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ANALYSES OF MULTI-DECADAL VARIABILITY AND TRENDS IN PRECIPITATION AND POTENTIAL EVAPO-TRANSPIRATION ACROSS LAKE KYOGA BASIN

BY

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APPROVAL

The undersigned here approve that they have read and hereby recommend for submission to the Graduate school of Kyambogo University a research dissertation title ‘‘Analyses of Multi-Decadal Variability and Trends in Precipitation and Potential Evapo-Transpiration across Lake Kyoga Basin’’, in fulfilment of the requirements for the award of Master of Science in Water and Sanitation Engineering Degree of Kyambogo University.

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DECLARATION

I, Acayo Grace, hereby declare that this submission is my own work and that, to the best of my knowledge, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

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DEDICATION

I dedicate this research thesis to my beloved parents Mr. Omoo John (deceased) and Mrs. Lucy Omoo. My supervisors, husband (Mr. Oranit Samuel), family, friends, sisters (Ketty and Beatrice) and brothers (Stephen, Mark, Caesar, Moses and Samuel) accept my appreciations for your unconditional love and support during the course of the study. May the Almighty God bless you all abundantly.

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LIST OF ACRONYMS

AMO	Atlantic Multi-Decadal Oscillation
ANN	Annual
ASA	Autocerration Spectral Analysis
CSD	Cumulative Sum of rank Difference
CV	Coefficient of Variation
DWRM	Directorate of Water Resources Management
ENSO	El Nino South Oscillations
EOF	Empirical Orthogonal Functions
ETo	Evapo-transpiration
GIS	Geographical Information System
HBV	Hydrologiska Byrans Vattenbansavdelning Model
IOD	Indian Ocean Dipole
IPCC	Inter-governmental Panel on Climate Change
IPCP	Indian Pacific Warm Pool
JICA	Japan International Cooperation Agency
MAM	March April May
MWE	Ministry of Water and Environment
NAM	North American Mesoscale Model
NAO	North Atlantic Ocean
NAPA	National Adaptation Programme of Action
OND	October November December

PCI	Precipitation Concentration Index
PETo	Potential Evapo-Transpiration
QPM	Quantile Perturbation method
SON	September October November
SST	Sea Surface Temperature
UMA	Uganda Meteorological Authority
VHM	Veralgemeend Conceptueel Hydrologisch

ABSTRACT

The Lake Kyoga basin is located in Kyoga water management zone covering eleven sub-catchments in Uganda. The population in this region mainly depend on rain fed agriculture for their livelihood. However, recent changes in precipitation and climatic conditions calls understanding trends and variability of current and historical hydro-climatic variables. This study analyzed long-term trends and variability in precipitation and Potential Evapo-Transpiration (PETo) covering the period 1901 -1960 and 1961- 2015 respectively. Two periods were considered to remove the effect of step-jump in precipitation mean on analyses. For PETo, the period 1961-2008 was considered. Both trends and variability were assessed non-parametrically using the cumulative sum of rank difference approach. Possible drivers of variability in PETo and precipitation were sought in terms of the co-variation of the climatic variables with the large scale ocean-atmospheric interactions. The correlation of precipitation, potential Evapo-transpiration and climate indices were assessed. The climate indices included Atlantic Multi-Decadal Oscillation (AMO), North Atlantic Ocean (NAO), Indian Ocean Dipole (IOD) and Nino3. It was found that precipitation over the period 1901-1960 for the month of March, April, May (MAM) exhibited positive anomalies was not significant ($p>0.05$) implying wet condition, however, for September, October, November (SON) and annual time series exhibited negative anomalies. The annual variability in precipitation yielded negative anomalies around 1960s to 1970s while positive anomalies were exhibited around 1990s and 2000. Variability in annual precipitation at most locations was found to be insignificant ($p>0.05$). Trends in PETo were not coherent as those of precipitation.

CHAPTER ONE: INTRODUCTION

1.1 Background

The impacts of land use and climate variability on the hydrology of a watershed have been an important area of research in recent decades in respect to the generated runoff (Li et al., 2009). According to the Inter-governmental Panel on Climate Change (IPCC, 2014) climate variability is the short-term fluctuations about the mean of the climate variables such fluctuations are caused by natural climatic processes and anthropogenic factors. Climate variability implies the short-term variations in climatic elements above and below the mean diurnal, seasonal, annual or interannual and decadal (IPCC, 2014). Over the past years, Uganda has experienced frequent droughts, increased intensity and occurrence of heavy rains which have led to floods and landslides (Onyutha, 2016a). Uganda with limited surface water infrastructures to inhibit flood response options, uncontrolled and inadequate land use and wetland degradation will continue to face future damages from flooding and extreme weather events National Adaptation Programme of Action (NAPA, 2007).

Applied flood risks analyses define the vulnerability of hydraulic features like reservoirs, buildings and channels. This require application of different models (Apel el at., 2008). According to Onyutha and Willems (2017) understanding the variability of extreme rainfall is essential for planning, operation and management of risks- based water resources applications. Lake Kyoga Basin is the least studied of the Nile tributaries but is an important link between Lake Victoria and Lake Albert and influences flow into Sudan (Brown and Sutcliffe, 2013).

This study focused on the analysis of long-term trends and multi-decadal variability in precipitation and Potential Evapo-transpiration over the Lake Kyoga Basin. This provides guidance to support predictive adaptation to the impacts of climate variability on water resources. Also vital to regulate the water usage and design of climate resilent technologies and conservation methods.

1.2 Statement of the Problem

The Lake Kyoga basin just like other basins in Uganda faces many formidable challenges including flood and drought due to climate variability, high demographic rates, food insecurity and many others. The anthropogenic factors have led to the alteration of the hydrologic cycle alongside climate variability and change in Uganda (Nyasimiyl, 2016). There are no studies on analyses of trends and variability in precipitation and Evapo-transpiration over the Lake Kyoga basin including testing the significance of both trend magnitudes and directions.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of the study was to determine the long-term trends and multi-decadal variability in the precipitation and potential Evapo-Transpiration across Lake Kyoga basin.

1.3.2 Specific Objectives

a) To determine the significance of trends in precipitation.

b) To assess the significance of non-zero slope of a linear variability of PETo with time.

c) To assess the multi-decadal co-variability in precipitation with climate indices.

d) To determine the multi-decadal variability in PETo as a result of changes in large-scale Ocean-atmosphere interactions.

1.4 Research Questions

i. Are the trends in precipitation significant?

ii. Is there significance of non-zero slope of linear variability of PETo with time?

iii. Is there co-variability in precipitation with climate indices?

iv. Is there multi-decadal variability in PETo with climate indices?

1.5 Research Justification

Investigation of the multi-decadal variability and trends in the precipitation and PETo over Lake Kyoga Basin was paramount. The need for proper guidance required to manage the water resources in the basin. Lake Kyoga basin are under threat due to external factor like increased demography and climate change. Also essential to the hydrologists, water resources engineers, managers and many policy makers in the basin to build the capacity of the stake holders on the adaptation measures to the impacts of climate variability.

1.6 Significance

Variability and trends analyses of precipitation and potential Evapo-Transpiration across Lake Kyoga basin, strengthen the adaptation and conservation measures to the impacts of climate change. The study is useful to the Kyoga Water Management Zone in planning and management of the water resources especially design of water infrastructures like dams, water supply systems and control of floods common in the low land areas of the region.

1.7 Scope of the Study

This study focused on analyzes of multi-decal variability and trends in precipitation and potential Evapo-Transpiration over the lake Kyoga basin. The data considered included precipitation and potential Evapo-Transpiration from 1901- 1960, 1961-2015 and 1960-2008 respectively. The eleven sub-catchments considered include: Okok, Okere, Lwere, Victoria Nile, Mpologoma, Akweng, Abalam, Sezibwa, Kyoga, Lumbuye and Awoja.

1.8 Conceptual framework

The increase or decrease in the precipitation and Evapo-transpiration (independent variables) as a result of influence from the sea surface temperature, sea level pressure (moderating factors), will cause changes in the trends and variability (dependent variables) Figure 1.1. The rate of increase or decrease varies depending on the variables.

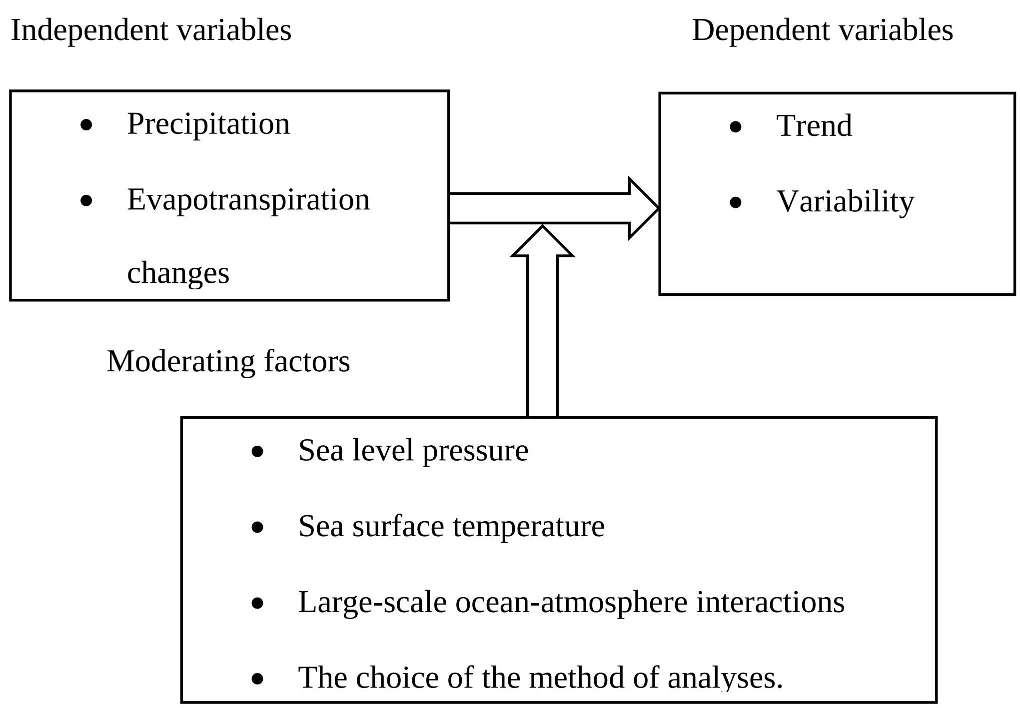

Figure 1: 1 Conceptual Framework

1.9 Chapter summary

This chapter described climate variability and its impact on the Lake Kyoga basin. It further states the study objective to determine the long term trends and multi-decadal variability in the precipitation and potential Evapo-transpiration across Lake Kyoga basin.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

According to the IPCC (2014) with increased variability and intensity of rainfall, floods will become more frequent than in the past. Flooding tends to be aggravated by land degradation through deforestation, poor land-use planning, and management of wetlands. The key drivers of the hydrological conditions of a catchment are changes in climate and land use/covers. Transition in the hydrologic cycles thereby causing changes in flood frequency by altering land-use/covers affects interception, infiltration rate, albedo and Evapo-Transpiration (ETo) (Rose and Peters, 2001). Whereas there is climate variability, another crucial aspect of hydro-climatic changes is trend. Trends illustrate decrease or increase within a given data, understanding trends in hydro-climatic variables is important, this depict the physical occurrence of events over time as a tool for decision making (Nsubuga et al., 2013). Trend describes long-term movement of any time series and movement can be demonstrated by use of graphical or statistical method (Ogallo, 1981).

Nyeko-Ogiramoi and Willems (2013) analyzed long-term records of extreme rainfall, temperature and stream flow for selected stations in the Lake Victoria basin from 47 to 87, 28 to 51 and 23 to 33 years. They used Mann Kendal test method and Sen's slope estimation technique which is robust, found that the basin is experiencing positive linear trend.

In this study both climate variability and trends in hydro-climatic variables like precipitation and potential Evapo-Transpiration are being exhibited across the study area. It is important to understand the long term trend and variability of a region especially for lake Kyoga basin which is least studied. The population in the area mainly depend on rain fed agriculture with high growth rates, floods and droughts.

2.2 Climate Variability

Climate variability implies the short term variations in climatic elements above and below the mean seasonal, annual, or inter-annual and decadal. It was regarded as the variability inherent in the stationary stochastic process approximating the climate on a scale of a few decades (IPCC, 2007). A significant future increase in heavy rainfall in many regions is projected and this will increase flooding which will posse challenge to the society, physical infrastructures and water quality. The increase in the frequency and severity of floods and droughts are projected to compromise sustainable development (IPCC, 2014).

Moist inflow from the West Indian Ocean converges over Uganda producing diurnal thunderstorm clusters that drift southwest-wards with high run-off (Jury, 2017). In the study to evaluate the ability of ten regional climate models to simulate the present day rainfall over Uganda within coordinated Regional Downscaling experiment from 1990 to 2008, the methods have underestimated the March-May seasonal rainfall. It was observed that short rains seasons presents an interannual variability slightly stronger than long rains seasons (Kisembe et al., 2019).

2.2 .1 Methods of Variability Analyses

The methods for variability analyses includes Auto Correlation Spectral Analysis (ASA), Cumulative Sum of rank Difference (CSD), Quantile Perturbation method (QPM), Empirical Orthogonal Functions (EOF) and others.

2.2.1.1 Auto Correlation Spectral Analysis

The Auto correlation function of a time series quantifies the linear dependence of successive values over a time period. Studies that applied Autocorrelation Spectral Analysis to analyze variability in rainfall include: Cattani et al. (2018), Kisaka et al. (2015), Ntale. (2003) and many others.

Cattani et al. (2018) examined East Africa rainfall trends and variability from 1983-2015 using three long-term satellite products. The daily estimates from three satellite rainfall products based on infrared geostationary brightness temperatures were considered and the satellite rainfall products were: African Rainfall Climatology version 2.0, African Climatology and Time series version 2.0 and Climate Hazards Group Infrared precipitation with stations version 2.0. The rainfall variability and trends was investigated considering the climate change index times series over the region. The results indicated that at annual scale three regions are associated with statistically significant trends. Increased trends were identified for October-November-December season over Eastern East Africa except Kenya. The March-April- May rainfall decreased over most part of the East Africa. Also noted that complete convergence of all satellite products was not achieved.

Kisaka et al. (2015) analyzed rainfall variability drought characterization and efficacy of rainfall data reconstruction for the case study of Eastern Kenya. The Geophysical Information System (GIS) spatial- interpolation techniques like inverse district weighted (IDW), spine and Kriging were adopted for data reconstruction. To minimize data gaps in the study area, evaluation of the efficacy of geostatistical or deterministic interpolation techniques in daily rainfall data was reconstructed. The results showed that available rainfall series from the study area stations are homogenous. The decadal rainfall trends indicated both long rains and average rainfall decreased for the last 13 years in the region.

Ntale and Mwale (2003) examined prediction of East African seasonal rainfall using simplex canonical correlation analysis. To predict the standardized seasonal rainfall totals of the East Africa at 3-month lead time. Sea level pressure and sea surface temperature anomaly fields of Indian and Atlantic oceans were combined together with 24 optimized weights of NMS (Simple method for function minimization) and reduced by principal component analysis. The results indicated that March-April-May season was better predicted in the western parts of East Africa. Also low September-October-November rainfall in East Africa is associated with cold sea surface temperature of Somali coast and the Benguela coast. The low March-April-May rainfall is a result of low temperature in the Indian ocean adjacent to East Africa and the Gulf of Guinea.

Auto Correlation Spectral Analysis method is used in rainfall analysis over a region but have disadvantages associated with it like it hardly gives information about long-term persistence, problem of smoothing and spectra are much harder to interpret than correlogram or variance-time diagram (Buishand,1978).

2.2.1.2 The Quantile Perturbation Method

The QPM is for deriving climate change scenarios or for propagating climate signals to historical observations by perturbing series using information from climate model runs. It analyses frequency of extreme events. However, the QPM is susceptible to the effect of serial correlation which can be addressed by the Cumulative Sum of rank Difference method. Several studies applied QPM to analyze variability in rainfall: Onyutha and Willems (2015), Onyutha and Willems (2017), Tabari et al. (2017), Rutkowska et al. (2017), Willems (2013), Nyeko-Ogiramoi et al. (2013) and Wang et al. (2019).

Onyutha and Willems (2015) applied Quantile Perturbation method to analyze spatial and temporal variability of rainfall in the Nile basin. The QPM considered changes in quantiles with similar return period *T* compared from two-time series. Estimation of *T*s from small samples series can be bias hence extrapolations are avoided. Preliminary analysis was performed using block periods of 5, 10 and 15 years. The block length of 15 years was selected for the study because it gave clearer oscillation pattern in the rainfall data. The Quantile Perturbation Method results of rainfall were significantly correlated to Sea level pressure taken over Atlantic and Indian oceans or Pacific and Indian oceans. These are useful for water management and planning for example flood control.

Onyutha and Willems (2017) used QPM to study space-time variability of extreme rainfall in the River Nile basin from 1948 to 2010. Extreme rainfall data for variability analysis was extracted from daily data including mean of ten highest rainfall intensities per year. Several Climate indices were obtained to establish linkage of extreme rainfall variability to large-scale ocean-atmosphere conditions. The results indicated that for the Equatorial region, extreme variability is linked to the anomalies in the Sea level pressure in the North Atlantic Ocean and the changes in the sea surface temperature.

Tabari et al. (2017) examined decadal analysis of river flow extremes hydrological events using quantile based approaches. The decadal analysis of monthly and annual river flows at 10 stations in Qazvin plain in Iran was conducted. The results indicated oscillatory patterns in extreme river flow quantiles with positive anomaly in 1990s and negative for 2000s. To avoid false conclusions assumptions were considered with threshold.

Rutkowska et al. (2017) analyzed temporal and spatial variability of flood quantiles in the Upper Vistula River basin, Poland. Forty-one gauging stations were considered using Quantile Perturbation method. Flood quantiles of main series were compared to corresponding quantiles extracted from sub-series. The results of the study indicated higher extreme quantiles in the 1960 to 1970s and late 1990s and lower quantiles in the 1980s. These findings can support design of hydraulic structures for flood control and water resources management.

Willems (2013) examined multi-decadal oscillatory behaviour of rainfall extremes in Europe. The analysis was based on data set of 108 years of 10-minutes precipitation intensities at Uccle (Brussels). The consistency of the results was checked with long precipitation records at 724 stations across the region. The results of the study confirmed that rainfall extremes in Europe have oscillatory behaviour at multi-decadal time scales.

Nyeko-Ogiramoi et al. (2013) analyzed trend and variability in observed hydrometerological extremes in the Lake Kyoga basin. To detect the significant temporal extremes anomalies, quantile perturbation method was used. Ten selected rainfall stations was analyzed and six demonstrated the presence of significant positive trend over the region.

Wang et al. (2019) employed quantile perturbation to study temporal variability of water level extremes across the plan river network region of the Taihu Basin. They found no consistent significant correlations between water level extremes and climatic indices are found in spring and autumn which is mainly related to hydraulic structure construction and operation.

The disadvantages of quantile perturbation methods are: The autocorrelation of data (time series) increases cycles in the anomalies and this can greatly affect results. Moreover, it is insufficient to analyze tails of distributions based on few data points.

2.2.1.3 The Empirical Orthogonal Function

The EOF applies principal component analysis to group of rainfall time series data to extract coherent variations that are dominant. There are several studies which applied the EOF method to analyze variability of rainfall across East Africa. Some of these studies include Lyon and Dewitt, (2012), Tierney et al. (2013), Ogallo (1989), Schreck and Semazzi (2004), Onyutha and Willems (2017), Indeje et al. (2000) and others.

Lyon and Dewitt (2012) examined a recent and abrupt decline in the East African long rains using EOF, noted that the recent increase in West Pacific Sea Surface Temperatures indicated heights over the past decade exceeded the previous maximum considering the year 1950. The study concluded that the recent increase in rainfall is not simply result of an El Nino South Oscillation variation or changes in Pacific decadal oscillation.

Tierney et al. (2013) in analyses of multi-decadal variability in East African hydro-climate controlled by the Indian ocean. EOF was employed in the analyses of annual precipitation data at an interval of fifty years or less 1300 and 3000 years' control runs from the US National Center for Atmospheric Research. The results indicated that Empirical Orthogonal Function imposes constraints of orthogonality which affects interpretation of loading patterns in climatic sense.

Ogallo (1989) analyzed the spatial and temporal pattern of the East African seasonal rainfall derived from principal component analysis from 1922 to 1983. The Principal

Component Analysis (PCA) was used to derived from the concept of variance. Computation of measures of association between sets of variables followed by construction of a linear set of orthogonal vectors to represent variables. The advantage of this method was equal weighing of all grid points to avoid bias positioning of the synoptic centres. The results of the study showed that the influence of large water bodies like Lake Victoria and Indian Ocean were outstanding throughout the year.

Schreck and Semazzi (2004) employed the Empirical Orthogonal Function in analysis of variability of the recent climate of Eastern Africa including Uganda, Kenya and Tanzania. The selection of the region was based on availability of gauge rainfall data from 1961 to 2001. They constructed Empirical Orthogonal Functions based on rain gauge observations and satellite estimates of recent years. The corresponding circulation pattern based on National Centers for Environmental Protection wind data was adopted to supplement the EOF rainfall analyses. This was obtained by calculating weighted averages of the grid-point wind data using amplitudes of the EOF time series as the weight. The results indicated that the entire region of Eastern Africa experiences enhanced rainfall. Also the ENSO is linked with widespread positive rainfall anomaly conditions over the entire region of Eastern Africa except for Sudan.

Onyutha and Willems (2017) applied EOF to analyze the rainfall of different spatial domains of gridded series in the River Nile basin. The Varimax procedure was adopted to preserve orthogonality. This gives physical explanation of variability patterns. The findings indicated variation in climate indices which explain rainfall variability at regional than location-specific spatial scale.

Indeje et al. (2000) employed EOF in analyses of ENSO signals in East African rainfall seasons from 1961 to 1990. They considered136 rainfall stations and subjected them to statistical quality control. The representative stations identified were grouped into homogenous region. After the analysis the warm ENSO events occurred in these years 1962, 1965, 1969, 1972, 1976, 1977 and 1988 were classified into post-ENSO (+1) rainfall composites. The results indicated unique seasonal evolution pattern in rainfall during the different phases of ENSO analysis. This provide guidance on patterns of seasonal rainfall anomalies occurrence over the region.

Empirical Orthogonal Functions method of analysis of rainfall variability is associated with the following disadvantages, the orthogonality in time and space and EOF are not efficient in CPU in transforming from a grid to coefficients and back. From the three methods reviewed all do not analyze both graphical and statistical data.

2.2.1.4 The Cumulative Sum of Rank Difference Method

The CSD method entails two ways of testing for variability including application of variability statistic and analyses of sub-trends. For the CSD-based sub-trends, the results can be readily used for attribution. The main advantage of the CSD approach is that it is non-parametric that is not affected by non-normality of data (Onyutha 2016b, c, d).

Some of the recent studies that applied CSD method include Cengiz et al. (2020), Vido et al. (2019), Tang and Zhang (2018), Mubialiwo et al. (2020) and Pirnia et al. (2020). Cengiz et al. (2020) used both graphical methods of refined Cumulative Sum of rank Difference and Innovative Trend Analysis (ITA)- Change boxes and the statistical method of MK for analyzing trends in annual and seasonal precipitation series at 16 stations for the period 1960 to 2015 in Turkey. The methods were capable of identifying the hidden trends in the precipitation times that cannot be detected using the statistical MK method.

Vido et al. (2019) analysed historical drought occurrences in the Horne Pozitavie region of Slovakia over the period 1966 to 2013 using standardized precipitation-Evapotranspiration index. Trend analyses were evaluated by MK and CRD test. The CSD trend analyses indicated the sub-trend change direction towards less drier condition in the late 1980s and early 1990s which is an indication of changing weather circulation pattern in the region.

Tang and Zhang (2018) used MK and CSD methods to detect the abrupt change in year of precipitation over Zhangjia Zhuang Reservoir from 1969 to 2015. The study found that the abrupt rainfall change has certain influence on flood season division was 16 days longer from 1996 to 2015 but three days shorter between 1969 to 1995.

Mubialiwo et al. (2020) employed CSD method to analysed historical rainfall and Evapo-transpiration changes over Mpologoma catchment in Uganda. The study found that seasonal Evapo-transpiration exhibited a positive trend ($p>0.05$). For the period 1948 to 2016, there was no negative sub trend in the October, November, December and March, April, May evapotranspiration. From the past studies use of cumulative sum of rank difference method was useful because both statistical and graphical dataset can be easily interpreted.

2.2.3 Past Studies on Climate Variability Across the Equatorial Region

Lyon and DeWitt (2012) studied recent and abrupt decline in the East African long rains from 1979 to 2009. The Empirical Orthogonal Function method was employed in the analysis of precipitation data. The findings indicated that March-April-May rainfall anomalies in the region are not significantly correlated with local Sea Surface Temperature but significantly correlated ($p < 0.05$) with anomalous low-level flow.

Funk et al. (2012) examined exceptional warming in western Pacific-Indian ocean warm pool has contributed to more frequent drought in Eastern Africa. The historical rainfall data from 1910 to 2010 and five simulated models were exhibited in the analysis. The results confirmed that the exception warming in Indian Pacific Warm Pool (IPCP) with an index computed by averaging selected long-running GHCN verses air temperature stations. This variability in air temperature conditions are the cause of rainfall variability within the region.

In the Eastern Equatorial Africa, interannual rainfall variability is strong with no particular trends observed (Nicholson, 2015). North Atlantic Ocean plays a major role in regulating the internal variability via impacts on storm tracks and regional atmospheric circulation (Knippertz et al., 2003)

In the study of multi-decadal variability in East African hydro-climate controlled by the Indian Ocean (Tierney et al., 2013) noted that the Indian Ocean Sea Surface Temperatures are the primary influence on the East African rainfall over multi-decadal and long time series. The EOF method was used but it imposed a constraint of orthogonality that complicate interpretation of loading patterns in a climatic sense.

Onyutha and Willems (2018) investigated flow-rainfall co-variation for catchment selected based sources of River Nile. Three main models that is NAM, VHM and HBV were applied under the same meteorological conditions in simulating daily flow at the outlet of two main catchments selected from 1948 to 2003. Kagera catchment at Kyaka Ferry in Equatorial region and the Blue Nile catchment at Khartoum were selected. The investigation was done in terms of changes in anomalies based on the quantile perturbation method, detection of trends using Mann-Kendal and cumulative rank difference tests. The findings indicated that all the selected catchments the null hypothesis of no correlation between rainfall and flow was rejected at significant level of 5% in both seasonal and annual time scales. It implied that the variation in flow of the River Nile basin over the selected data period was strongly attributed to that of rainfall.

Nsubuga (2015) studied changes in surface water area of lake Kyoga sub-basin using remotely sensed imagery in a changing climate, reveals that surface water area fluctuation is linked to rainfall variability.

2.3 Trend Analysis

Analyses of trends entails both slope and direction of the linear variation of the variable with time. This is vital in prediction of the future likely occurrence of climatic conditions which guides planning and management of water resources within a region.

2.3.1 Trend Magnitude

Trend magnitude also referred to as the trend slope expresses the amount by which the variable is expected to linearly change over a time unit of the observations while trend direction is an indication of the dependence of the variable on time and this can be positively or negatively (Onyutha, 2016d).

Trend magnitude is computed using Theil (1950) and Sen (1968). The slope is determined by the binomial distribution is robust estimate of the magnitude of the monotonic trend.

2.3.2 Trend Significance

To quantify where the amount of linear increase or decrease is significant, trend tests are conducted both parametric and non-parametric methods. The parametric method like simple linear regression used to test long term linear trend. The Mann-Kendall test Mann

(1945) is non-parametric test for detecting trends and distribution of test statistic derived by Kendall (1975).

Kendall (1938) is used to test correlation between run off, precipitation and temperature. An Inverse Distance Weighted Interpolation (IDW) based on assumption that the interpolating surface should be influenced by most nearby points and less by more distant points used to map the regional distribution of test statistics (Gemmer et al., 2004).

2.3.3 Past Studies on Trends in Hydro-Climatic Variables across the Equatorial Region

In East Africa, Ogallo (1981) studied trend of rainfall from 1922 -1975 and used spearman ranked correlation test. The findings indicated no significant trends of rainfall in nine stations especially for Uganda.

Also in Africa, Ogallo (1979) examined trends in annual rainfall series using both graphical and statistical approach. The statistical tests revealed positive or negative trends from smooth graphs were insignificant and their distribution formed no pattern. This made it difficult to describe climatology for the observed trends. The overall results indicated that most of the annual series examined indicated an oscillatory characteristic without significant trend. Recent decline in rainfall is linked to warming of the pacific and Indian ocean (Funk, 2012) observed that the warming trends are more likely to continue in the same direction than rainfall trends.

Nyeko-Ogiramoi et al. (2013) used a combination of linear and cyclic trends analysis to examine the long-term trends and variability of hydrometerological extremes in Lake Victoria basin. The methods employed were Mann-Kendall test for linear trend and quantile perturbation for cyclic trend analysis. The data considered for the study were temperature, rainfall and stream flows from 1930 to 2008. The findings were: for all stations selected for rainfall extremes demonstrated increasing trends of positive slopes. For maximum daily temperature, seven stations indicated increasing trend and two decreasing trend. For minimum daily temperature increasing trends was indicated in seven out of nine stations, no significant trends were detected in all the seven stream flows extreme series.

Mbungu et al. (2012) examined the temperature and spatial variations in the hydro-climatic extremes in the Lake Victoria basin. The data for rainfall and discharge were considered for the period of 1902 to 2006. The analysis for each wet season performed separately for March April May, October November December and annual time series. The quantile perturbation method and sliding window were employed in the analysis. The results of the study indicated that the observed significant decreasing trends in the 1930s, 1950s, 1970s and 1980s for precipitation extremes showed that most parts of the basin experienced drought conditions in those decades. Increasing trends were observed in 1960s,1980s and 1990s. However, based on their findings further studies recommended to understand the causes of variability in extremes with recent validated data for analysis.

Onyutha (2016a) analyzed trends and variability in series consisting of fifteen highest daily rainfall intensities in Uganda from 1948 to 2008. The data for the study were obtained from the Princeton Global Forcing's (PGFs) in gridded (0.5^ox0.5^o) form for rainfall and rainfall variability climate indices (NAO, IOD and Nino3). The Nonparametric Anomaly Indicator Method (NAIM) was applied to extract decadal anomalies from the observed Princeton Global Forcings (PGF) rainfall series because of its capacity to eliminate the possible outliers in the series for variability analysis. Empirical orthogonal function was used to examine the maximum amount of variance in the NAIM anomalies at various grid points. Cumulative rank difference was used for statistical analysis of trends. The results of the study indicated that rainfall above the long-term mean from mid-1950 to late 1960s ,1990s and 2000s. Also from 1970s to 1980s rainfall was characterized by decrease.

Jury (2017) studied Uganda rainfall variability and prediction using monthly rainfall index from 1950 to 2013 formed by area-averaging 0.5^o resolution GPCC7 gauge. Surface air temperature and potential Evaporation at 0.5^o resolution obtained from Climatic Research Unit (CRU). The meteorological fields were analyzed using Modern-Era Retrospective Analysis for Research and Application (MERRA). The findings revealed that: Uganda smoothed continuous rainfall anomalies indicate a stationary trend with significant oscillations. The wettest period was 1961 and 1998 and late seasons events are linked to warm-phase ENSO. The 3-and 6-year fluctuations in rainfall over Uganda are varied by large-scale atmospheric circulation. Hence parallel study recommended to consider potential Evapo-transpiration and its impacts on Uganda’s water resources (Jury, 2017).

Kizza et al. (2009) analyzed trends and step changes in the seasonal and annual rainfall for 20 stations in Lake Victoria basin from 1900 to 2000. The method used for trend test was Mann-Kendall test and Worsely likelihood ratio test for one step-jump. The hypothesis considered for Mann-Kendall test was there is no trend in the data. For worsely likelihood ratio test was, there is no change in the mean of the data series for two different periods. Worsely likelihood ratio test method determines whether the mean of two parts of a record are different and estimate the most likely time of change. It assumes that the data are normally distributed. The findings of the study showed that Lake Victoria basin experience positive trend over the twentieth century. The magnitude of the trend depends on data period used in analysis.

2.3.4 Possible Drivers of the Variability in Precipitation and PETo

North Atlantic Ocean (NAO) plays a major role in regulating internal variability via impacts on storm tracks and regional atmospheric circulation (Knippertz et all., 2003)

Linking changes in precipitation and IOD

The observational and modelling studies suggest that the Indian Ocean Dipole (IOD) is consistently influencing the rainfall variability over the East African (Clark et al., 2003). The stronger correlation of IOD with Equatorial East Africa Rainfall and established linkage do not depend on the intensity of the Indian Ocean SST zonal gradient but on particular epoch (Manatsa, 2012).

Linking changes in precipitation and ENSO

El Nino- Southern Oscillation (ENSO) is an important inter annual variation in rainfall. Plisnier et al. (2000) studied impact of ENSO on East African ecosystems and found that teleconnections with climate data, most correlation values between Pacific Sea Surface Temperature anomalies and air temperature are positively and highly significant ($p < 0.05$). ENSO tends to have its maximum impacts on African rainfall during the period of March-April-May.

Linking changes in precipitation and NAO

The period 1958/59 to 1995-96 were used to evaluate moisture and circulation field variations associated with NAO index. McHugh and Rogers (2001) found that rainfall with NAO correlation negative high significant around the Lake Kyoga and Equator region. There are no studies on linking variability in Potential Evapo-Transpiration to large scale ocean atmospheric conditions and it's the focus of this paper.

2.4 Methods of Trend Analyses

Trend was analyzed using Cumulative Sum of rank Difference method (Onyutha, 2016b-d) which employed both statistical and graphical. Non-parametric tests are used to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear. Non-parametric can be used in place of a parametric linear regression analysis, which can be used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the Non-parametric.

2.5 Past studies on Possible Drivers of Trends in Precipitation and PETo

Ogallo (1989) studied the spatial and temporal patterns of the East African seasonal rainfall derived from principal component analysis from 1922-1983. The influence of the large water bodies, especially Lake Victoria and the Indian Ocean were outstanding throughout the year. Twenty-six homogeneous regional groups were delineated from the spatial characteristics of the dominant eigenvectors. The general conclusion was El Nino exerted some control on equatorial and coastal East African rainfall with warm events being associated with high rainfall and cold events with low rainfall in the region.

Nicholson et al. (2017) observed that despite contrasting seasonality in Eastern Equatorial Africa, the rainfall time series are similar and interannual variability is strong and no trend in annual rainfall.

The possible drivers of trends in precipitation and potential Evapo-Transpiration in Uganda are the Sea Surface Temperature, Sea Level Pressure of Indian and Pacific Oceans, Nino3 and the extent varies depending on the location as observed by these authors: Nyeko-ogiramoi et al. (2013), Mbungu et al. (2012), Onyutha (2016a) and Jury (2017).

2.6 Chapter summary

This chapter indicates the relevant literature reviewed on climate variability, method of variability analyses, trend analysis in terms of magnitude and significance. Also possible drivers on trends in precipitation and potential Evapo-transpiration.

CHAPTER THREE: METHODS AND MATERIALS

3.1 Introduction

This section describes the methods employed in the study to analyzed the data, data types used inclusive of their sources and the location of the study area.

3.2 Research Design

The dissertation was based on observed data and Princeton Forcings data of high resolutions. The detection of changes in trends and variability employed both statistical and graphical methods in analyses shown below;

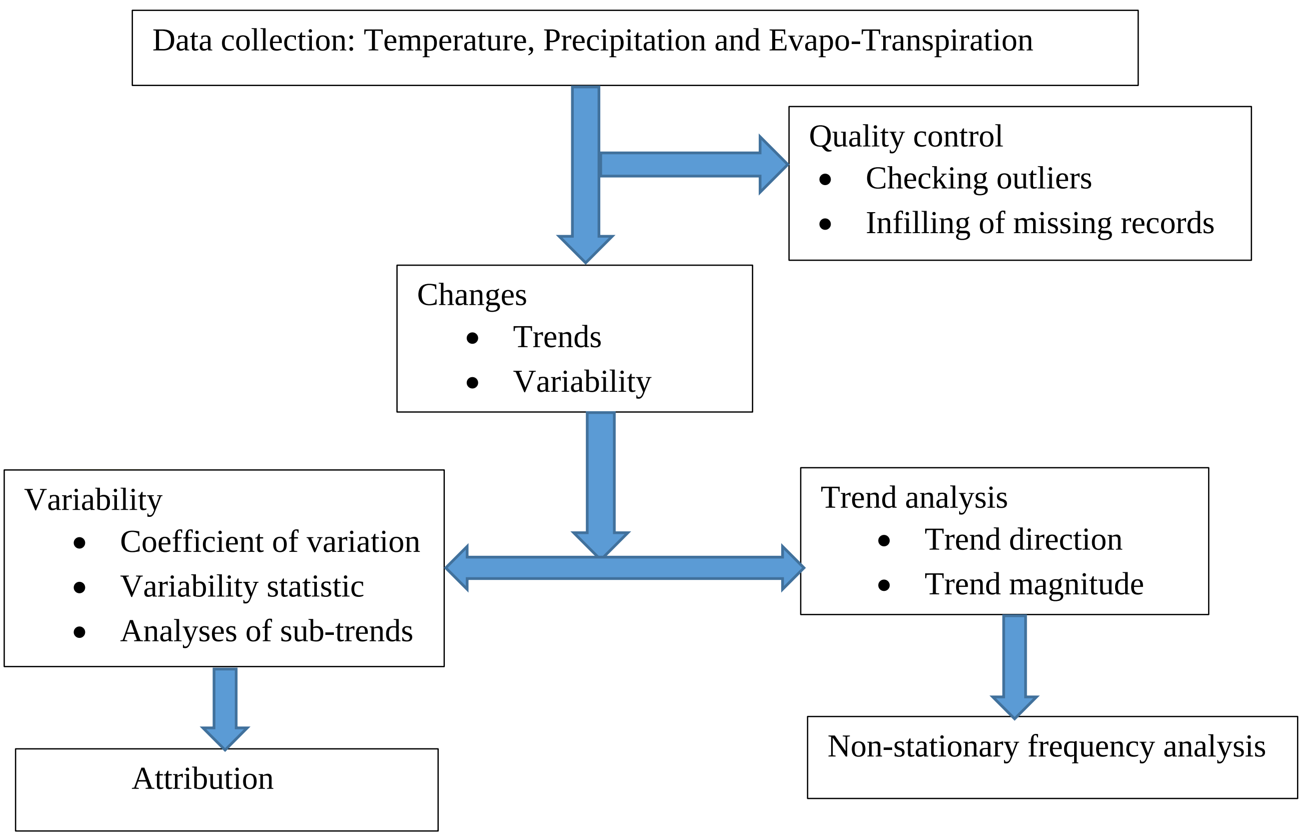

Figure 3.1 Theoretical and conceptual methodology pattern

3.3 Research approach

A quantitative research approach was used in analysis of multi-decadal variability and trends in precipitation and potential Evapo-transpiration across Lake Kyoga basin.

3.4 The Study Area

Lake Kyoga basin land area is 53,685km^2 and water area is 4,553 km^2, the catchment consists of eleven sub-catchments which include: Awoja, Okok, Okere, Mpologoma, Victoria Nile, Sezibwa, Akweng, Abalang, Lwere and Kyoga Lake side zones. The Basin experiences the modified equatorial type of climate with maximum temperatures during the December, January and February. The average rainfall received ranges between 600mm to 1500mm annually in the north and the south western part of the basin. The catchment is characterized by forests, grassland, agro-ecosystem and fresh water consisting of rivers and wetlands.

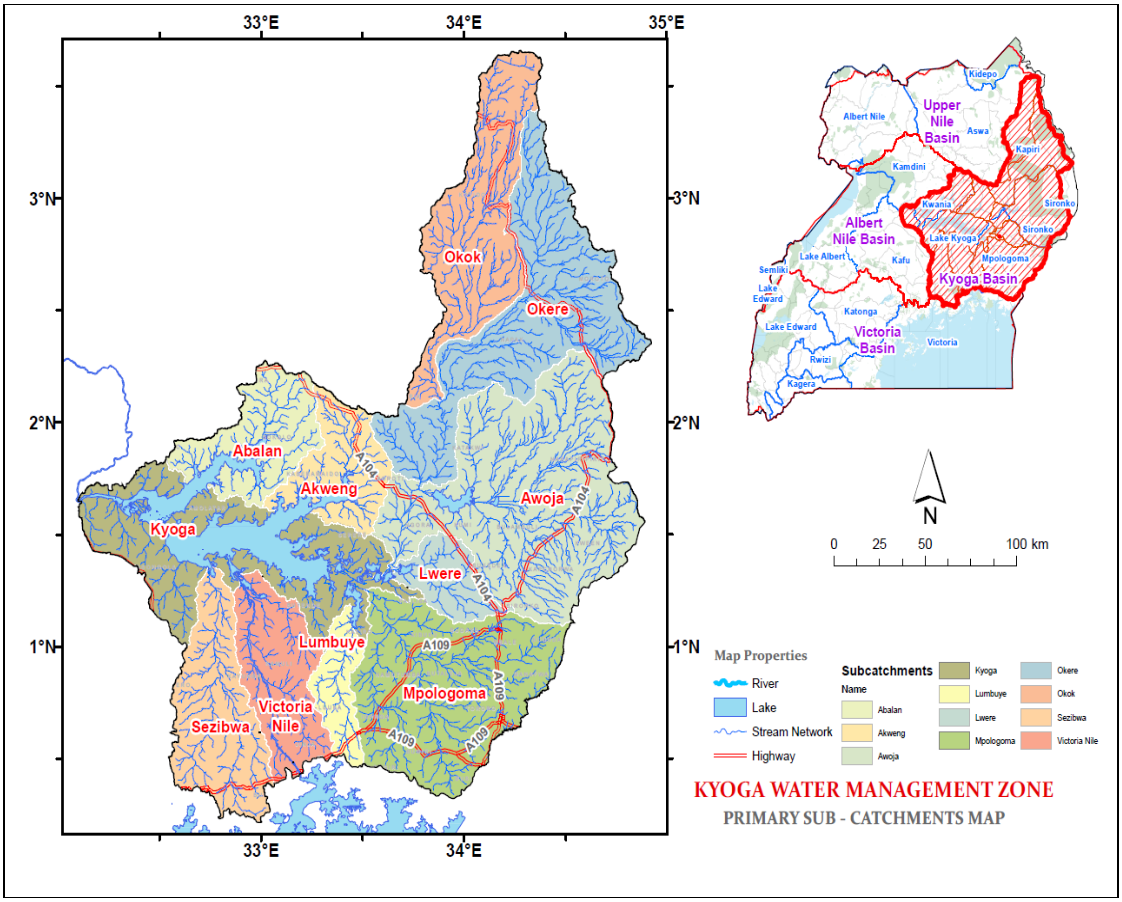

Figure 3:1 Location of Lake Kyoga basin (Source: Digital Elevation Map)

3.5 Data Analysis and Processing

The data for the study was obtained from various sources that is observed and online from the website like secondary data was obtained from Ministry of Water and Environment, Directorate of Water Resources Management (DWRM) and the meteorological data from the Uganda Meteorological Authority (UMA).

3.5.1 Temperature

The temperature data for mean daily minimum temperature (T_{min}) and mean daily maximum temperature (T_{max}) from 1960 to 2008 was obtained from Princeton global forcing (PGFs) of high spatial (0.5^0x0.5^0grid) resolution covering lake Kyoga basin (Sheffield et al., 2006). This was used to compute data for PETo using Hargreaves method (Hargreaves and Allen, 2003).

3.5.2 Potential Evapo-Transpiration (PETo)

PETo was computed from the mean daily maximum and mean daily minimum temperature (1960 - 2008) using Hargreaves formula (Hargreaves and Allen, 2003) below:

$$T_r = T_{max} - T_{min} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [w_s \sin \emptyset \sin \gamma + \cos \alpha \sin w_s] \quad \ldots\ldots\ldots\ldots \quad (2)$$

where,

R_a is the water equivalent of extraterrestrial radiation (MJ m^{-2} day^{-1}),

G_{sc} - the solar constant equal to 0.0820 MJ m^{-2} day^{-1},

d_r -the relative distance between the Earth and the Sun,

w_s- the sunset hour angle (rad),

$\emptyset$ -the latitude (rad), and α the solar declination angle (rad). The coefficient of 0.408 is used for converting MJ m^{-2} day^{-1} into mm day^{-1} (Schendel, 1967)

$$PET_0 = 0.0023 Ra\, [T_{max} + 17.8]\, T_r^{\ 0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where,

T_{max} = mean daily maximum temperature (^{0}C)

T_{min}= mean daily minimum temperature (^{0}C)

T_r = the difference between the mean daily maximum temperature and mean daily minimum temperature (^{0}C)

R_a = extra-terrestrial solar radiation (W/m^2), Q =discharge (m^3/s)

n =number of weather stations , ρH =vapour pressure (kpa)

PET_0 = Potential Evapo-Transpiration (mm)

There is possibility of bias in evapotranspiration estimates by using these un calibrated coefficients.

3.5.3 Precipitation

Gridded precipitation of Cen Trends v1.0 data (https://doi.org/10.1038/sdata.2015.50) accessed: 25th May 2019 was used in the study. The data was from 1901-2015. These period before and after 1960 were separated because of the well-known step jump in the mean of precipitation which occurred in the equatorial region (Kizza et al., 2009)

The choice of the Princeton Global Forcings data set for temperature and Cen Trend for precipitation because they are reanalysed data which is suitable for the study given that the study require long term data.

3.5.4 Climate Indices

To understand the consequences on variability in precipitation, pressure or temperature changes occurring over the different oceans, climate indices were used. The selected climate indices include:

3.5.4.1 North Atlantic Oscillation (NAO)

The NAO is traditionally defined as the normalized pressure difference between a station on the Azores and one on Iceland. An extended version of the index can be derived for the winter half of the year by using a station in the southwestern part of the Iberian Peninsula (Hurrell, 1995). That data downloaded via link (http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/NAO/ (accessed 30th June 2019)

3.5.4.2 Atlantic Multi-Decadal Oscillation (AMO)

The AMO index is the area weighted average sea surface temperature (SST) of the Atlantic Ocean from latitudes 0N to 70N.The AMO index data are monthly values of the area weighted SST of the Atlantic Ocean from the equator to 70N. The data range from 1856 to the present (Douglass, 2018).

3.5.4.3 Nino3 index

The Nino 3 is a large climate index defined as average sea surface temperature over the Pacific Ocean. The data was obtained online from this website (http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino3/index.html (accessed:25th May 2019))

3.5.4.4 Indian Ocean Dipole Index (IOD)

The IOD is the climate mode associated with the state of Sea Surface Temperature (SST) over western equatorial and southeastern Indian Ocean. The monthly time series from 1901-2008 was accessed online via website of National Oceanic and Atmospheric Administration.

3.6 Analyses of Trends

The monthly time series data obtained for the study area was converted into seasonal and annual using Cent-Trend for two seasons that is March, April, May (MAM), September, October, November (SON) and Annual covering the lake Kyoga basin. The trend slope is computed first then secondly, test of significance of trend slope and direction. The computed trend statistic Z is compared with the normal probability value from a table of normal distribution. The null hypothesis H_o (no trend) and selected significance level for the study was 0.05 corresponding to the *Z* value of 1.96. If *p*-value from the table computed for Z is less than 0.05 then reject the null hypothesis of no trend and vice versa. If *Z* is negative implies decrease.

3.6.1 Trend Magnitude

The magnitude of the linear trend in terms of its slope m was computed using (Sen, 1950; Theil ,1968) is given by;

$$m = median\left(\frac{x_j - x_i}{j - i}\right) \forall i < j \quad \text{...} \quad (4)$$

Where; x_j and x_i are the j^{th} and i^{th} observations respectively

$m =$ Magnitude of linear trend.

3.6.2 Trend Significance

To determine the trend significance, the Cumulative Sum of ranked Difference (CSD) developed by Onyutha, (2016c) was used in the study to analyze trend statistic given by the equations below:

$$T = \frac{6}{(n^3-n)} \sum_{i=1}^{n-1} S_i \text{ .... } (5)$$

where, $T =$ Trend statistic

$$S_i = \sum_{j=1}^{i} d_j \text{ .... } (6)$$

$n =$ sample size , d_j = the difference between exceedence and non-exceedence events of data points and $S_i =$ the cumulative sum of rank difference d_j

The positive and negative trends are indicated by $T > 0$, and $T < 0$, respectively.

The standardized trend test statistic Z which correspond to the standard normal distribution with mean (variance) of zero (one) is computed by

$$V = \frac{T}{\sqrt{V}} \text{.. } (7)$$

Where,

$$V = \frac{1}{n-1}\left(1 - \frac{10}{17}d^2 - \frac{7}{17}\mathrm{d}\right) \mathrm{x} \left|1 + \frac{2}{n(n^2-3)}\, x \sum_{k=1}^{n-2}(n-k)^3 r_k^{\alpha}\right| \text{...............} (8)$$

Where d is the measure of ties in the data.

$$d = \frac{1}{n^2-n}\Big(\sum_{i=1}^{n} \sum_{j=1}^{n} sgn_2\,(y_j - x_i) \text{.. } (9)$$

and r_k^{α} as the lag- k correlation coefficient (r_k) significant at α

considering $Z_{\alpha/2}$ as the standard normal variate at the selected α,the *Ho* (no trend) is rejected if $|Z| \geq Z_{\alpha/2}$ vice versa, *Ho* is not rejected (Onyutha, 2016b).

$$\mathrm{CI}_{lim} = \frac{-1 \pm Z_{\alpha/2}\sqrt{n-k-1}}{n-k} \text{ .... } (10)$$

3.7 Variability Analysis and its Significance

How do we test significance of variability?

Variability analysis can be determined by testing the null hypothesis H_o (natural randomness) using the following procedures:

- Let Q be the number of times when $d_{i-1} > 0$ and $d_i < 0$ for $2 \leq i \leq n$
- Consider U as the number of times when $d_{i-1} < 0$ and $d_i > 0$ for $2 \leq i \leq n$. Then $V = Q + U$
- The distribution V is approximately normal with the mean and variance given by $[2^{-1} \times (n-1)]$ and $[4^{-1} \times (n-1)]$ respectively.

If the probability (p) value computed using Z- statistic given by

$[(n-1)^{-0.5} \times |(1 - n + 2V)|]$ is less than or equal to the selected significance level, then H_o is rejected; otherwise the H_o is not rejected.

3.8 Correlation between precipitation sub-trends and climate indices

The relationship between the variation in precipitation sub-trends to changes in large scale ocean-atmosphere conditions was obtained in terms of correlation analysis. The monthly climate indices were converted into seasonal (May, April, May and September, October, November). The same applied to annual times scales as done for the gridded precipitation dataset using Cent trend. The sub-trends were computed using 15-year time scale from precipitation and potential Evapo-Transpiration at each grid point and climate indices.

The coefficient of determination R^2

The coefficient of determination measures the proportion of variation in y that is explained by x, and is often expressed as percentage. The higher the value of R^2,the better the model fits the data. In this study correlation of precipitation, potential Evapo-Transpiration between climate indices are compared to determine coefficient of determination.

3.9 Chapter summary

This chapter describe the research design, research approach, study area, data types and methods employed (cumulative sum of rank difference) in the study.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Illustration of Trends Slope

Figure 4:1 indicate multi-decadal trends in precipitation from 1901-1960. The gridded precipitation data was obtained across the Lake Kyoga basin at (longitude: $32^{\circ} 30' 0''$, latitude: $0^{\circ} 30' 0''$) The observed precipitation is represented by blue line oscillation over the years with trend slope of 0.4549. The long-term mean is indicated by the green dotted lines bisecting the observed precipitation. The trend line is shown by the small dotted red line across the observed precipitation.

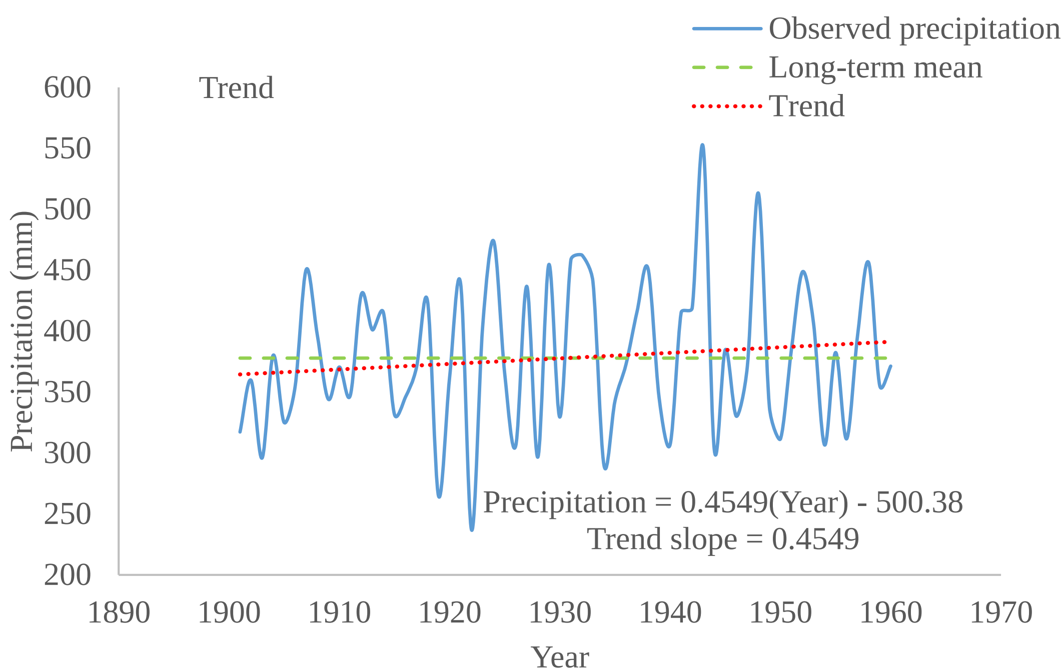

Figure 4:1 Trend in precipitation with trend slope of 0.4549 from 1901 – 1960

4.2 Illustration of variability

Figure 4:2 defined the observed precipitation over 15-years running average obtained across the Lake Kyoga basin at (longitude: 32° 30′ 0″, latitude: 0° 30′ 0″). Variability is shown by dotted black lines following the precipitation trend. The long-term mean dotted green is crossing the observed precipitation at 350mm point from 1901- 1960.

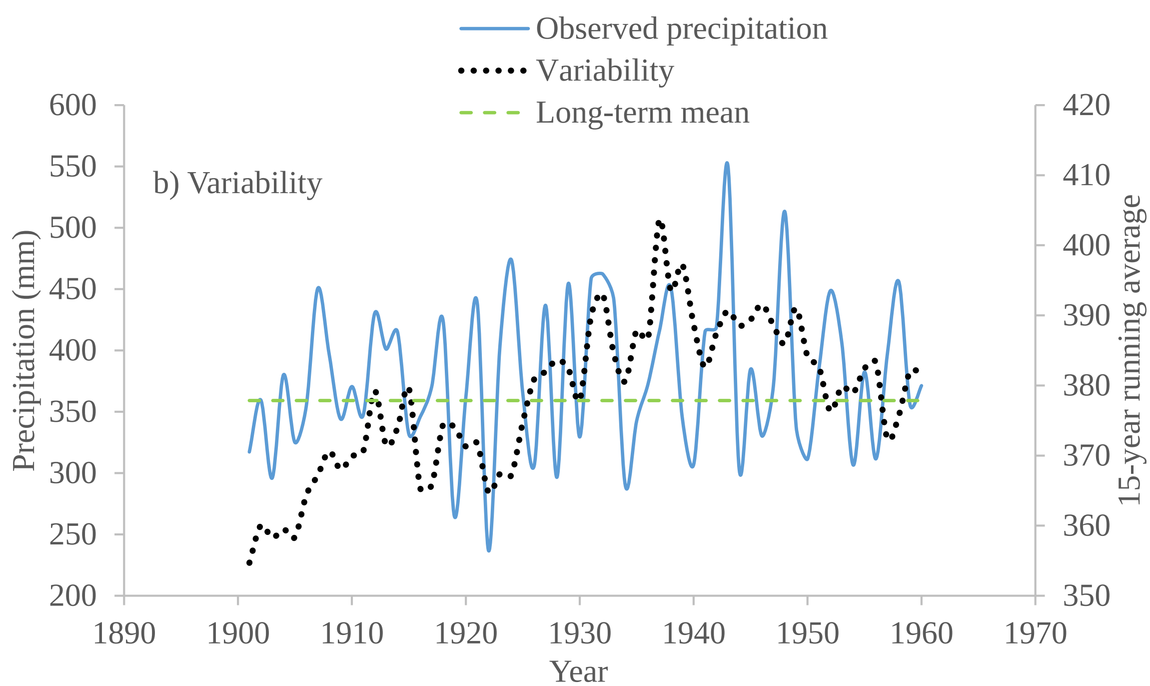

Figure 4:2 Variability in observed precipitation and long term mean from 1901-1960

4.3 The significance of trends in precipitation

Figure 4:3 shows precipitation trend in terms of statistic *Z* (a, c, e) and slope (mm/year) (b, d, f) covering the period 1901 - 1960. It can be observed that the trend for the MAM season (Figure 4:3a) was mainly positive in the Western and Northern parts. The South Eastern area exhibited negative trend (Figure 4:3a). Again it can be seen that the decrease was not significant ($p > 0.05$). The rate of precipitation decrease for the MAM season over the South Eastern area was as low as 0.233mm/year. Decrease in precipitation implies dry conditions. However, the increase in the MAM precipitation was not significant ($p > 0.05$) (Figure 4:3a). The rate of increase in the MAM precipitation was up to 0.536mm/year. The increase in precipitation implies wet conditions. For the SON season (Figure 4:3c) the observed trend is negative in most parts of the basin except small area of the Northern part with slight increase. The decrease in the SON precipitation was not significant ($p > 0.05$). The rate of increase in the SON precipitation was -0.147mm/year. Also the decrease was not significant ($p > 0.05$). The rate of precipitation decrease over the Eastern, southern and South Western was -0.970mm/year (Figure 4:3d). It's observed that the trend for the Annual precipitation (Figure 4:3e) was positive in the Northern and Western parts. The South Eastern area exhibits negative trend. The increase was not significant ($p > 0.05$). The rate of increase in Annual precipitation was 0.219mm/year (Figure 4:3f). The rate of Annual precipitation decrease was as low as -1.341mm/year. Based on visual judgement the Annual precipitation was influenced more by the SON than MAM season.

In relation to past studies when extreme precipitation conditions were considered using PGFs data, Onyutha (2016a) found positive and negative trends in the southern and Northern parts of Lake Kyoga basin. This difference in the results from Onyutha (2016a) and the findings of this study especially of the annual time scales shows that precipitation total and extreme events can decrease or increase in different directions over the same area.

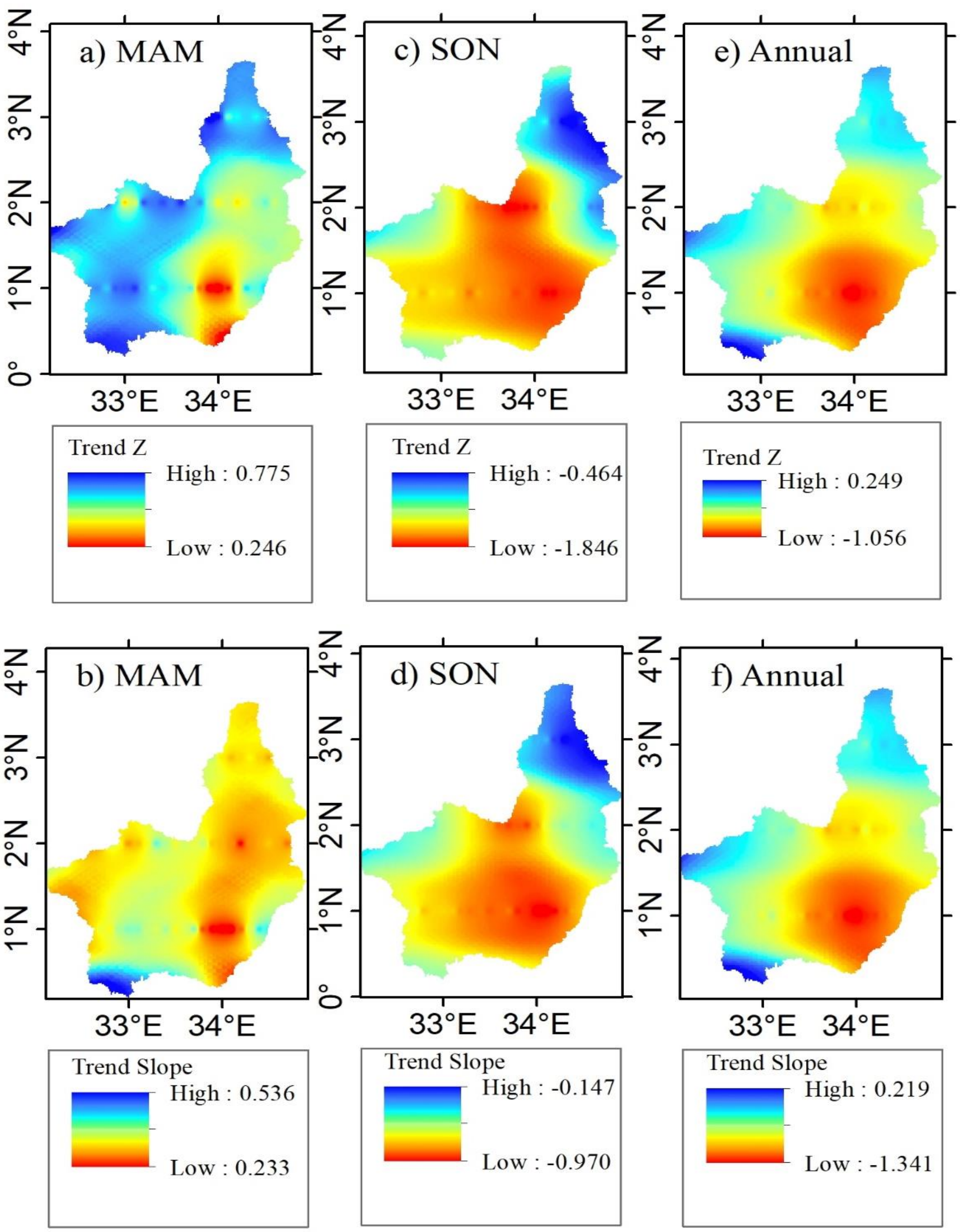

Figure 4:3 Precipitation trends in terms of statistic Z (a, c, e) and slope (mm/year) (b, d, f) covering the period 1901- 1960

Figure 4:4 shows precipitation trends in terms of statistics *Z* (a, c, e) and slope (mm/year) (b, d, f) covering the period 1961-2015. For the MAM season (Figure 4.4a) it can be observed that the Northern part exhibits decrease in precipitation trend compared with the Southern part. The decrease was not significant ($p > 0.05$) (Figure 4:4a). The rate of decrease in MAM precipitation was -0.089mm/year over the Northern region of the basin (Figure 4:4b). In the Southern part was as low as -0.752mm/year (Figure 4:4b). The increase in precipitation reflects wet condition.

The SON season (Figure 4:4c) positive trend in precipitation was observed in the Northern part. The Western and Eastern region indicated negative trend. The increase in SON precipitation was not significant ($p > 0.05$). However, the rate of increase in precipitation was up to 0.966mm/year (Figure 4:4d). Also decrease in SON precipitation over the Western part was not significant ($p > 0.05$). The rate of decrease in SON precipitation was as low as -0.078mm/year.

It can be seen that positive trend exists in the North Eastern region (Figure 4:4e). The Southern part indicated negative trend. The increase is not significant ($p > 0.05$). The rate of increase in annual precipitation was up to 0.747mm/year (Figure 4:4f). Also decrease in annual precipitation was not significant ($p > 0.05$). The rate of decrease in annual precipitation over the Southern part was as low as -1.393mm/year.

Considering the period covering 1901- 1960 and 1961 - 2015. The precipitation trends for seasonal and annual scales, more wet conditions were observed from 1961-2015 than 1901 -1960. This condition is vital in determining and planning for water resources applications like water for irrigation, domestic usage and others. In a related past study (Nyeko-Ogiramoi, Willems and Ngirane-Katashaya, 2013) analysis of long-term records of hydro-climatic extremes showed positive trends in rainfall, temperature and stream flow for selected stations in the Lake Victoria basin.

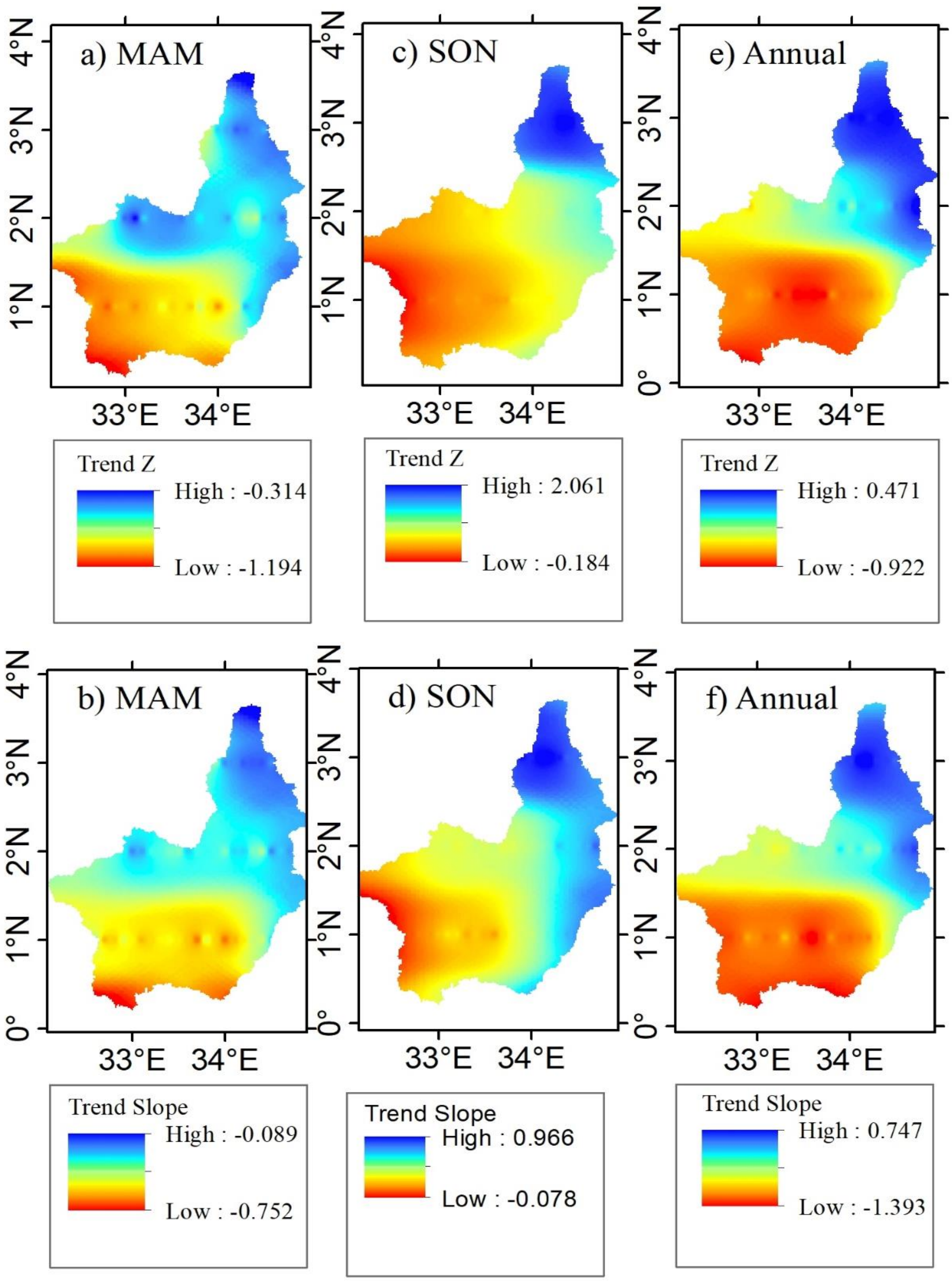

Figure 4:4 Precipitation trends in terms of statistics Z (a, c, e) and slope (mm/year) (b, d, f) covering the period 1961- 2015

4.4 The significance of non-zero slope of a linear variation of PETo with time

Figure 4:5 shows PETo trends in terms of statistic Z (a, c, e) and slope (mm/year) (b, d, f) covering the period 1960 - 2008. The values Z= 1.96 and 2.5 are thresholds for rejecting the null hypothesis H_o (no trend) at significant level $\alpha = 0.05$.

For the MAM season PETo trend (Figure 4:5a) was observed positive around the central part of the basin. The increase in PETo is not significant ($p > 0.05$). In the southern part PETo was negative. However, the increase in PETo was not significant ($p > 0.05$). The rate of PETo decrease over the Southern part was -0.018mm/year (Figure 4:5d).

The observed trends generally in PETo for all the seasons and annual time scales are not coherent as those of precipitation. This could be due to higher variability in PETo than precipitation across the basin.

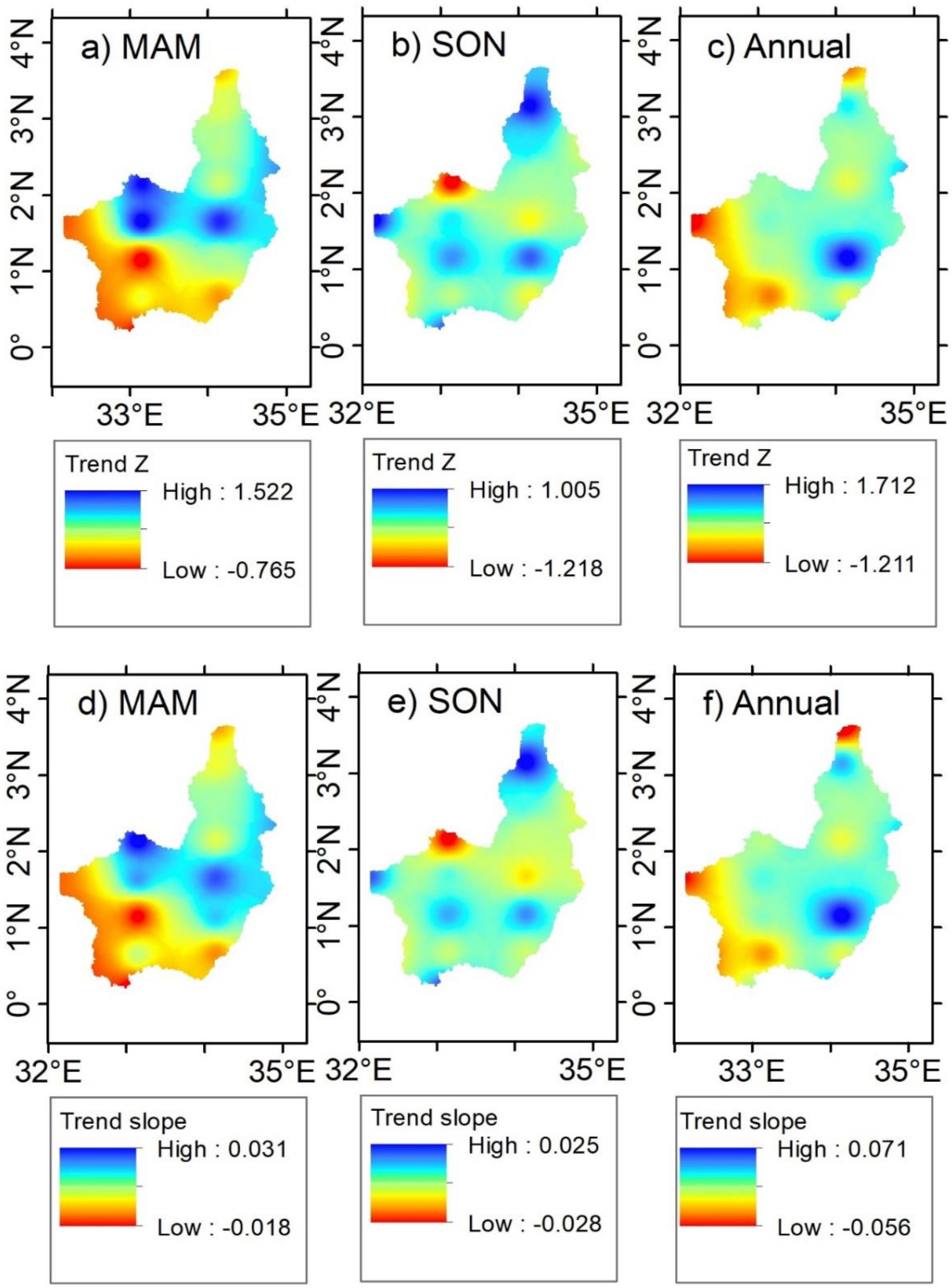

Figure 4:5 PETo trends in terms of statistic Z (a, b, c) and slope (mm/year) (d, e, f) covering the period 1960 - 2008

Table 4:1 Location of selected points for Variability analysis in Precipitation covering period 1961 - 2015

S/n	**Direction**	**Longitude (°)**	**Latitude (°)**
1	South	31° 30′ 0″	4° 0′ 0″
2	North	32 °24′ 0″	0° 0′ 0″
3	East	33° 12′ 0″	0° 0′ 0″
4	West	35° 0′ 0″	0° 0′ 0″

Table 4:2 Location of selected points for Variability analysis in PETo covering the period 1960 - 2008

S/n	Direction	Longitude (°)	Latitude (°)
1	South	31° 30′ 0″	0° 30′ 0″
2	North	32 °30′ 0″	4° 0′ 0″
3	East	34° 30′ 0″	3° 30′ 0″
4	West	31° 30′ 0″	3° 0′ 0″

The choice of the selected sites was based on the human activities and the terrain of the area.

4.5 Variability Analysis in Precipitation and PETo

Variability in annual precipitation and PETo was analyzed covering the period 1901 to 1960, 1961 to 2015 and 1960 to 2008 respectively. The points considered were selected from the Southern, Northern, Eastern and Western parts across Lake Kyoga basin for comparison of trends with time described in sections 4:5.1 and 4:5.2

4.5.1 Precipitation Variability Analysis

4.5.1.1 Annual Time series Variability Analysis

Figure 4:6 shows variability of annual precipitation for selected locations across Lake Kyoga basin. It can be seen that negative anomaly occurred between 1901 and 1910 as well as from 1920 to mid- 1930s (Figure 4:6a). The positive anomaly occurred over the period 1930s, 1940s and 1950s. It's significance due to positive anomaly in 1942. Its observed that positive anomaly occurred around 1910, 1936 and 1956. Negative anomaly seen around 1906, 1914, 1932 and 1948. It's insignificance due to positive anomaly in 1936 (Figure 4:6b) Also in Figure 4:6c, positive anomaly was observed around 1916, 1914, 1932 and 1948. Negative anomaly seen around 1907,1922,1938 and 1943 to 48 which is insignificant (Figure 4:6c).

Its observed that positive anomaly occurred around 1920, 1935 and 1960 with negative anomaly in 1910, 1943 and 1950. The variability was insignificance. Generally, for the period covering 1901- 1960 the positive and negative anomalies occurred across the Lake Kyoga basin was not significant (P>0.05). The findings are consistent with past studies on hydro-climatic variability in Uganda (Jury, 2017).

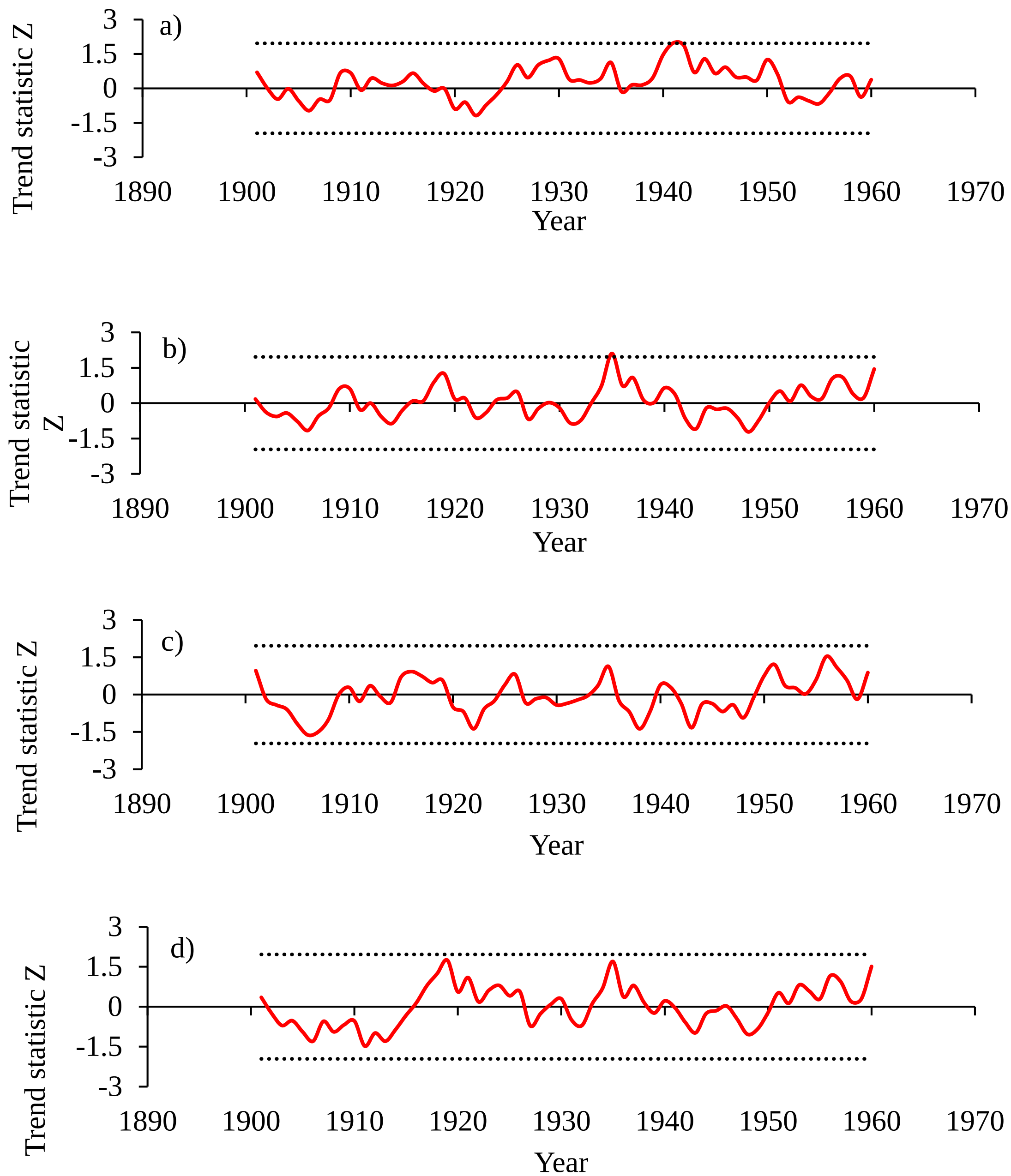

Figure 4:6 Precipitation variability in annual data covering the period 1901 - 1960 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

Figure 4:7 indicates Precipitation Variability analysis (ANN) covering the period 1961 - 2015 across Lake Kyoga basin targeting four regions as illustrated below:

Its observed that positive anomalies occurred around 1970s, 1980s and 2010s. The negative anomalies occurred around 2000. The anomaly was significant due to negative anomaly in 1964 and 2002 (Figure 4:7a). Its seen that negative anomalies occurred around 1970s and 2000s. The anomaly was significant in 1969 and 2002. The positive anomalies occurred around 1990s and significant (Figure 4:7b)

Also positive anomalies occurred around 1990s and 2006. The anomalies were not significant. The negative anomalies occurred around 1970s and 1980s (Figure 4:7c). Its seen that negative anomaly occurred around 1969 and 2002. The anomaly was significant due to negative anomaly in 2002. The positive anomaly occurred around 1990s and 2010. The anomaly was not significant (Figure 4:7d).

For the period covering 1961- 2015 it was observed that the annual precipitation anomaly was significant in some part of the Western, Southern and Northern parts of the basin across Lake Kyoga basin.

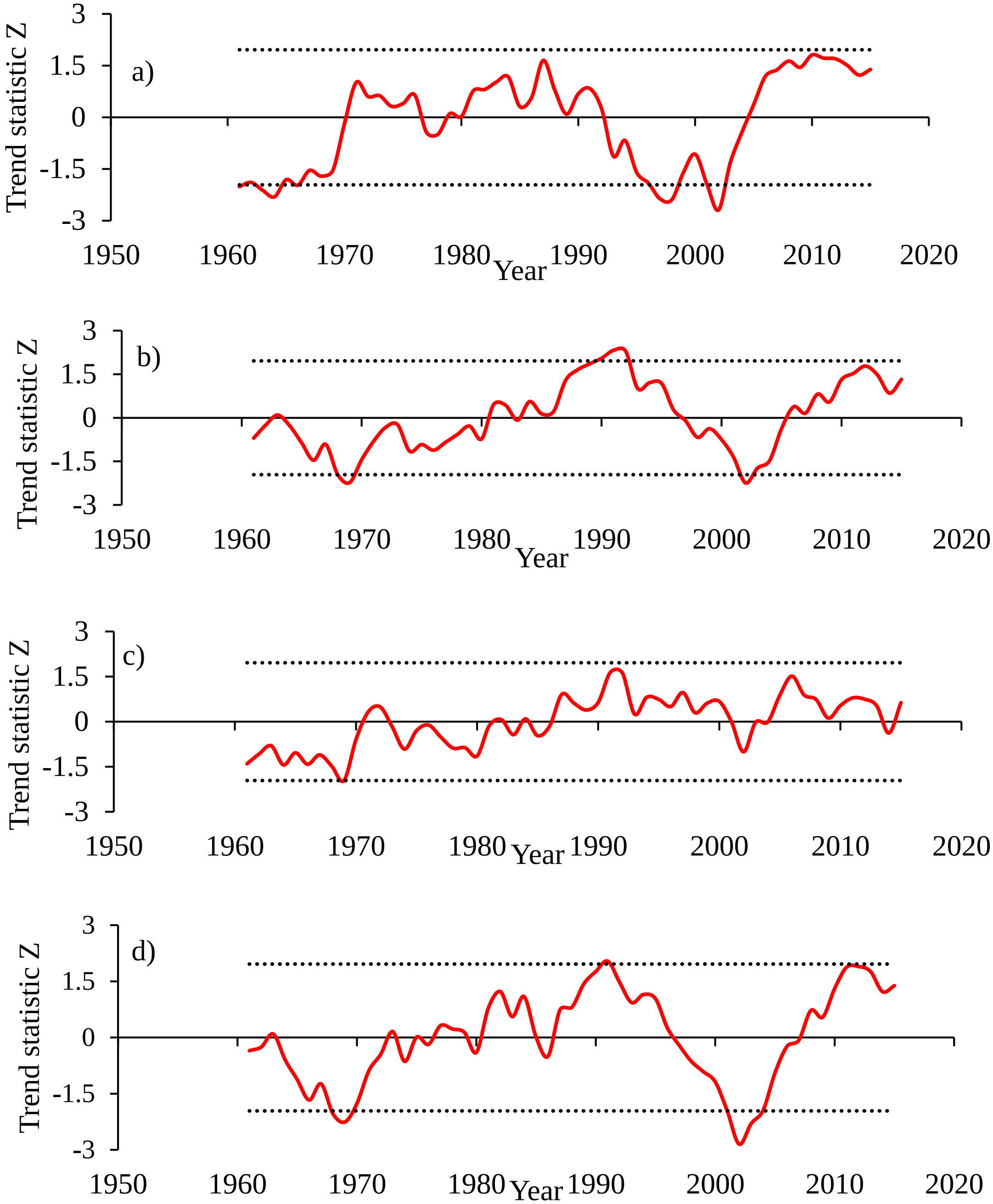

Figure 4:7 Precipitation variability in annual data covering the period 1961 - 2015 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

4.5.1.2 Seasonal Time Series Variability Analysis

Precipitation Variability Analysis (MAM) covering the period 1901 - 1960 across Lake Kyoga basin. Four selected locations were considered across the lake Kyoga basin. The findings are illustrated in Figure 4:8 discussed below:

Its observed that negative anomaly occurred around 1913 and 1948. The positive anomaly occurred around 1950s (Figure 4:8a). The anomaly was insignificant. The positive anomaly occurred around 1907 and 1925. The anomaly was significant in 1907. The negative anomalies occurred around 1914, 1938 and 1958 (Figure 4:8b.) Its seen that positive anomaly occurred around 1910, 1925, 1940 and 1950. The negative anomaly occurred around 1960s (Figure 4:8c).

The negative anomaly seen around 1914, 1920 and 1948. The positive anomalies occurred around 1907, 1940 and 1950s (Figure 4:8d). The anomalies were significant for the Southern, Northern and Western region in selected locations across the Lake Kyoga basin for the period covering 1901-1960.

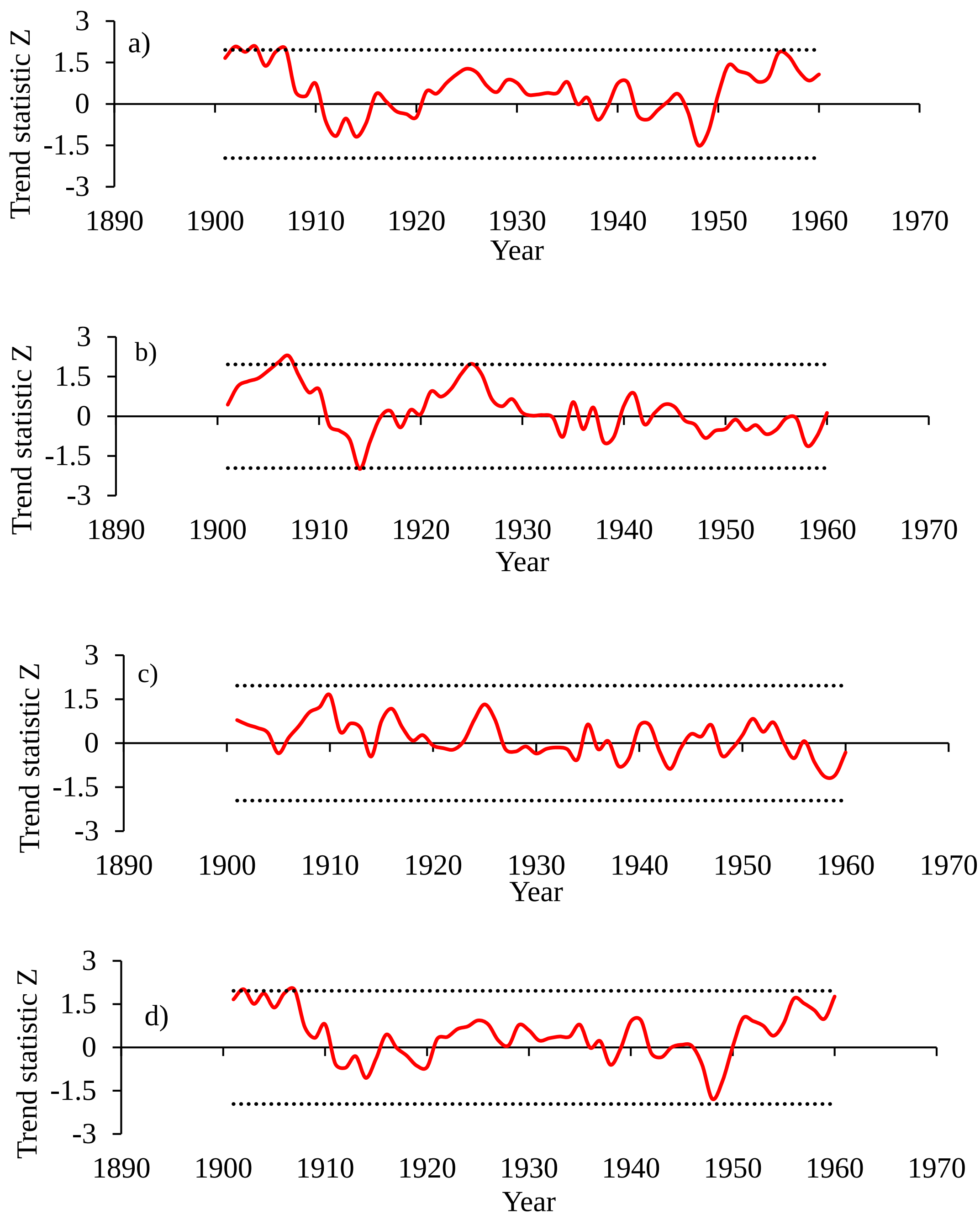

Figure 4:8 Precipitation variability in seasonal data (MAM) covering the period 1901 - 1960 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

Precipitation Variability Analysis (MAM) covering the period 1961 - 2015 across Lake Kyoga basin. Four selected locations were considered for analysis and findings are indicated in Figure 4:9 and discussed below: The positive anomaly occurred around 1980s. The anomaly was not significant. The negative anomaly occurred around 2000, the anomaly was significant in 2002 (Figure 4:9a).

Its observed that positive anomaly occurred around 1990s. The MAM anomaly was significant. The negative anomalies occurred around 2000 (Figure 4:9b). Also negative anomaly observed around 1970s and 1990s. The positive anomalies occurred around 2000. The MAM anomaly was significant in the Eastern part (Figure 4:9c).

Its seen that in Figure 4:9d positive anomaly occurred around 1980s and 1990s. The negative anomaly occurred around 2000. The MAM precipitation was not significant ($P>0.05$) for the Western region.

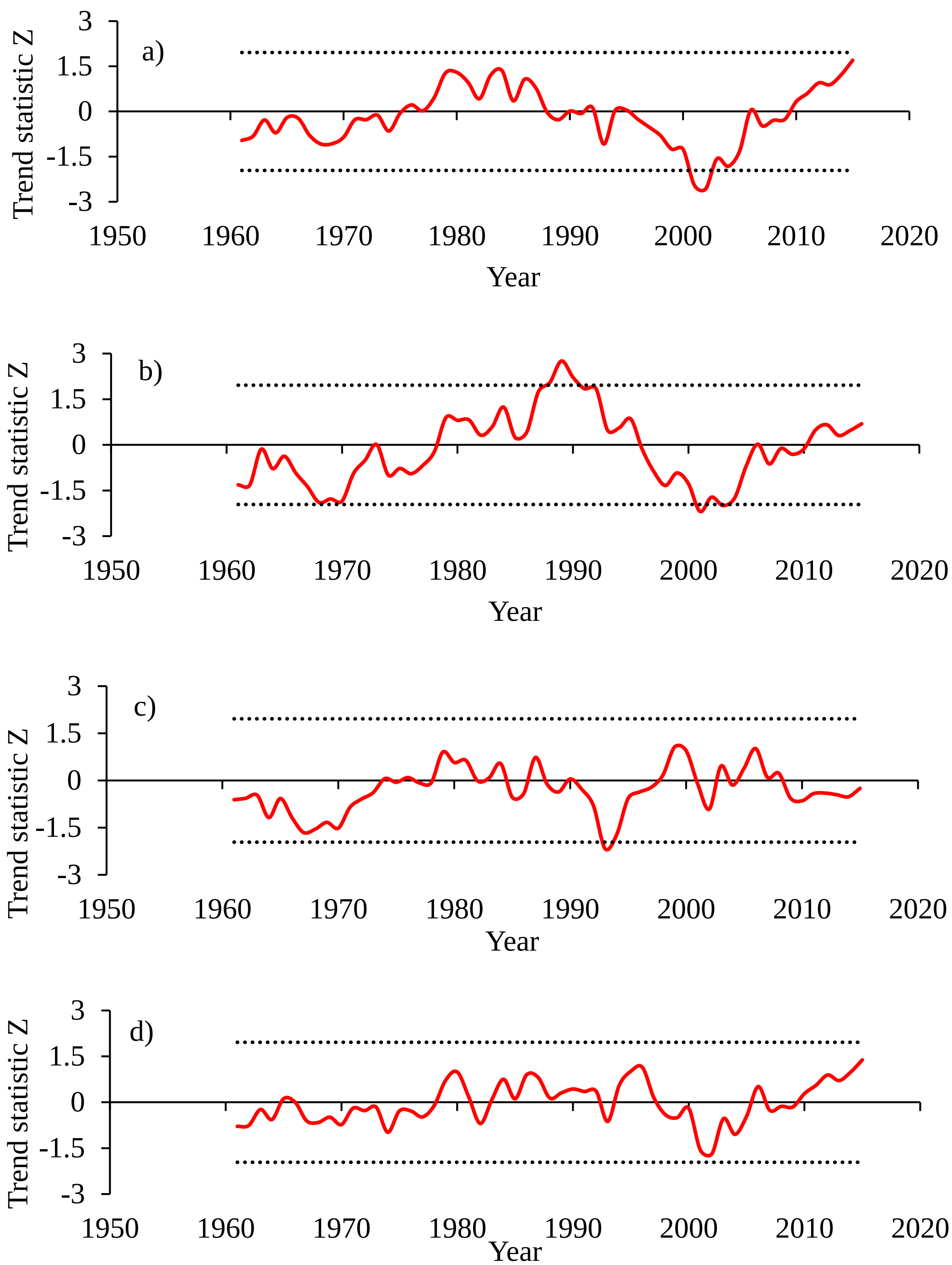

Figure 4:9 Precipitation variability in seasonal data (MAM) covering the period 1961 - 2015 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

Precipitation Variability Analysis (SON) covering the period 1901-1960 across Lake Kyoga basin. Four selected locations were considered for analysis. The results are shown in Figure 4:10 as discussed below:

It can be seen that positive anomaly occurred around mid-1940s. The anomaly was not significant. Also the negative anomaly occurred around 1922 which was insignificant (Figure 4:10a). Also in Figure 4:10b positive anomaly occurred around 1950s and 1960s. The anomaly was not significant. The negative anomalies occurred around 1930s.

Its observed that in Figure 4:10c negative anomaly occurred around 1906, 1930s and 1950s. The anomaly was not significant. The positive anomaly occurred around 1940s and 1950s and was not significant (P>0.05). The negative anomaly was observed around 1920s and 1930s (Figure 4:10d).

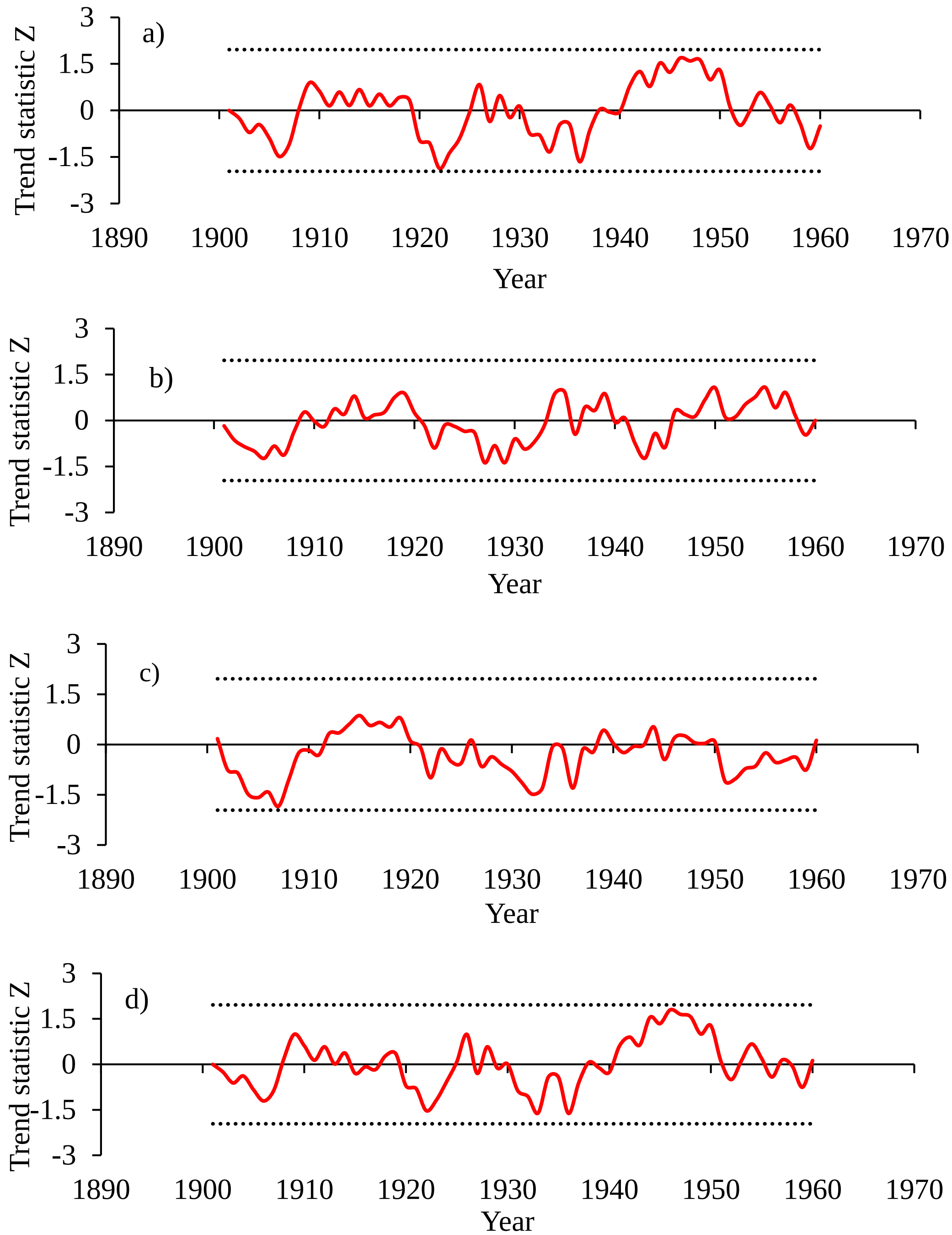

Figure 4:10 Precipitation variability in seasonal data (SON) covering the period 1901 - 1960 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

For precipitation variability covering the period 1961 - 2015 across Lake Kyoga basin, four locations were selected and observations illustrated in figure 4:11 discussed below:

It can be seen that in Figure 4:11a positive anomaly occurred around 1970s, 1980s, 1990s and 2010. The anomaly was not significant in the southern region. The negative anomaly occurred around 2000. The negative anomaly occurred around 1970s and 2000. The positive anomaly was observed around 1980s and 2011(Figure 4:11b). The anomaly was significant due to positive anomaly in 1982.

Also in Figure 4:11c, positive anomaly occurred around 1990s and 2010. The negative anomaly was observed around 1970s. The positive anomaly occurred around 1970s and 2010s. The negative anomaly was observed around 1980s and 2003 (Figure 4:11d).

Despite the variability in the Northern part of the Lake Kyoga Basin, it is noticeable that the changes in precipitation from 1960 to 2015 were dominated by an increasing trend in the SON (Figure 4:11).

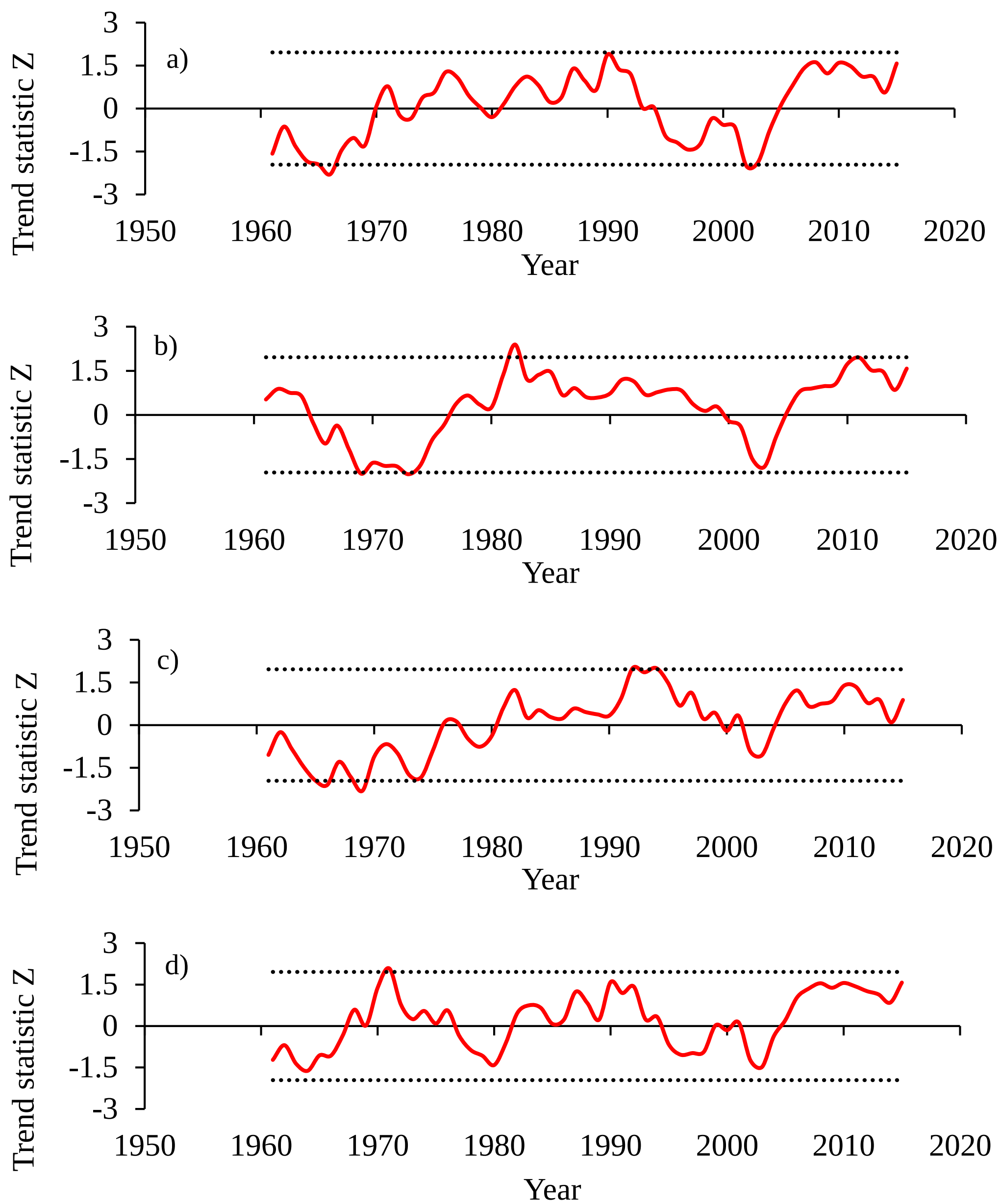

Figure 4:11 Precipitation variability in seasonal data (SON) covering the period 1961 - 2015 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

4.5.2 Potential Evapo-Transpiration Variability Analysis

4.5.2.1 Annual Time series Variability Analysis

PETo Variability Analysis (ANN) covering the period 1960 - 2008 across Lake Kyoga basin. Four locations were selected for analysis from the South, North, East and Western parts of the basin as illustrated in figure 4:12 below:

Its observed that in Figure 4:12a positive anomaly occurred around 1990s. The anomaly was significant due to positive anomaly in 1994. Also negative anomaly occurred around 1980s in the Southern part. The positive anomaly occurred around 2000 however, the annual precipitation anomaly was significant in 2000. The negative anomaly occurred around 1970 and was not significant (Figure 4:12b).

It also seen that in Figure 4:12c indicates positive anomaly around 1980s. The annual precipitation anomaly was not significant and negative anomaly occurred around 1970s. The positive anomaly occurred around 1961 to 1970, and 2003 which is significant in 1987. The negative anomalies occurred around 1973 to 1980s (Figure 4:12d).

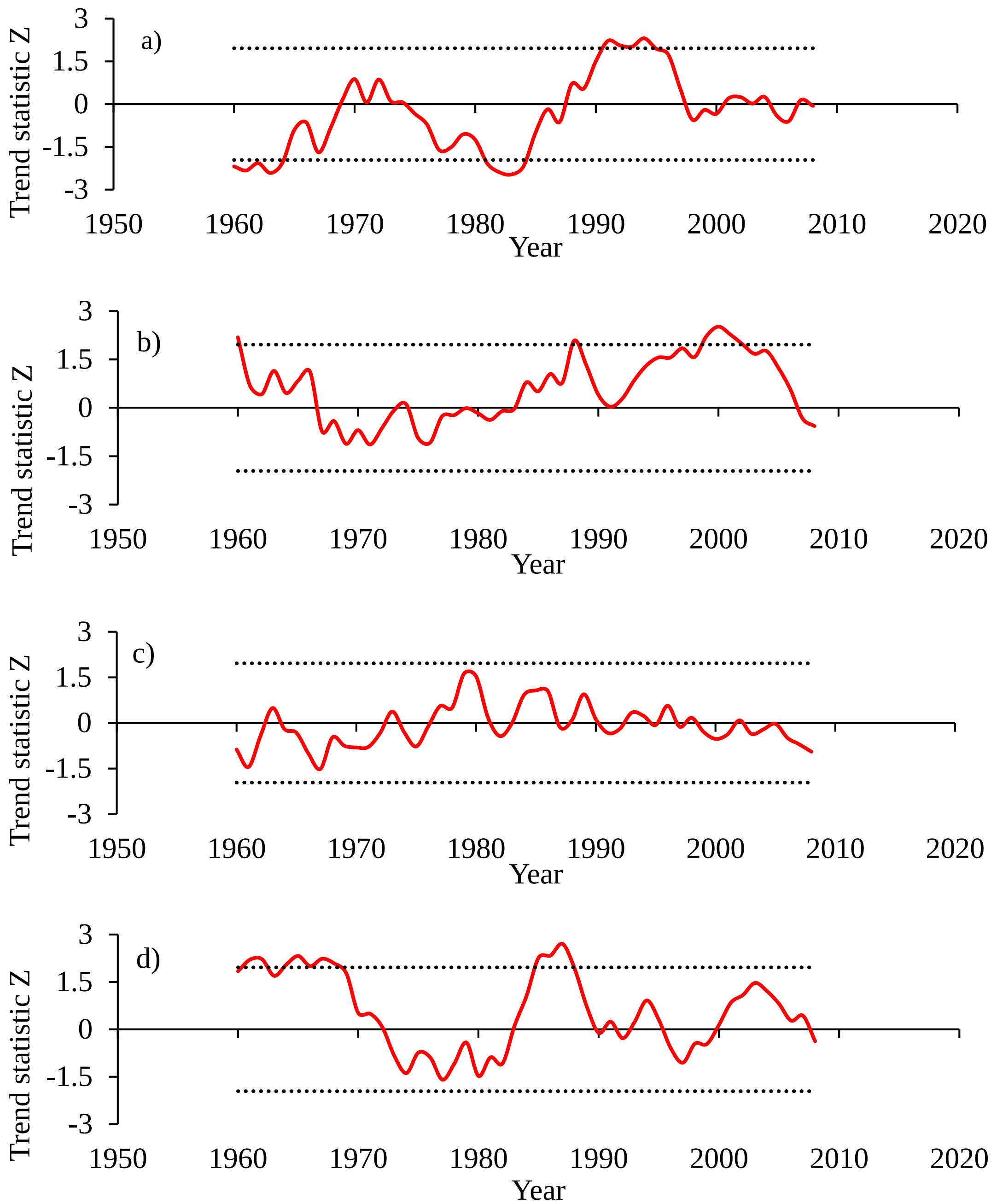

Figure 4:12 PETo variability in annual data covering the period 1960 - 2008 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

4.5.2.2 Seasonal (MAM and SON) Time series Variability Analysis in PETo covering the period 1960 - 2008

Two seasons were considered to examine variability in PETo covering the period 1960-2008 across Lake Kyoga basin. Four selected locations taken in the Southern, Northern, Eastern and Western. The findings for MAM season are indicated below:

PETo variability analysis (MAM) covering the period 1960 - 2008

It can be seen that in Figure 4:13a positive anomaly occurred around 1970s and 1990s. The negative anomaly occurred around 1980s. The anomaly was significant due to positive anomaly in 1994. Also in Figure 4:13b positive anomaly occurred around 1965 and 1997. The anomaly was not significant. Also negative anomaly occurred around 1970s and 1990s, was significant due negative anomaly in 1976.

The positive anomaly occurred around 1980s and 2000 and negative anomaly occurred around 1990s however, the anomaly was not significant (Figure 4:13c). It can be observed that Figure 4:13d, positive anomaly occurred around 1970s and 1990s. Also negative anomaly occurred around 1980s which was not significant.

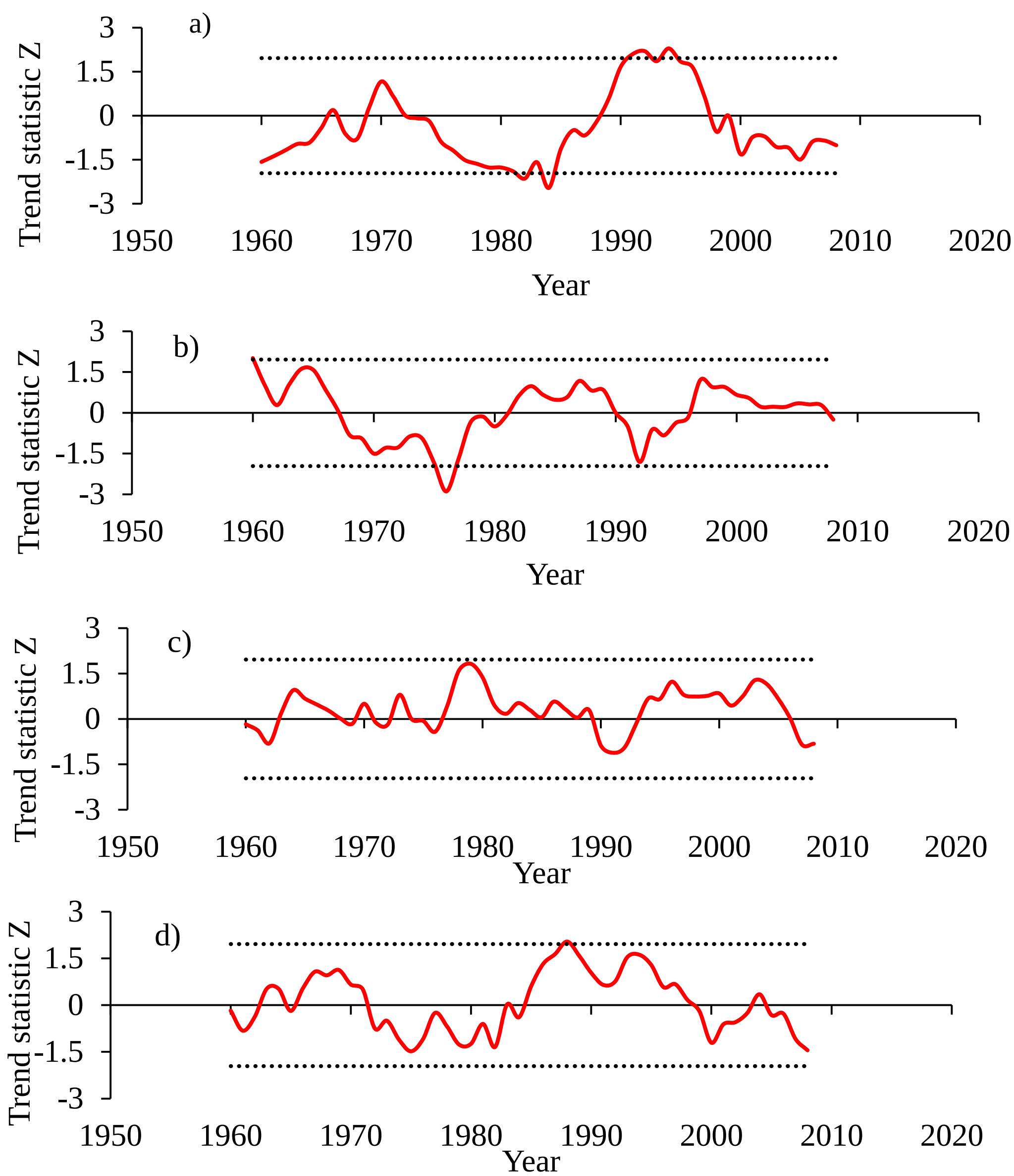

Figure 4:2 PETo variability in seasonal data (MAM) covering the period 1960 - 2008 Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin.

For PETo variability analysis (SON) covering the period 1960 - 2008 across Lake Kyoga basin, four locations were selected for analysis. Figure 4:14 presents the results of analysis.

It can be observed that in Figure 4:14a positive anomaly occurred around 2000. The anomaly was not significant and the negative anomaly occurred around 1980s. The positive anomaly occurred around 2000 with the negative anomaly exhibited around 1990s (Figure 4:14b) which was significant. It can be seen that in Figure 4:14c positive anomaly occurred around 1980s. The anomaly was not significant and negative anomaly occurred around 1990s in the Eastern part.

Also in Figure 4:14d negative anomaly occurred around 1970s, which was significant due to negative anomaly in 1973. Positive anomaly occurred around mid-1980s and 2004.

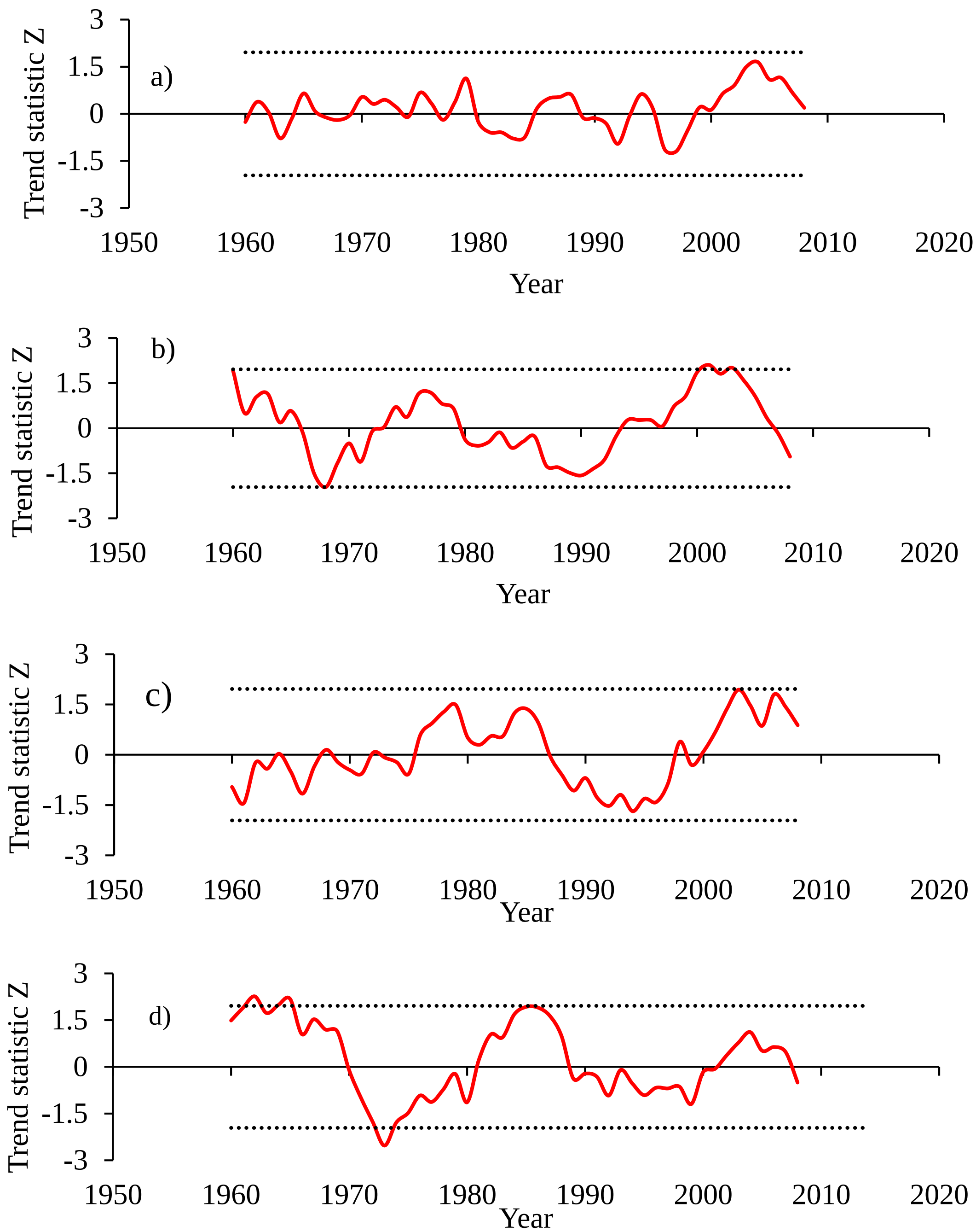

Figure 4:3 PETo variability in seasonal data (SON) covering the period 1960 - 2008 across Lake Kyoga basin. Chart a), b), c), and d) is for the Southern, Northern, Eastern and Western parts of the basin

4.5.3 Variability Analysis with Climate Indices

Figure 4:15 present comparison of variability in precipitation and potential Evapo-transpiration with climate indices AMO from (1961-2015) and (1960 -2008) for the months of March, April and May. The data was obtained across Lake Kyoga basin at (Longitude: 32° 30′ 0″, Latitude: 0° 30′ 0″). The variability in Precipitation and AMO climate index from 1961-1980 the two variables exhibit slightly similar trend but from 1990 to 2008 there is deviations where AMO is positive and precipitation is negative.

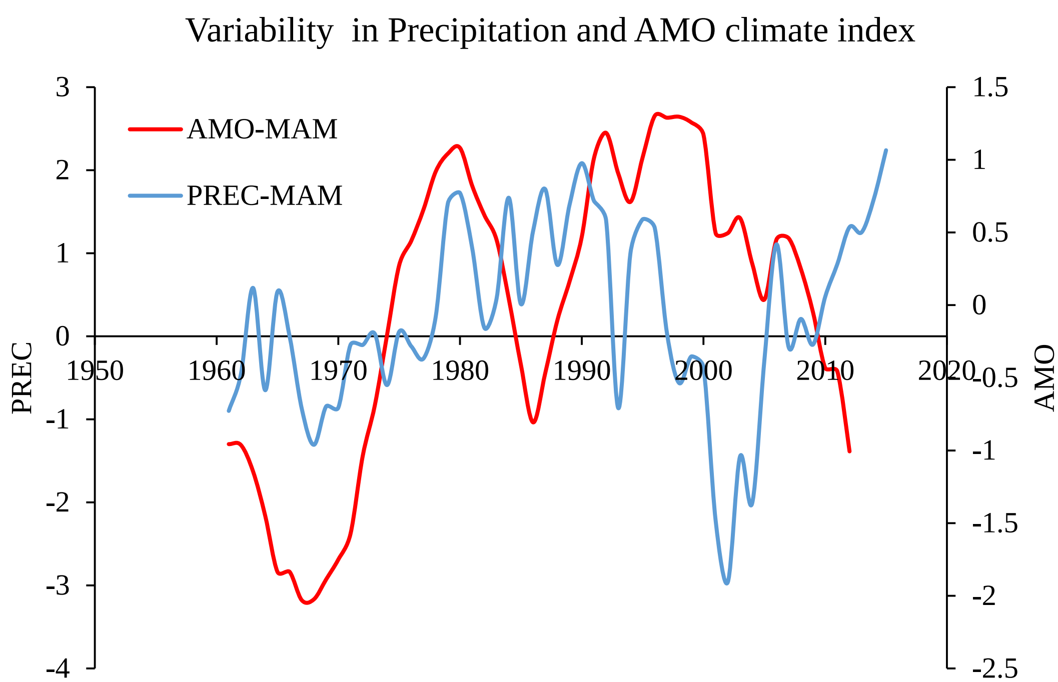

Figure 4:4 Variability in precipitation with AMO covering the period 1961 - 2015

Figure 4:16 shows variability in PETo with AMO climate index across Lake Kyoga basin at (longitude: 32° 30′ 0″, latitude: 0° 30′ 0″). The year 1960 to 1970 negative variability exhibited. From 1980 to 1990 the two variables AMO and PETo indicated similar trend but from 1991 to 2008 there is deviations where AMO is positive and PETo is negative.

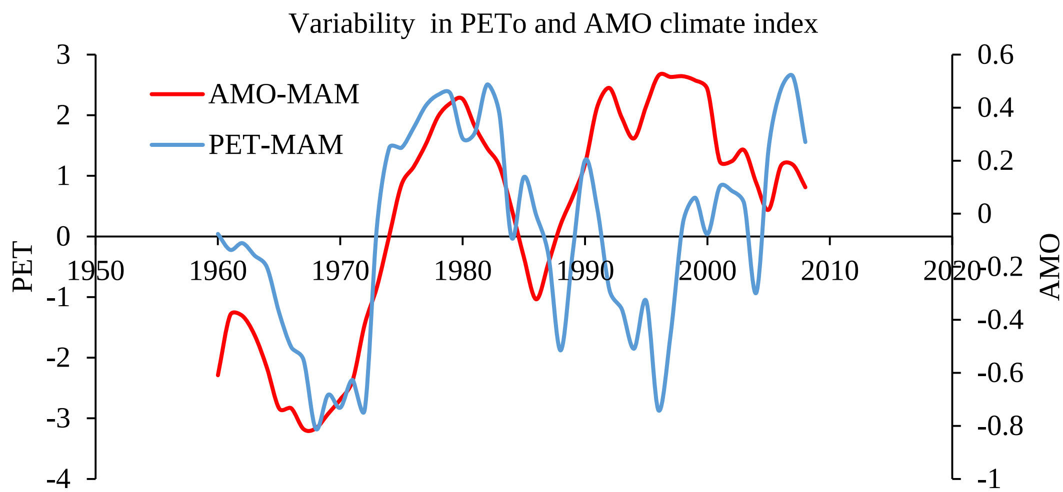

Figure 4:5 Variability in PETo with AMO covering the period 1960 – 2008

Critical value is a factor used to compute margin of error. In this study critical values are determined from Alpha level. The α level chosen was 0.05 and critical value expressed as *t* statistic (*t*), where degree of freedom *(df)* was computed from the sample statistics. The critical value corresponding to the degree of freedom was determined from the table through interpolation.

Table 4:3 Correlation between climate indices and Annual Precipitation at selected locations covering the period 1961-2015

S/n	Direction	Longitude (°)	Latitude (°)	NAO	AMO	IOD	Nino3	Critical valves
1	South	31° 30′ 0″	4° 0′ 0″	0.59	0.12	0.02	0.13	0.26
2	North	32 °24′ 0″	0° 0′ 0″	-0.36	0.34	0.31	0.08	0.26
3	East	33° 12′ 0″	0° 0′ 0″	-0.20	0.58	0.41	-0.03	0.26
4	West	35° 0′ 0″	0° 0′ 0″	0.29	0.05	0.16	0.16	0.26

Table 4:4 Correlation between climate indices and SON Precipitation at selected locations covering the period 1961- 2015

S/n	Direction	Longitude (°)	Latitude (°)	NAO	AMO	IOD	Nino3	Critical valves
1	South	31° 30′ 0″	4° 0′ 0″	-0.29	0.30	-0.06	0.01	0.26
2	North	32 °24′ 0″	0° 0′ 0″	-0.59	0.33	0.52	-0.27	0.26
3	East	33° 12′ 0″	0° 0′ 0″	-0.22	0.64	0.27	-0.27	0.26
4	West	35° 0′ 0″	0° 0′ 0″	-0.44	-0.05	-0.17	-0.29	0.26

Table 4:5 Correlation between climate indices and MAM Precipitation at selected locations covering the period 1961- 2015

S/n	Direction	Longitude (°)	Latitude (°)	NAO	AMO	IOD	Nino3	Critical valves
1	South	31° 30′ 0″	4° 0′ 0″	0.68	0.08	-0.45	0.32	0.26
2	North	32 °24′ 0″	0° 0′ 0″	0.41	0.29	-0.12	0.37	0.26
3	East	33° 12′ 0″	0° 0′ 0″	0.56	0.53	-0.51	0.05	0.26
4	West	35° 0′ 0″	0° 0′ 0″	0.15	-0.08	-0.41	0.56	0.26

4.6 The multi-decadal co-variability in precipitation with climate indices

The correlation between precipitation variability and climate indices AMO, NAO, IOD and Nino3 was examined from 1961- 2015 as illustrated in Figure 4:17 and Figure 4:18 respectively. The set threshold limits are the correlation coefficient of magnitude greater than 2.5 implies *Ho* (no correlation between precipitation and climate indices). Figure 4:17a, 4:17b and 4:17c indicates seasonal and annual positive and negative correlation across the entire basin within acceptable limits. Figure 4:17d shows positive high correlation in the southern part of the basin and in the extreme North negative correlation. Figure 4:17e indicates negative and correlation for the entire basin for the month of September, October and November. In Figure 4:17f the negative low correlation dominated most parts of the basin except the western and partially north.

The overall results indicated correlation between precipitation and climate indices (AMO and NAO) Figure 4:17a-f. Similar to past studies as observed by Onyutha (2018) in analysis of trends and variability in African long-term precipitation from 1901-2015.

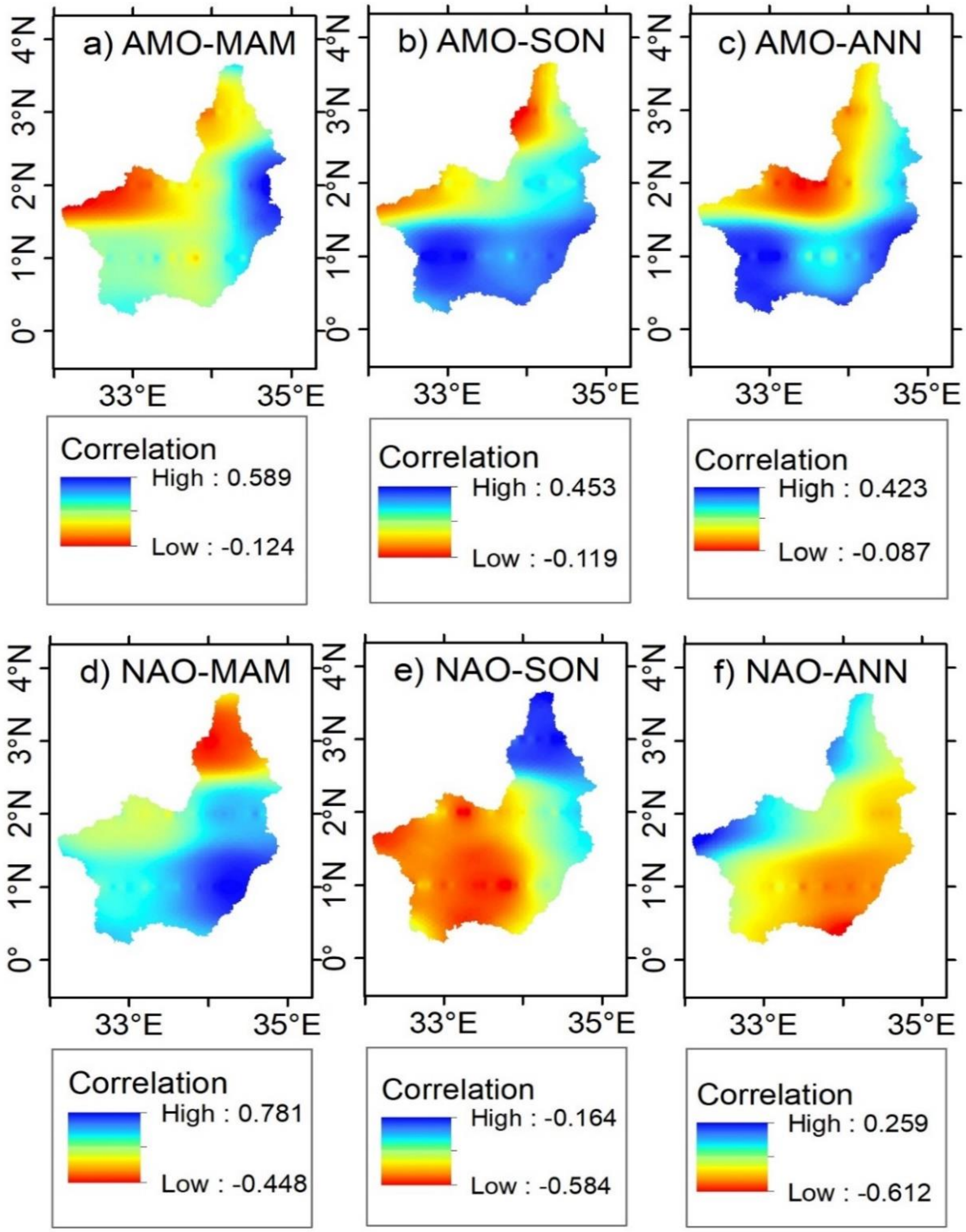

Figure 4:6 Correlation between precipitation variability and AMO (a, b,c), NAO (d,e,f) covering the period 1961 - 2015

Figure 4:18 showed correlation between variability in precipitation and climate indices (IOD and Nino3) from 1961-2015. Figure 4:18a indicates positive correlation in the northern part and most of the southern region shows negative correlation. Figure 4:18b shows negative correlation in the northern part and positive correlation in the south. Figure 4:18c indicate the annual correlation are positive for the entire basin. Figure 4:18d and 4:18f the seasonal and annual correlation are both positive high and negative low respectively accept for the month of September, October and November figure 4:18e which indicated negative correlation. There is correlation of precipitation variability with climate indices (IOD and Nino3) as illustrated in figure 4:18a-f. This confirms the findings of other authors (Wenhaji et al., 2018) in an observational study of the variability of East Africa rainfall with respect to sea surface temperature and soil moisture.

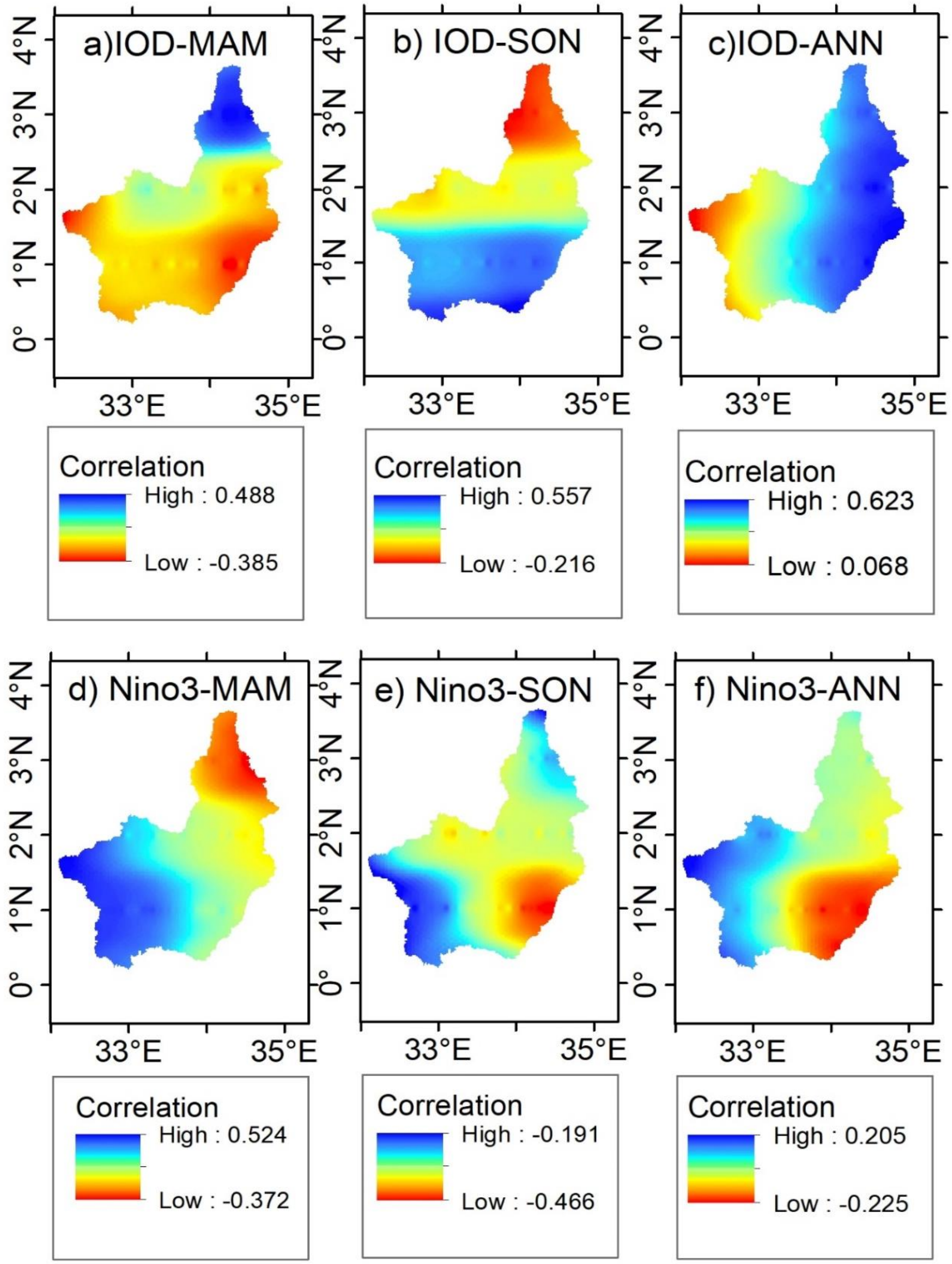

Figure 4:7 Correlation between precipitation Variability and IOD (a, b,c), Nino3 (d,e,f) covering the period 1961 - 2015

Table 4:6 Correlation between climate indices and Annual PETo at selected locations covering the period 1960 -2008

S/n	Direction	Longitude (°)	Latitude (°)	NAO	AMO	IOD	Nino3	Critical valves
1	South	31° 30′ 0″	0° 30′ 0″	-0.24	0.39	0.25	0.06	0.28
2	North	32 °30′ 0″	4° 0′ 0″	-0.62	0.31	0.40	-0.27	0.28
3	East	34° 30′ 0″	3° 30′ 0″	-0.08	0.44	-0.30	0.14	0.28
4	West	31° 30′ 0″	3° 0′ 0″	-0.08	-0.66	0.39	-0.23	0.28

Table 4:7 Correlation between climate indices and SON PETo at selected locations covering the period 1960 -2008

S/n	Direction	Longitude (°)	Latitude (°)	NAO	AMO	IOD	Nino3	Critical valves
1	South	31° 30′ 0″	0° 30′ 0″	0.14	-0.09	0.14	0.08	0.28
2	North	32 °30′ 0″	4° 0′ 0″	0.43	0.15	0.44	0.24	0.28
3	East	34° 30′ 0″	3° 30′ 0″	-0.13	0.11	0.24	-0.04	0.28
4	West	31° 30′ 0″	3° 0′ 0″	-0.65	-0.53	0.40	-0.39	0.28

Table 4:8 Correlation between climate indices and MAM PETo at selected locations covering the period 1960 - 2008

S/n	Direction	Longitude (°)	Latitude (°)	NAO	AMO	IOD	Nino3	Critical valves
1	South	31° 30′ 0″	0° 30′ 0″	-0.65	0.09	0.48	0.13	0.28
2	North	32 °30′ 0″	4° 0′ 0″	0.35	-0.10	0.32	-0.53	0.28
3	East	34° 30′ 0″	3° 30′ 0″	0.05	0.20	-0.20	-0.37	0.28
4	West	31° 30′ 0″	3° 0′ 0″	-0.32	-0.22	0.47	-0.07	0.28

4.7 The multi-decadal variability in potential Evapo-transpiration in respect to changes in large-scale ocean-atmosphere interactions

Figure 4:19 and 4:20 shows correlation between variability in potential Evapo-transpiration and climate indices: AMO, NAO, IOD and Nino3 from 1960-2008. Figure 4:18a, 4:18b and 4:18c indicates high positive and low negative correlation for seasonal and annual with AMO climate index, similarly for both seasonal and annual correlation with NAO as reflected in Figure 4:18d, 4:18e and 4:18f which are within acceptable limits. The results indicate correlation of potential Evapo-transpiration with climate indices (AMO and NAO).

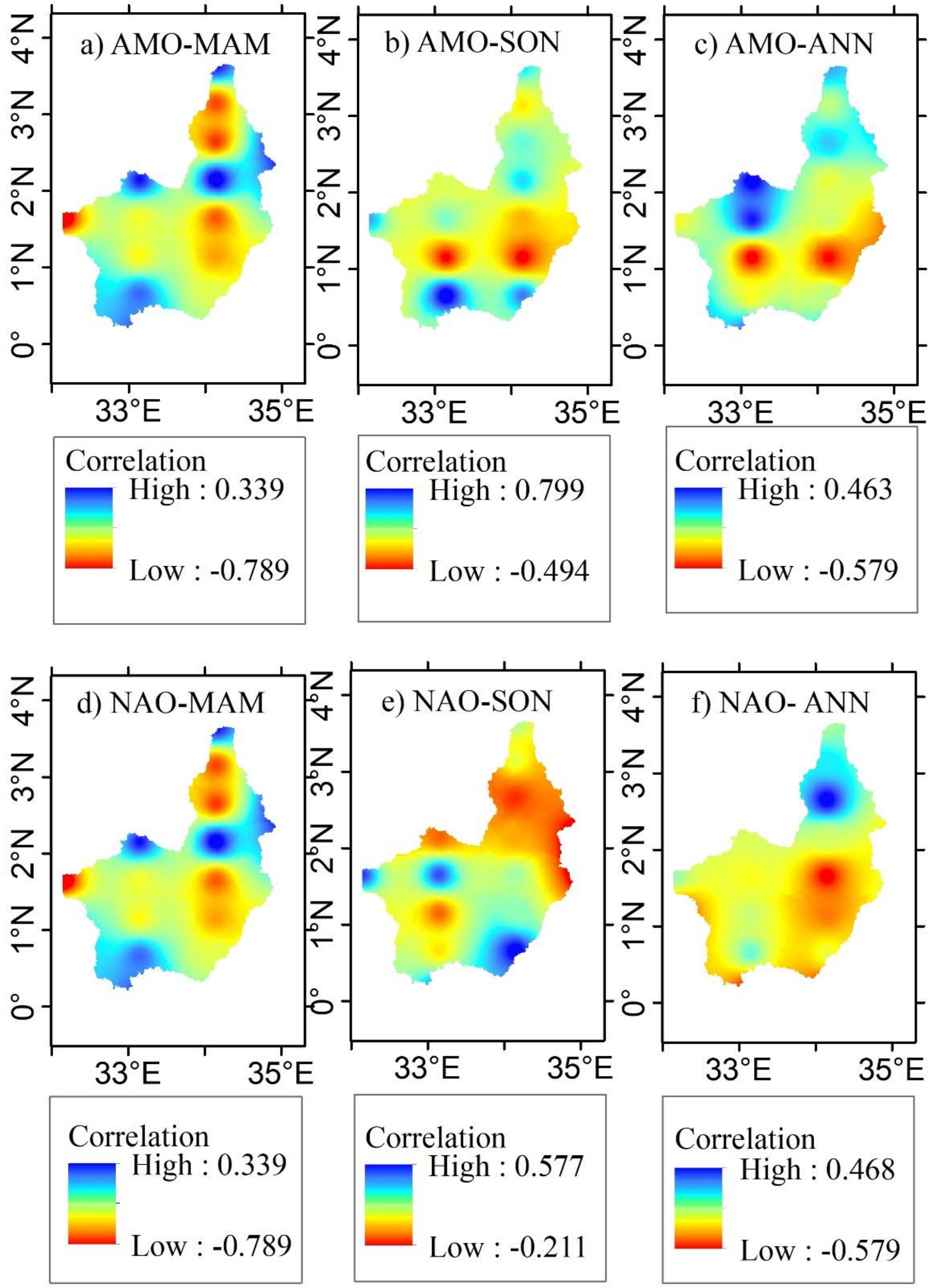

Figure 4:8 Correlation between PETo and AMO (a, b,c), NAO (d,e,f) covering the period 1960 - 2008

Figure 4:20 indicated the correlation variability of potential Evapo-transpiration with IOD and Nino3. Figure 4:20a, 4:20b and 4:20c the correlation is positive and negative for all the seasons and annual potential Evapo-transpiration with IOD. Figure 4:20d, 4:20e and 4:20f showed similar results for seasonal and annual potential Evapo-transpiration with Nino3. The overall results showed correlation of potential Evapo-transpiration with climate indices IOD and Nino3 for all the seasons and annual time series though the magnitude varies. This finding is consistent with Clark et al. (2003), who observed that the Indian Ocean Dipole is consistently influencing the rainfall variability over the East Africa.

The study found that precipitation at some of the locations were decreasing, Potential Evapo-transpiration exhibited an increasing trend. Precipitation decrease and PETo increase is a shift towards dry condition. If such trends are to continue in future (10 years, 20 years and above), the changes in the hydro-climate may affect the operation of water resources in the Lake Kyoga Basin.

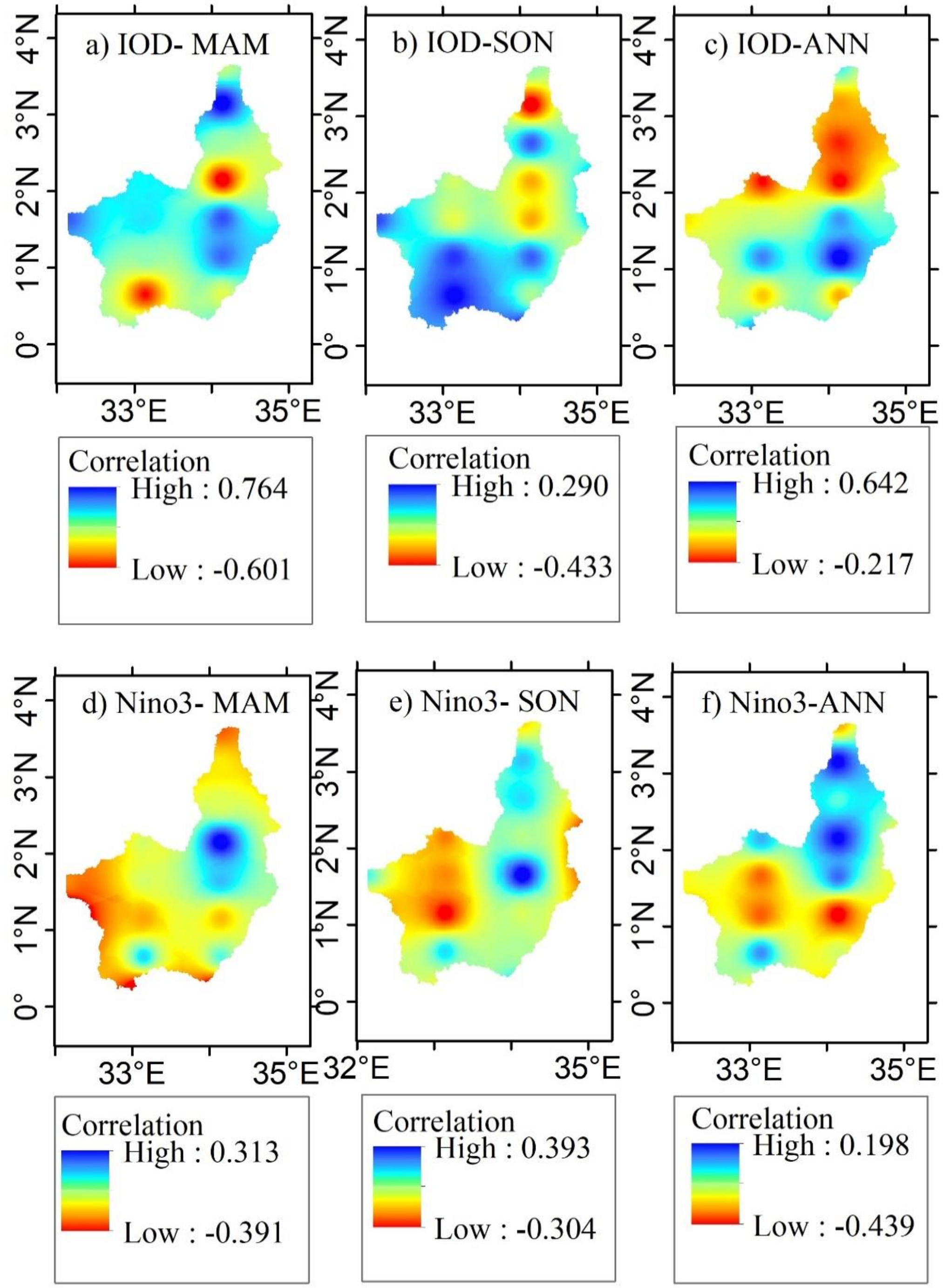

Figure 4:20 Correlation between PETo and IOD (a, b, c), Nino3 (d, e, f) covering the period 1960 - 2008

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Trends and variability in precipitation and PETo across Lake Kyoga basin was examined. The data covering long-term period from 1901-1960, 1961- 2008 and 1961-2015 was considered for precipitation and PETo. The monthly time series were converted into seasonal and annual before analysis. The cumulative sum of ranked difference method and (Sen,1950, Theil,1968) were employed. The results of this study indicated the following:

Precipitation from (1901-1960) for the month of March, April, and May increased, thereby implying wet condition and for September, October, November and Annual decrease is observed which is an indication of dry condition. This implies variability in seasonal rainfall over the basin.

PETo for the month of MAM, SON and Annual time series from (1960 - 2008) showed decreasing trends implying wet condition. This means careful planning required for water usage especially for agriculture, industrial, hydro-power generation and human consumption taking into consideration the changing trends and variability in climatic condition across Lake Kyoga basin.

The general observations from 1961 to 2015 annual variability in precipitation yielded negative anomalies also around 1960s to 1970s while increase was observed around the1990s and 2000 across the basin.

PETo variability from 1960 to 2008 across Lake Kyoga basin differs from the region to region but for the Northern and Eastern exhibit similar trends likewise for Southern and Western.

Correlation between variability in precipitation and Indian Ocean Dipole was positive for both annual and seasonal time series. The largest amount of variance in PETo was also found to be explained by Indian Ocean Dipole. Influences from especially North Atlantic Ocean and Pacific Ocean on variability of precipitation and PETo across the study rea were also notable. These findings showed that rainfall distribution across the basin may be influenced by the changes in sea surface temperature from the various ocean and the amount of contribution of the driving influence varies in magnitude from one ocean to another.

5.2 Relevance of the findings

Given that drivers of variability of precipitation and PETo are established from this study, it can be possible to predict an upcoming period of dry and wet conditions for appropriate predictive adaptation to the impacts of climate variability on water resources. This can be used for planning and supporting several water resources applications such as irrigation schemes, and operation of hydroelectric power plant or Karuma Dam is at the outlet of Lake Kyoga. Guidance to the policy makers and water resources managers in development of integrated water resources management plan. For risk-based applications, this study can support preparation of catchment management plan for the different sub-catchments inclusive of the conservation measures for flood control.

5.3 Recommendations

Future research studied to be conducted across the Lake Kyoga basin are recommended to consider;

- the effects of climate variability on water resources,
- impacts of climate change on rainfall, PETo and rainfall-runoff,
- the influence of the choice of methods on results of rainfall and PETo variability attribution, and
- interaction between climate change and climate variability.

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APPENDIX

Location of Kyoga Sub-catchments

Figure 5:1 The Study area

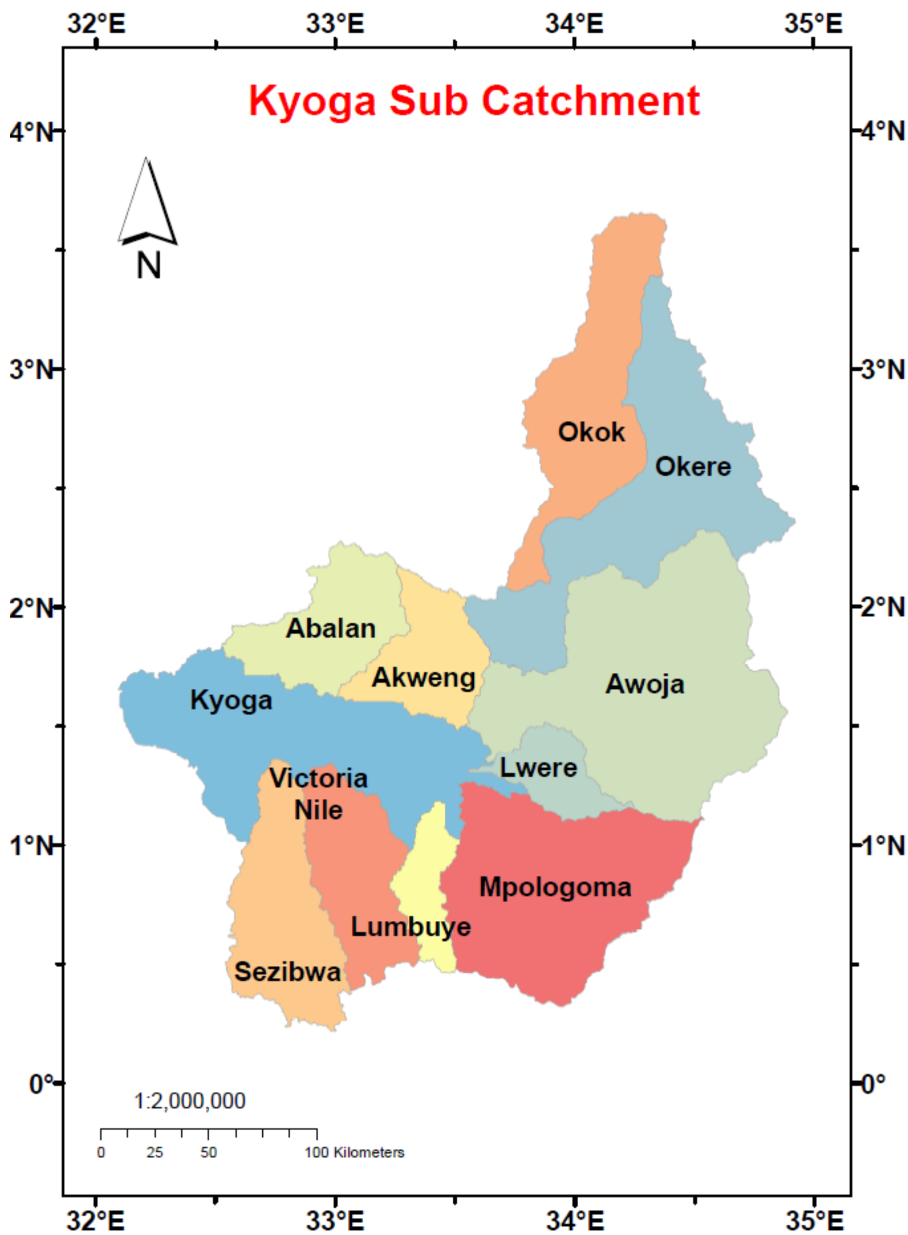

Table 5:2 Critical values of Pearson's correlation coefficient

	Level of Significance of a One-Tailed or Directional Test H_0: $\rho \leq 0$ or H_0: $\rho \geq 0$					
	$\alpha = 0.1$	$\alpha = 0.05$	$\alpha = 0.025$	$\alpha = 0.01$	$\alpha = 0.005$	$\alpha = 0.0005$
	Level of Significance of a Two-Tailed or Nondirectional Test H_0: $\rho = 0$					
df	$\alpha = 0.2$	$\alpha = 0.1$	$\alpha = 0.05$	$\alpha = 0.02$	$\alpha = 0.01$	$\alpha = 0.001$
1	0.9511	0.9877	0.9969	0.9995	0.9999	0.9999
2	0.8000	0.9000	0.9500	0.9800	0.9900	0.9990
3	0.6870	0.8054	0.8783	0.9343	0.9587	0.9911
4	0.6084	0.7293	0.8114	0.8822	0.9172	0.9741
5	0.5509	0.6694	0.7545	0.8329	0.8745	0.9509
6	0.5067	0.6215	0.7067	0.7887	0.8343	0.9249
7	0.4716	0.5822	0.6664	0.7498	0.7977	0.8983
8	0.4428	0.5494	0.6319	0.7155	0.7646	0.8721
9	0.4187	0.5214	0.6021	0.6851	0.7348	0.8470
10	0.3981	0.4973	0.5760	0.6581	0.7079	0.8233
11	0.3802	0.4762	0.5529	0.6339	0.6835	0.8010
12	0.3646	0.4575	0.5324	0.6120	0.6614	0.7800
13	0.3507	0.4409	0.5140	0.5923	0.6411	0.7604
14	0.3383	0.4259	0.4973	0.5742	0.6226	0.7419
15	0.3271	0.4124	0.4821	0.5577	0.6055	0.7247
16	0.3170	0.4000	0.4683	0.5425	0.5897	0.7084
17	0.3077	0.3887	0.4555	0.5285	0.5751	0.6932
18	0.2992	0.3783	0.4438	0.5155	0.5614	0.6788
19	0.2914	0.3687	0.4329	0.5034	0.5487	0.6652
20	0.2841	0.3598	0.4227	0.4921	0.5368	0.6524
21	0.2774	0.3515	0.4132	0.4815	0.5256	0.6402
22	0.2711	0.3438	0.4044	0.4716	0.5151	0.6287
23	0.2653	0.3365	0.3961	0.4622	0.5052	0.6178
24	0.2598	0.3297	0.3882	0.4534	0.4958	0.6074
25	0.2546	0.3233	0.3809	0.4451	0.4869	0.5974
30	0.2327	0.2960	0.3494	0.4093	0.4487	0.5541
35	0.2156	0.2746	0.3246	0.3810	0.4182	0.5189
40	0.2018	0.2573	0.3044	0.3578	0.3932	0.4896
50	0.1806	0.2306	0.2732	0.3218	0.3542	0.4432
60	0.1650	0.2108	0.2500	0.2948	0.3248	0.4079
70	0.1528	0.1954	0.2319	0.2737	0.3017	0.3798
80	0.1430	0.1829	0.2172	0.2565	0.2830	0.3568
90	0.1348	0.1726	0.2050	0.2422	0.2673	0.3375
100	0.1279	0.1638	0.1946	0.2301	0.2540	0.3211
150	0.1045	0.1339	0.1593	0.1886	0.2084	0.2643
300	0.0740	0.0948	0.1129	0.1338	0.1480	0.1884
500	0.0573	0.0735	0.0875	0.1038	0.1149	0.1464
1000	0.0405	0.0520	0.0619	0.0735	0.0813	0.1038