed a significant trend (p=0.001; α=0.05) whilst SMXP from the World Bank revealed a statistically non-significant trend (p=0.434; α=0.05). STP from the NCDC revealed a statistically significant trend (p=0.000, α=0.05) and the STP from the World Bank showed a statistically significant trend (p=0.014, α=0.05 .The study concludes that climate change is occurring in Zimbabwe and it have a direct impact of declining in seasonal precipitation as shown by significant changes in the trends of bioclimatic variables assessed. There is need to emphasize implementation of adaptation and mitigation measures to enable the resilience of communities and various climate sensitive sectors in the nation.

Keywords: Climate Change, Zimbabwe, Trend Analysis

1. INTRODUCTION

Rainfall or precipitation is among the most investigated meteorological variables in climatic trend studies, because of its serious implications that it have on spatial and temporal changes on several environmental and socio-economic aspects. With regard to the temporal distribution of rainfall, long-term trends have been detected in several areas of the world. In Zimbabwe, an alternation of extreme rainy periods and severe droughts or water shortages has been detected. Furthermore, this area is characterized by significant decrease in rainfall due to the impacts of climate change.

Long term trend analysis of climatic elements, rainfall variables have shown that climate is indeed changing (Warburton and Schulze, 2005; Dore, 2005; Kruger and Shongwe, 2004; New et al., 2006; Warburton et al., 2005).From previous studies in Zimbabwe, rainfall has shown a declining trend that is not statistically significant, however, several studies (e.g. Makarau, 1995; Unganai, 1996; Mason and Jury, (1997); Mazvimavi, 2010); Simba et al., 2012) established that the decrease of rainfall in Zimbabwe has translated into a decline of up to 10% on average over 100 years. Furthermore, Simba et al. (2012) postulated an increase in the number of seasons recording below normal rainfall over time.

From a global perspective many studies were done to show how climate is changing using both temperature and rainfall variables. In Africa, IPCC (2007) avers that there will be major changes in rainfall in terms of annual and seasonal trends and extreme events of flood and drought in the region. These define climate change. In Zimbabwe, Brazier (2015) points out that the total amount of rainfall received during a rainy season annually has decreased by about 5 % since 1900 and more rain than the average is occurring at the beginning of the season, October and less rain than average is being received between January and March. The frequency and length of dry spells during the rainy season have increased while the frequency of rain days has been reducing and droughts and floods have increased in frequency since 1990, often occurring back to back with a flood year immediately following a drought year. The situation in Zimbabwe is such that although the quantity of rainfall in a year may be normal, this may fall during violent storms. Furthermore, recent studies which use global circulation models show that from the current period up to the year 2080, Zimbabwe will face a general decrease in reliability and predictability of rainfall patterns.

Rainfall distribution in Zimbabwe is erratic both in space and time across all the provinces of Zimbabwe and in the drier parts of the country in the Midlands, Masvingo and Matabeleland provinces, precipitation has declined by about 15% since 1960 (Manyeruke *et al*,2013). Manyeruke *et al* (2013), further assert that month on month rainfall patterns indicate that there will be a further reduction in annual rainfall during the summer (November to March) the rainy season and in the drier parts of the country in the Midlands, Masvingo and Matabeleland provinces, precipitation has declined by about 15% since 1960 using the Zimbabwe Meteorological Services Department ground based station climatic data.

Other studies done in this area shows that decline in seasonal precipitation as a result of climate change affect the bio-physical environment, for example Parmesan and Yohe, 2003; John et al., 2008; Dillon et al., 2010; Gilman et al., 2010; Pereira et al., 2010; Salamin et al., 2010; Beaumont et al., 2011; Dawson et al., 2011; McMahon et al., 2011; Bellard et al., 2012). These studies are significantly contributing in informing scientists and decision makers about forthcoming threats of decreasing of seasonal precipitation as a result changing climate and its impacts on vegetative species, crop diversity and yield production from ecosystem as a result of climate change at global level in general and Zimbabwe in particular.

How to explain climate change using a simultaneous trend analysis of rainfall pattern is consensus among scientists to give a clear and comprehensive picture on how climate change is leading to a significant decrease in seasonal precipitation in Zimbabwe using climatic data from two different meteorological satellites .In Zimbabwe previous studies in the field of meteorology and climatology showed a statistically significant trend and results of precipitation pattern on different time periods. Previous studies showed that precipitation in is decreasing as a result of climate change. However the knowledge gap exist in this field of study because previous studies on climate change in Zimbabwe was based on using the local data from the Zimbabwe Meteorological Services Department (ZMSD) which is rain gauge ground based station climatic data,(Chapungu and Nhamo, 2016, and Simba et al 2012).This means simultaneous trend analysis of seasonal rainfall pattern in Africa and in Zimbabwe in general merge as an active area which need serious attention from both meteorologists and climatologist expects to give a clear and comprehensive picture and explanation on how climate change directly lead to a statistically significant decrease in seasonal rainfall in Zimbabwe.

In an effort to cover this gap on how climate change directly impacts seasonal rainfall over a 30 year period., the purpose of this study is to critically examine simultaneous trend analysis of rainfall pattern in Zimbabwe over a 30 year period time. Simultaneous means to analyse trend and pattern of three seasonal precipitation variables from the National Climate Data

Centre (NCDC) and World Bank climatic data to give a comprehensive and clear picture on how climate change have leading to a decline of seasonal precipitation over a 30 year period in Zimbabwe.

2. MATERIALS AND METHODS

2.1 STUDY AREA

Zimbabwe is a landlocked country in southern Africa, lying between latitudes 15° and 23° South of the Equator and longitudes 25° and 34° East of the Greenwich Meridian. Its area is 390,757 square kilometers. The country is bordered by Mozambique to the East, South Africa to the South, Botswana to the West and Zambia to the North and North-west. The Zambezi River to the north and the Limpopo River to the south, form Zimbabwe's borders with Zambia and South Africa, respectively.

Zimbabwe has a sub-tropical climate with four seasons: cool dry season from mid-May to August; hot dry season from September to mid-November; the main rainy season running from mid-November to mid-March; and the post rainy season from mid-March to mid-May. The mean monthly temperature varies from 15 ^{0}C in July to 24 ^{0}C in November whereas the mean annual temperature varies from 18 ^{0}C on the Highveldt to 23 ^{0}C in the Lowveldt. The lowest minimum temperatures (7 ^{0}C) are recorded in June or July and the highest maximum temperatures (29 ^{0}C) in October, or if the rains are delayed, in November. The climate is moderated by the altitude with the Eastern Highlands enjoying cooler temperature compared to the low lying areas of the Lowveldt. Zimbabwe is generally a semi-arid country with low annual rainfall reliability. The average annual rainfall is 650 mm but geographically it ranges from around 350 to 450 mm per year in the Southern Lowveldt to above 1,000 mm per year in the Eastern Highlands. The rainfall pattern of Zimbabwe is variable with years below and above normal rainfall.

According to the Zimbabwe National Statistical Agency (ZIMSTAT) Census Report published in 2013, Zimbabwe had a total population of 13,061,239 people as of August 2012. Of these, 41 per cent were children below the age of 15 years while four per cent were the elderly above the age of 65 years. This means that Zimbabwe's population still has the potential to grow even though its annual growth rate has declined in recent years, with a 2002-2012 inter-censal population growth rate of 1.1 per cent. With such a growth rate, the population will double in about 70 years. The economy of Zimbabwe is agro-based economy and most of the agricultural activities rely on rain-fed agricultural production.

2.2. SEASONAL RAINFALL DATA

Seasonal minimum precipitation, seasonal maximum precipitation and Seasonal total precipitation for Zimbabwe was obtained from the National Climate Data Centre (NCDC) which is managed under National Oceanic and Atmospheric Administration (NOOA) programs for preserving, monitoring and provision of climate and historic weather data (www.ncdc.noaa.gov) and the World Bank on http://www.world_bank_climate_data.gov and simultaneously used in this study to give a clear and comprehensive picture on how climate change lead to a significant decrease in seasonal rainfall received in Zimbabwe over a 30 year period from 1986-2016.

2.3. DATA ANALYSIS

Time series data were subjected to distribution tests using the Kolmogorov-Smirnov test to ascertain how the data satisfy assumptions of parametric or non-parametric statistical analysis methods (Chikodzi and Mutowo, 2014). Lettenmaier, (1976) and Hirsch et al., (1993) noted that, unless the assumption of normal distribution for parametric statistics is met, it is generally advisable to use non-parametric tests. Non-parametric statistical analysis methods were therefore used in the study.

2.4. AUTO-CORRELATION AND PRE-WHITENING

The Mann-Kendall (MK) test (Mann, 1945) was used to test if there was a significant change in seasonal rainfall trend and patterns in Zimbabwe over a period of 30 years. This process is done simultaneously (at the same time) using climatic data from National Climatic Data Centre and World Bank. This helps to give a clear and comprehensive picture on how climate change lead to a significant decline in seasonal rainfall in Zimbabwe from 1986-2016. The MK test is a non-parametric method to determine trends in time series data. Dietz and Kileen; (1981); Hirsch et al., (1993) concur that the test is simple, robust, can cope with missing values, and seasonality and values below detection limit. An add-in of Microsoft excel, XLSTAT 2015 was used to carry out this non-parametric test.

However, prior to this test, the data was first tested for autocorrelation to ascertain the need for pre-whitening. Detection of auto-correlation would require the data to be pre-whitened.

Hamed and Rao (1998) put forward that auto-correlation is the correlation of a time series with its past and future values. Geophysical time series are frequently auto-correlated because of inertia or carryover processes in the physical system (Hamed and Rao, 1998). This confounds the application of statistical tests by reducing the number of independent observations thereby increasing the chances of detecting significant trends and pattern even if they are absent and vice versa. Pre-whitening is the process of removing undesirable autocorrelations from time series data prior to analysis. Thus, the data was pre-whitened in Paleontological statistics (PAST 3.0) software using the Autoregressive Integrated Moving Average (ARIMA) model (Hamed and Rao, 1998).

The ARIMA model performs time series forecasting and smoothening and project the future values of a series based entirely on its inertia. It takes into account trends, seasonality, cycles, errors and non-stationary aspects of a data set when making forecasts (Von Storch, 1995).

3. EXPERIMENTAL ANALYSIS

3.1 SIMULTANEOUS TREND ANALYSIS OF SEASONAL RAINFALL PATTERN IN ZIMBABWE

3.1.1 Seasonal Minimum Rainfall from NCDC

The Mann-Kendall test shows that there is no significant trend ($P > 0.05$) in seasonal minimum rainfall amount received in the country over 30 years using the climatic data from NCDC. Results indicate a non-significant ($p=0.586$ $\alpha=0.05$) change in seasonal minimum rainfall over 30 years (Fig.1). The null hypothesis was that there is no significant trend of seasonal minimum rainfall between 1986 and 2016 while the alternative hypothesis was that there is a significant trend. Formally stated:

H_0: There is no significant trend in the seasonal minimum rainfall between 1986 and 2016 in Zimbabwe.

H_1: There is a significant trend in the seasonal minimum rainfall between 1986 and 2016 in Zimbabwe.

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis. The Mann-Kendall trend test computed p-value (0.586) is higher than the significance level alpha (0.05). Therefore, the null hypothesis is not rejected. The risk of rejecting the H_0 while it is true is 46.56%. However, although the trend is statistically not significant, the decrease in rainfall pattern is observed. The decrease in the seasonal minimum precipitation clearly indicates that climate change directly lead to the decrease in seasonal rainfall in Zimbabwe.

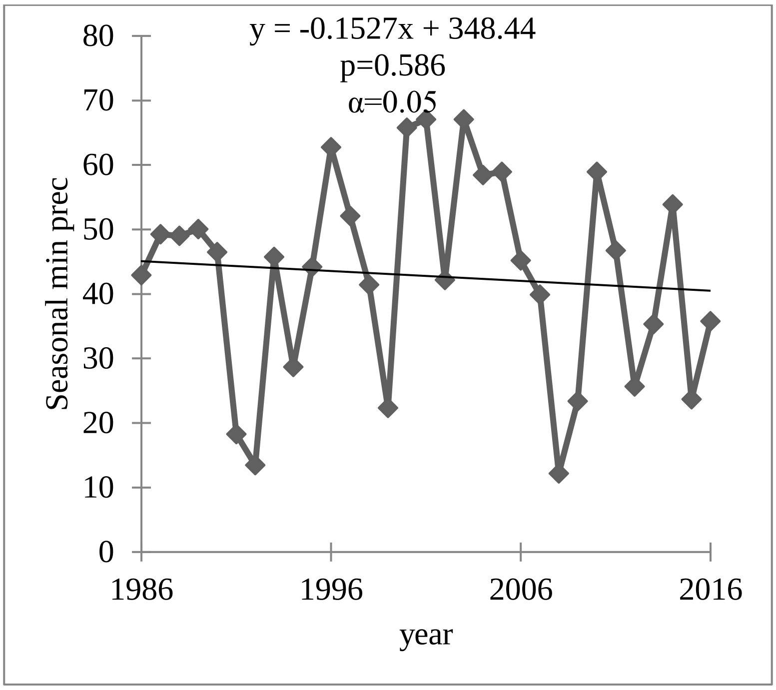

Fig.1 Seasonal Minimum Precipitation from NCDC

3.1.2. Seasonal Minimum Rainfall from World Bank

Results of this study from the World Bank show that the seasonal minimum precipitation in the area under study decreased over time. Mann Kendall trend tests show a significant (p=0.0017, α=0.05) trend in precipitation between 1986 and 2016 (Fig. 2).

The null hypothesis was that there is no significant trend of seasonal minimum precipitation between 1986 and 2016 while the alternative hypothesis was that there is a significant trend. Formerly stated:

H_0: There is no significant trend in seasonal minimum precipitation between1986 and 2016 in Zimbabwe.
H_1: There is a significant trend in seasonal minimum precipitation between 1986 and 2016 in Zimbabwe.

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

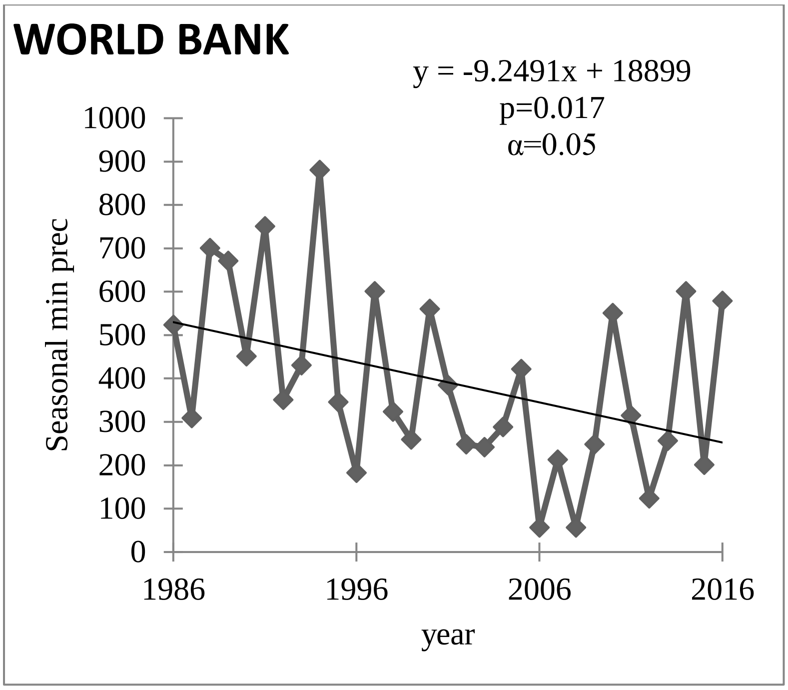

Fig. 2 Seasonal Minimum Precipitation from the World Bank

The computed p-value (0.017) is lower than the significance level alpha (0.05). Therefore, the null hypothesis is rejected while the alternative hypothesis is accepted. The risk of rejecting the H_0 while it is true was lower than 0.33% The result shows that the change in the seasonal minimum precipitation over time in Zimbabwe is statistically significant as shown by the trend line equation y=-9.2491x+18899. The trend shows that the climate in Zimbabwe is showing a decrease in seasonal minimum precipitation over a 30 year period and this actually shows that there is a significant decrease in seasonal rainfall. This clearly indicate that climate change and variability in Zimbabwe have a direct impact of seasonal rainfall decrease ($P<0.05$).

3.1.3. Seasonal Maximum Precipitation from NCDC

Results show that the seasonal maximum precipitation from NCDC is decreasing over time. There is a significant ($p=0.001$, $\alpha=0.05$) trend of tation over the period of 30 years.

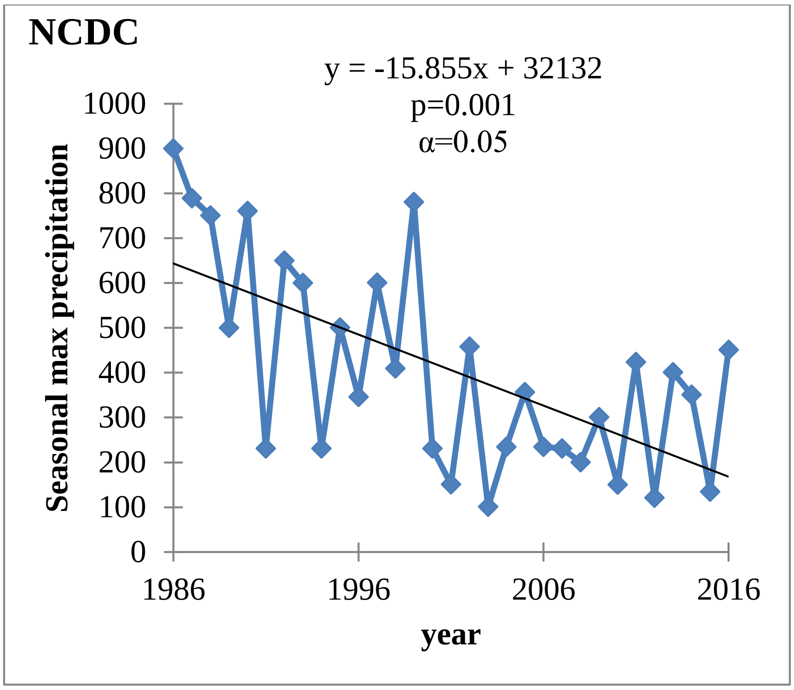

Fig. 3 Seasonal Maximum Precipitation from NCDC

The null hypothesis was that there is no significant trend of temperature between 1986 and 2016 while the alternative hypothesis was that there is a significant trend. Formerly stated:

H_0: There is no significant trend in seasonal maximum precipitation between 1986and 2016 in Zimbabwe.

H_1: There is a significant trend in seasonal maximum precipitation between 1986 and 2016 in Zimbabwe.

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis. The computed P-value (0.001) is lower than the significance level alpha (0.05). Therefore, the null hypothesis is rejected while the alternative hypothesis is accepted. The risk of rejecting the H_0 while it is true was lower than 0.38%. The result shows that the change in the seasonal maximum precipitation over time in Zimbabwe. The trend shows that the climate change is leading to a warming trend and drying pattern in Zimbabwe.

The P value which is less than 0.05 shows a sharp decrease in seasonal maximum precipitation over time. Rainfall patterns have become highly unpredictable and highly variable between years and within seasons. This is congruent with the findings of Muteka (2009), Manyeruke et al (2013), and Simba et al., (2012) who reported that years of below normal rainfall are becoming more frequent and that the prevalence of mid-season dry spells has increased in the whole of Zimbabwe.

3.1.4 Seasonal Maximum Precipitation from World Bank

The Mann-Kendall test shows that there is no significant trend ($P > 0.05$) in seasonal minimum rainfall amount received in the country over 30 years using the climatic data from the World Bank. Results indicate a non-significant ($p=0.434$ $\alpha=0.05$) change in seasonal maximum rainfall over 30 years (Fig.4). The null hypothesis was that there is no significant trend of seasonal maximum rainfall between 1986 and 2016 while the alternative hypothesis was that there is a significant trend. Formally stated:

H_0: There is no significant trend in the seasonal maximum rainfall between 1986 and 2016 in Zimbabwe.

H_1: There is a significant trend in the seasonal maximum rainfall between 1986 and 2016 in Zimbabwe.

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis. The Mann-Kendall trend test computed p-value (0.434) is higher than the significance level alpha (0.05). Therefore, the null hypothesis is not rejected. The risk of rejecting the H_0 while it is true is 46.56%. However, although the trend is statistically not significant, the decrease in rainfall pattern is observed. The decrease in the seasonal maximum precipitation clearly indicates that climate change directly lead to the decrease in seasonal rainfall in Zimbabwe.

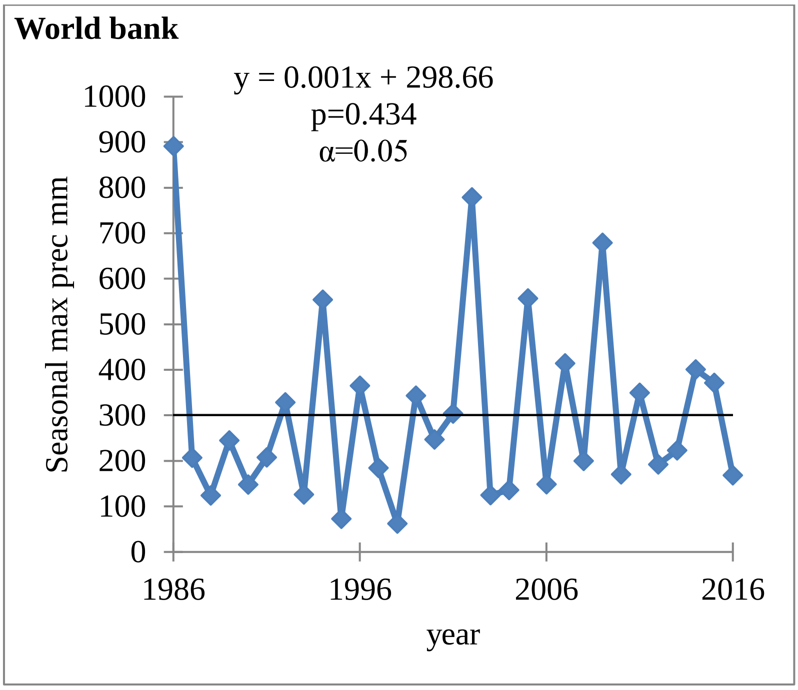

Fig.4 Seasonal Maximum Precipitation from the World Bank

3.1.5 Seasonal Total Precipitation from NCDC

Results of this study from the NCDC show that the seasonal total precipitation in the area under study decreased over time. Mann Kendall trend tests show a significant (*p*=0.000, α=0.05) trend in precipitation between 1986 and 2016 (Fig 5).

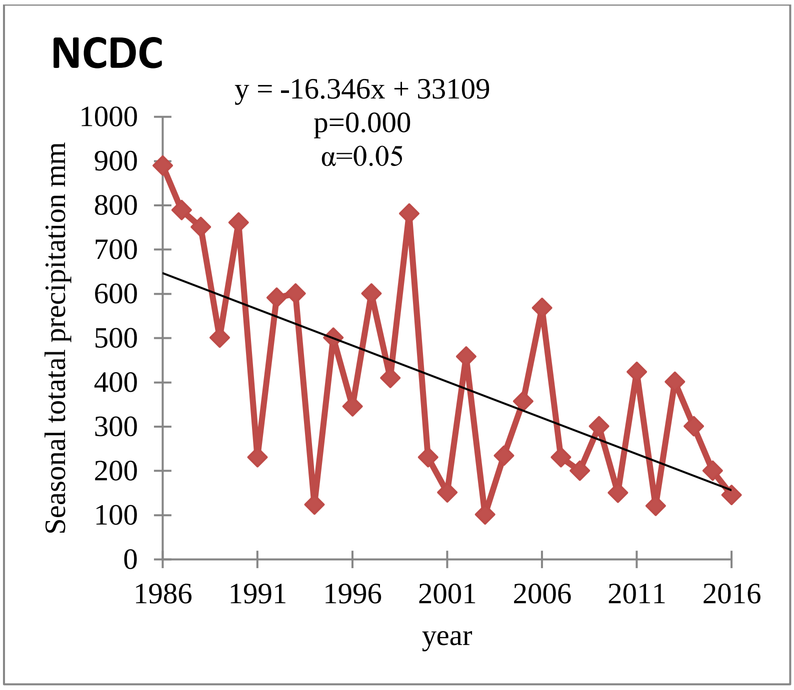

Fig. 5 Seasonal Total Precipitation from NCDC

The null hypothesis was that there is no significant trend of seasonal total precipitation between 1986 and 2016 while the alternative hypothesis was that there is a significant trend. Formerly stated:

H_0: There is no significant trend in seasonal total precipitation between 1986 and 2016 in Zimbabwe.

H_1: There is a significant trend in seasonal total precipitation between 1986 and 2016 in Zimbabwe.

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

The computed p-value (0.000) is lower than the significance level alpha (0.05). Therefore, the null hypothesis is rejected while the alternative hypothesis is accepted. The risk of rejecting the H_0 while it is true was lower than 0.50% The result shows that the change in the seasonal total precipitation over time in Zimbabwe is statistically significant as shown by the trend line equation y=-16.346x+33109 The trend shows that the climate in Zimbabwe is showing a sharp decrease in seasonal total precipitation over a 30 year period and this actually shows that there is a significant decrease in seasonal total rainfall. This clearly indicate that climate change and variability in Zimbabwe have a direct impact of seasonal total rainfall decrease ($P<0.05$).

3.1.6 Seasonal Total Precipitation from the World Bank

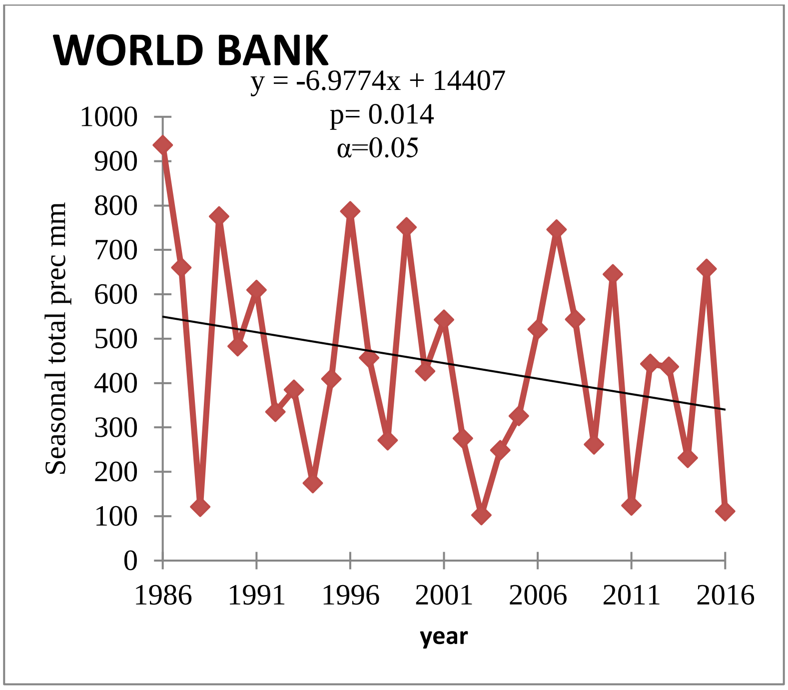

Fig.6 Seasonal Total Precipitation from the World Bank

Results of this study from the World Bank show that the seasonal total precipitation in the area under study decreased over time. Mann Kendall trend tests show a significant (p=0.014, α=0.05) trend in precipitation between 1986 and 2016 (Fig.6).

The null hypothesis was that there is no significant trend of seasonal total precipitation between 1986 and 2016 while the alternative hypothesis was that there is a significant trend. Formerly stated:

H_0: There is no significant trend in seasonal total precipitation between 1986 and 2016 in Zimbabwe.

H_1: There is a significant trend in seasonal total precipitation between 1986 and 2016 in Zimbabwe.

Where H_0 is the null hypothesis and H_1 is the alternative hypothesis.

The computed p-value (0.014) is lower than the significance level alpha (0.05). Therefore, the null hypothesis is rejected while the alternative hypothesis is accepted. The risk of rejecting the H_0 while it is true was lower than 0.50% The result shows that the change in the seasonal total precipitation over time in Zimbabwe is statistically significant as shown by the trend line equation y=-6.9774x+14407. The trend shows that the climate in Zimbabwe is showing a sharp decrease in seasonal total precipitation over a 30 year period and this actually shows that there is a significant decrease in seasonal total rainfall. This clearly indicate that climate change and variability in Zimbabwe have a direct impact of seasonal total rainfall decrease ($P<0.05$).

Table 1. Results of the simultaneous Mann Kendall trend tests analysis of three seasonal bio-climatic variable patterns.

Climatic variable	Source of data	m+c	P-value	Description of trend
Seasonal Minimum Precipitation	NCDC	-0.1527x+348.44	0.586	Not significant /Declining trend
	World Bank	-9.2491x+18899	0.017	Significant/Declining trend
Seasonal Maximum Precipitation	NCDC	-15.855x+32132	0.001	Significant/Declining trend
	World Bank	0.001x+298.66	0.434	Not significant /Declining trend
Seasonal Total precipitation	NCDC	-16.346x+33109	0.000	Significant /Declining trend
	World Bank	-6.9774x+14407	0.014	Significant /Declining trend

As shown in Table 1 there is a significant change in seasonal rainfall totals in Zimbabwe. Moreover, it should be noted that annual total rainfalls from both NCDC and World Bank decreasing trends in rainfall as indicated by the results. The results also show that rainfall is highly variable in the country showing highs and lows along the years. The decreasing trend and the picks are indicator of climatic change and variability. These changing climatic conditions and variability are impacting negatively on the socio-economic activities of the nation. This is in line with the Zimbabwe rainfall situation (Unganai and Mason, 2002, Kusangaya et al., (2013)). The trend tends to show a continuous decline is seasonal rainfall in Zimbabwe. While Christensen et al. (2007) argue that there is uncertainty on the magnitude of climate change impacts on rainfall in Southern Africa; this study indicates that climate change is taking place as shown by the decreasing rainfall and that decrease in itself constitutes climate change. These findings are in concurrence with those of IPCC (2007), which observed that rainfall patterns is Southern Africa are experiencing a declining trend and this is part of the evidence that the region is being affected by climate change. . These findings are augmented by who indicated that there is robust scientific evidence pointing to an increased inter-annual variability, with extremely wet periods and more intense droughts and this constitutes climate change. This also concurs with Christensen et al., (2007)'s view that besides volumes, rainfall patterns are also expected to change in intensity and frequency, resulting in more extreme events and longer periods between rainfalls. Kusangaya et al., (2013) avers that many models project that by 2050 the interior of Southern Africa will experience decreased in seasonal rainfall during the growing season due to the negative direct impacts of climate change in the region.

4. CONCLUSION

This study used a simultaneous trend analysis of seasonal rainfall pattern from two different climatic data sources over a 30 year period (1986-2016). The study sought to give a comprehensive picture on how climate is change is leading to a decline in seasonal rainfall pattern in Zimbabwe. From the six trends analysis tests done in this study two test showed that the trend is not significant although it shows a declining trend. However, four trend analysis tests showed a significant and declining trend of seasonal rainfall pattern in Zimbabwe. It is the conclusion of this study that gives 66.6 percent of the three seasonal precipitation variables from both NCDC and World Bank analysed show significant trend, seasonal precipitation in Zimbabwe is generally decreasing.

4.1. RECOMMENDATIONS

The researcher recommends that the findings of this study be considered by all stakeholders interested in climate change across the African region because although the findings are based on the case study of Zimbabwe, they can be applied to other countries with similar biophysical conditions across the continent. Because of the findings of this study, farmers, researchers, biologist and agriculture extension agencies are challenged with the identification of new and viable adaptation strategies that farmers and the whole of Zimbabwe can employ to reduce the impacts of climate change on food crops production. Farmers would benefit a lot from learning about the degree of losses they are likely to incur due to climate change from researchers and agricultural extension agencies.

Farmers should delve into the adoption of various approaches and practices for adaptation strategies which include a shift from late maturing to early maturing crop varieties since the growing seasons have been seen to be shortening. This would require supportive government policies to ensure adequate and affordable seed supplies. There is also need for farmers to cultivate a wider range of species and varieties (crop diversification) in associations, rotations and sequences and using well adapted, high-yielding varieties and good quality seeds.
In order to create an adaptive community to address climate change in Zimbabwe and even the rest of Africa there is need of strengthen the capacity of the National Meteorological and Hydrological Services to carry out research on climate change through improved data collection and management, and climate modelling. Strengthen the documentation of and tapping into indigenous knowledge systems to complement scientific knowledge for climate change forecasting and early warning systems. Establish an enabling framework for sharing and disseminating information on climate change (i.e. at provincial, district and ward levels) in the country. As an adaptation measure Zimbabwe needs stronger representation in international climate change negotiations in order to secure technical support and funding for adaptation strategies to address climate change.

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How to cite this article:
Tinashe Dondo, "Simultaneous Trend Analysis of Seasonal Rainfall Pattern in Zimbabwe", International Journal of Intelligent Computing and Technology (IJICT), Vol.4, Iss.1,pp.01-17, 2020