Pan African University
Institute of Water
and Energy Sciences

PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

[WATER ENGINEERING]

Presented by

HALIME Abdoulaye Affadine

WATER RESOURCES MODELING IN A CONTEXT OF CLIMATE CHANGE IN CÔTE D'IVOIRE

Defended on 21/09/2020 Before the Following Committee:

Chair	Sameh Kantoush	Dr.	University of Kyoto, Japan
Supervisor	Karima BENHATTAB	Dr.	University of Oran, Algeria
Co. Supervisor	Jean-Emmanuel PATUREL	Dr./HDR	HSM (UM, CNRS, IRD), France
External Examiner	Derdour Abdessamad	Dr.	CU_Naama
Internal Examiner	Ziani Cherif Chewki	Prof.	PAUWES, Tlemcen, Algeria

CERTIFICATION AND APPROVAL

WATER RESOURCES MODELING IN A CONTEXT OF CLIMATE CHANGE IN CÔTE D’IVOIRE

Submitted by:

<u>HALIME Abdoulaye Affadine</u>		<u>09/08/2020</u>
Name of Student	**Signature**	**Date**

This thesis was submitted with the approval of the thesis supervisors:

<u>Dr. Karima BENHATTAB</u>		<u>09/08/2020</u>
Name of Supervisor	**Signature**	**Date**
<u>Dr. Jean-Emmanuel PATUREL</u>		<u>09/08/2020</u>
Name of Supervisor	**Signature**	**Date**

PAN AFRICAN UNIVERSITY

STATEMENT OF THE AUTHOR

By my signature below, I, **HALIME Abdoulaye Affadine**, declare that this thesis is my work. I have followed all ethical principles of scholarship in the preparation, data collection, data analysis, and completion of this thesis. I have given all scholarly matter recognition through accurate citations and references. I affirm that I have cited and referenced all sources used in this document. I have made every effort to avoid plagiarism.

I submit this document in partial fulfilment of the requirement for a degree from Pan African University. This document is available from the PAU Library to borrowers under the rules of the library. I declare that I have not submitted this document to any other institution for the award of an academic degree, diploma, or certificate.

Scholars may use brief quotations from this thesis or dissertation without special permission if they make an accurate and complete acknowledgment of the source. The dean of the academic unit may grant permission for extended quotations or reproduction of this document. In all other instances, however, the author must grant permission.

HALIME Abdoulaye Affadine	____________	21/09/2020
Name of Student	**Signature**	**Date**

DEDICATION

This dissertation is dedicated to:

- My beloved and sweetie mother **AMINA Ahmat Barka**, who always takes care of me, who supported me throughout my studies until the completion of this dissertation. Thank you "**Cherie coco**" for your sacrifices and love, thank you for having been the bedrock on which we were built.

- My beloved father **ABDOULAYE Affadine**, who has never failed to support me and for the wise advice he has provided me during my entire academic studies. Thank you for this education dad.

- My beloved brothers and sisters (**Hafiz, Habiba, Madina, Ismail, Baina, Hawa, Hamat, Fatimé-Zara, Abdel-Rassoul, Ahmat, Laila, Brahim**) for their affection and support. Your good attitude and successful career are my source of motivation and inspiration.

ACKNOWLEDGEMENT

I would like to thank the African Union for granting me the scholarship and financial support to study my Masters' Degree at PAUWES in Tlemcen, Algeria.

I would like to express my sincere gratitude to my supervisor **Dr**. **Karima BENHATTAB** for her encouragement, motivation and advice since the beginning of the project. You have also provided me unfailing support which allowed me to secure an internship at HydroSciences Montpellier. I cannot find the right words to express all my gratitude, but may you find, beyond these lines, the expression of my deep respect and admiration.

My warmest gratitude extends to my co-supervisor **Dr**. **Jean-Emmanuel PATUREL**, who, despite his multiple responsibilities, has accepted to supervise this work. There are no words to qualify his help. Despite the difficult situation due to Covid-19, he was available to make telework, read my documents and make relevant suggestions. Through his scientific rigorous approach, I benefited a lot from his pertinent comments, and his critical analysis. You inspired me and helped me to better understand all the concepts.

I also wish to thank HydroSciences Montpellier and IRD for providing rainfall and streamflow data.

I would like to thank **Prof. Benedict Mutua**, my professor of Hydrology and Hydraulics at PAUWES for the quality of the lectures received and for his words of encouragement during this period of research. Now is doable!

I would like to extend my sincere appreciation to my family **5th Cohort PAUWES** for the friendly atmosphere, the spirit of peace and happiness they have created around us during our journey in Algeria. You are amazing! Together we built Africa and make it the better continent!

Finally, may all those who have contributed to one or another way to the successful completion of this work find here the expression of my deepest gratitude.

ABSTRACT

During the period 1961-2000, Côte d'Ivoire, has been challenged by irregular rainfall distribution leading to frequent extreme events (drought and floods), resulting in agriculture losses. This study is sought to analyze spatial and temporal variability of rainfall time series by using a statistical model based on R software and their packages and its impact in rainfall/runoff modeling. The methodological approach consisted to analyze the annual rainfall variability from the twenty-seven meteorological stations by the use of statistical test (Mann Kendall and Pettitt), to characterize the daily rainfall extreme events and the meteorological drought by the use of climate's indices based on ETCCDI and the Standardized Precipitation Index (SPI) with RClimDex and RDIT software's. Indeed, in order to know the best suitable period for the calibration and validation, to analyze the transferability of the parameters and to prevent natural hazards, a hydrological model GR2M at monthly scale (Mouelhi 2006 version) was performed at five stations (Semien, Soubré, Mbasso, Nzienoa and Bada).

It was found that the North and South portion of Côte d'Ivoire present a significant decreasing trend. Pettitt test showed a break in the time series around 1969-1977 and 1977-1982. The result of SPI-6 and SPI-12 indicated that most of frequent drought in term of severity, duration and frequency was observed after 1980. An alteration of dry and wet conditions was showed after1990. Based on the results of the climates indices, the annual total precipitation (PRCPTOT) is highly decreasing while the Consecutive Wet Days (CWD) and the monthly maximum 1-day precipitation (R*1day) showed an increasing trend. The results obtain shows that the GR2M performs well in **Semien** as the average Nash criterion is greater than **0.75**.

<u>Keywords</u>: Côte d'Ivoire, extreme events, GR2M, climates indices, Hydrological modeling, climate variability.

RESUME

Au cours de la période 1961-2000, la Côte d'Ivoire a été confrontée à une répartition irrégulière des précipitations qui a entraîné de fréquents événements extrêmes (sécheresses et inondations), engendrant des pertes agricoles. Cette étude vise à analyser la variabilité spatiale et temporelle des séries chronologiques des précipitations et son impact sur la modélisation pluie-débit en utilisant un modèle statistique basé sur le logiciel R. L'approche méthodologique a consisté à analyser la variabilité annuelle des précipitations des vingt-sept stations météorologiques par l'utilisation de tests statistiques (Mann Kendall et Pettitt), à caractériser les événements des extrêmes pluviométriques et la sécheresse agricole, météorologique et hydrologique par l'utilisation des indices climatiques basés sur l'ETCCDI et l'indice de précipitation standardisé (SPI) avec les logiciels RClimDex et RDIT. En effet, afin de connaître la période la plus appropriée pour la calibration et la validation, d'analyser la transférabilité des paramètres et de prévenir les risques naturels, un modèle hydrologique GR2M à l'échelle mensuelle (version Mouelhi 2006) a été réalisé sur cinq stations (Semien, Soubré, Mbasso, Nzienoa et Bada).

Il a été constaté que le Nord et le Sud de la Côte d'Ivoire présentent une tendance à la baisse significative. Le test de Pettitt a montré une rupture dans les séries chronologiques autour de 1969-1977 et 1977-1982. Les résultats des SPI-6 et SPI-12 indiquent que la plupart des sécheresses en termes de sévérité, de durée et de fréquence ont été observées après 1980. Une altération des conditions sèches et humides a été observée après 1990. D'après les résultats des indices climatiques, les précipitations totales annuelles (PRCPTOT) sont en forte diminution, tandis que les jours humides consécutifs (CWD) et les précipitations mensuelles maximales sur 1 jour (R*1jour) ont montré une tendance à la hausse. Les résultats obtenus montrent que le modèle GR2M se comporte bien à Semien avec un critère de Nash (Q) supérieur à 0,75.

Mots clés : Côte d'Ivoire, variabilité climatique, modélisation hydrologique, GR2M, indices climatiques, événements extrêmes.

ABREVIATIONS AND ACRONYMS

AU: African Union

CEMAGREF : Centre d'Etudes du Mécanisme Agricole, du Génie Rural, des Eaux et Forêts

DEM: Digital Elevation Model

GDP: Growth Domestic Product

HSM : HydroSciences Montpellier

INRAE : Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement

IPCC: Intergovernmental Panel on Climate Change

IRD : Institut de Recherche pour le Développement (formerly ORSTOM)

IRSTEA : Institut national de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture (formerly CEMAGREF and nowadays INRAE)

ITCZ : Inter-Tropical Convergence Zone

MRC : Mekong River Commission

NSE : Nash-Sutcliffe Criterion

ORSTOM : Office de la Recherche Scientifique et Technique Outre-mer

PNCC : Programme National Changement Climatique de la Côte d'Ivoire

RDIT : Rainfall Drought Indices Tool

SIEREM : Système d'Information sur les Ressources en Eau et leur Modélisation

SPI: Standardized Precipitation Index

UNDP: United Nations Development Program

WDB: World Development Bank

WMO: World Meteorological Organization

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1 INTRODUCTION

Climate change is a global issue that affects many countries around the world (IPCC, 2013). Indeed, there is a high likelihood that developing countries will be more vulnerable to climate change than developed countries, and there is a medium likelihood that climate change would exacerbate income inequalities between and within countries (Fankhauser et al., 2001).

However, Sub-Saharan Africa is considered the most vulnerable to climate change impacts because of its high dependence on agriculture and natural resources, warmer baseline climates, increasing temperature, low precipitation, and limited adaptive capacity (Hassan & Nhemachena, 2008). The most significant impact on climate change has been the long-term reduction in rainfall in the semi-arid regions of Africa. Thus, West Africa has experienced a decrease in annual rainfall since 1970 (Goula Bi et al., 2010).

Apart from his humid equatorial climate, Côte d'Ivoire has been experiencing different types of disaster that are increasing in intensity, duration, and severity. In the past twenty years, seasonal droughts and flash floods have been the most frequent causing damages in agriculture production, social-economic activities and water resources (PNCC, 2015).

According to the IPPC glossary, extreme events are described to be the occurrence of climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (IPCC, 2012). Even so, significant research has been done on climate variability in Côte d'Ivoire by the ICCARE program, (Servat et al., 1998), and other researchers (Goula Bi et al., 2010) but research on extreme rainfall events characteristics remained quite limited over the extreme Southern and Northern portions of the country. In this fact, trend analysis in rainfall time series, and climates, the indices-based calculation is crucial to mobilizing, planning water resources, management, and monitoring extreme events.

Nevertheless, extreme events such as droughts and floods can be difficult to predict for a long-term period (Yuan et al., 2016). Then it is crucial to strengthen our capacities to adapt to the adverse effects of climate change, in order to manage effective solutions to future extreme events. Although, accurate and thorough assessments of the climate properties are required, it is possible to characterize it despite the underlying difficulty of understanding extreme conditions. Characterizing extreme events requires long-term data onto precipitation, temperature, evapotranspiration, and soil moisture. Among these parameters, rainfall is a key parameter for monitoring meteorological droughts and rainfall extremes (Li et al., 2015). Some studies have recommended the use of SPI (Standardized Precipitation Index) with long-term monthly rainfall data onto forecasting future droughts or wet events (De Sherbinin et al., 2015; Forsythe et al., 2012; Jongman et al., 2015). The main objective of this study is to analyze spatial and temporal variability of rainfall conditions and its impact in rainfall/runoff modelling in Côte d'Ivoire, over a period (1961-2000) by using a statistical model based on R software and their packages.

1.1 Problem statement

Nowadays, extreme events are the major challenges that humanity faces. Indeed, Côte d'Ivoire is a country based on rain-fed agriculture and it has a strong dependence on river flow for the power generation and fisheries for its economy (Soro et al., 2017). However, the spatial and temporal variability of the climate in the country resulted in a significant impact on the quantity and frequency of rainfall, which have often led to the decline of agricultural production. With reduced rainfall distribution, high temperatures, ever-increasing population, varying weather patterns, high rates of deforestation, coastal erosion, the country has become more vulnerable to droughts and floods. In its National Program for Climate Change (PNCC, 2015), the Government of Côte d'Ivoire argues that the impacts of climate change are multisectoral and affect various sectors such as: agriculture, water resources, public health, coastal resources, energy, and the environment.

Despite its vulnerability to climate change, few studies have been conducted to analyze the spatial and temporal distribution of the rainfall in order to characterize the extreme events conditions in the Southern and Northern part of the country. Despite that, inadequate knowledge on extremes events can be an obstacle to meet efficiently the National strategic plan which is fundamental for sustainable water resources management.

For example, we can mention the floods of the 11 th May and 19th June 2018 in Abidjan. These floods caused losses of human life, as well as an enormous damage to crops (UNDP, 2019).

Even though these torrential rains are exceptional, the damage recorded reminds us of their magnitude and urges us to take decisions to deal with it. Thus, there is a high need to study extreme event characteristics at regional and national scales in different regions.

1.2 Objectives of the study

1.2.1 Main objective

The overall objective of this study is to analyze spatial and temporal variability of extreme rainfall condition and its impact in rainfall/runoff modeling in Côte d'Ivoire.

1.2.2 Specific objectives

- To perform statistical analysis of time series using R software.
- To determine and characterize the indices of rainfall extremes for 40 years.
- To model the hydrological regime of the catchments using GR2M.

1.3 Research Questions

- How the extreme climates have evolved in Côte d'Ivoire?
- How to assess the different rainfall extreme indices?
- How the climate change/variability impact the rainfall/runoff relationship in a conceptual model?

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Definition of extreme events

According the Intergovernmental Panel on Climate Change glossary (IPCC, 2012) and World Meteorological Organization (WMO, 2018), extreme events are defined as the occurrence of a climate variable value above (or below) a threshold value near the upper (or lower) ends of the observed values range. Even so, the Mekong River Commission (MRC, 2013) also defined extreme events as the rare climate event within its statistical reference distribution at a particular place. This includes, for example, heat waves, cold waves, heavy rains, periods of drought and flooding, and severe storms. Indeed, it emphasizes that the definition of term "rare" vary, but an extreme event would normally be as rare as or rarer than the 10th or 90th percentile. However, (McPhillips et al., 2018) highlighted that extreme events definition is various and depend on the field in which the term is in use. Some scientists have taken in consideration the term impacts in their definition of extreme events, but others are focusing more on the magnitude. Despite these definitions, (Stephenson, 2008) said "extreme events are generally easy to recognize but difficult to define due to the no unique meaning of the word "**extreme**".

In addition, extreme events have a variety of different attributes such as:

- rate of occurrence (probability per unit time)
- magnitude (intensity)
- temporal duration and timing
- spatial scale (footprint)
- multivariate dependencies

Due to that fact, understanding the processes that lead to creation of extreme event are a key factor. Therefore, the report done by the National Weather Service (at the time called U.S. Weather Bureau) on rainfall intensity and frequency (U.S. Weather Service, 1959) was the earliest scientific document found using the term "extreme event". The extreme events origin was started from some disciplines such as meteorology, climatology, geology, mathematics, and focussed only on the magnitude of an event. The social scientists were quickly adopted and thus extended to include an event's impacts in its definition.

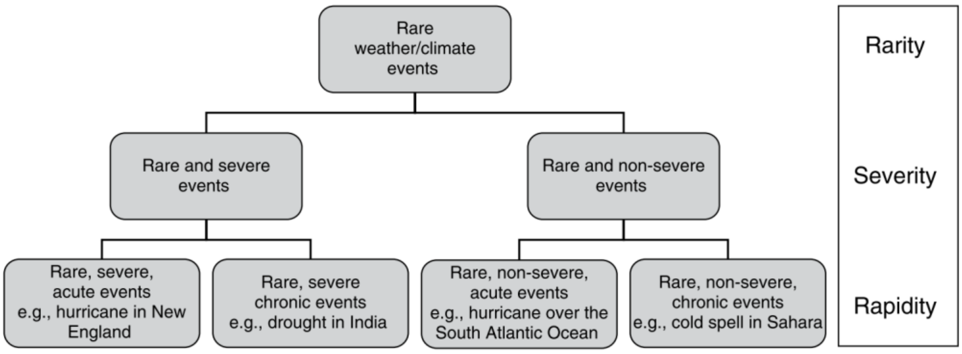


Figure 1:Simple taxonomy of extreme weather and climate events

(David B. Stephenson, 2008)

2.2 Extreme events characterization indices

The agricultural sector has always been one of the key drivers of the Ivorian economy with over 25 percent of the Country's Gross Domestic Product (GDP) generates from agriculture (World Bank, 2019). Due to the high dependency of the country on agriculture, farmers are more vulnerable to droughts and floods (PNCC, 2015). According to the report of (PNCC, 2015), droughts, coastal erosion, rainfall irregularities, rapid urbanization, floodings, environmental degradation have increased the vulnerability of the population to natural disasters, reduced their yield productivity and the resources on which they live. However, climate changes further intensifies the severity and frequency of disasters in the country (Noufé et al., 2015).

The study conducted by Goula Bi et al. (2010) showed that West Africa has experienced a decrease in annual rainfall since 1970 and these rainfalls have decreased on average from 20 to 40%. Dekoula et al (2019) have highlighted the significant rainfall patterns resulted in reduction of cumulative annual rainfall in Cote d'Ivoire. Indeed, the National Meteorological Directorate DMN (PNCC, 2015) have showed also an increase of 0.5°C on annual average temperature since 1980. Out of these studies, knowledge of extreme events is vital in the planning water resources and monitoring meteorological and agricultural droughts. Therefore, extreme events characterization is performed by climate indices. Climate indices are powerful tools to describe the state of climate system (WMO, 2015). The Expert Team on Climate Change Detection and Indices (ETCCDI, http://www.clivar.org/organization/etccdi/etccdi.php) compute 27 indices through Rclimdex software. Among those indices, some are based on drought indices Consecutive Dry Days

(CDD); others on Precipitation indices Consecutive Wet Days (CWD), Monthly Maximum 1-day (R*1 day), Monthly maximum consecutive 5-days (R*5day), Simple Precipitation Intensity Index (SDII), Annual total precipitation (PRCPTOT) etc.; Cold indices; Heat indices and Multi-element indices. The Rain based Drought Indices Tool (RDIT) software based on Agricultural and Meteorological Software is another important tool for analyzing drought characteristics. It performs Standardized Precipitation Index (SPI), deciles index (DI), Percent of Normal Index (PN), Rainfall Anomaly Index (RAI), Effective drought index (EDI), China-Z index (CZI), modified CZI (MCZI) and Z-Score Index (ZSI).

SPI is used to characterize meteorological droughts and it’s suitable for different time scales (3, 6, 12 and 48 months). SPI for a short period (3, 6 months) refers to meteorological and agricultural drought while the longer periods (12, 48 etc.) apply for hydrological and socio-economic drought (WMO, 2012).

Summarily, the study of the climates indices is vital for the understanding of climate change on several sectors such as agriculture.

2.3 Previous study on extreme events

The studies done by (Kouakou et al.,2007; Mahé et al., 2001 and Nicholson et al., 2000) showed that West Africa has experienced a decrease in annual rainfall since 1970. This resulted in a reduction of stream flow and wetlands leading to severe droughts (Niasse et al., 2004). Houghton et al (2001) highlighted that extreme climatic events should become more frequent with climate change. These events have a negative impact on most West African country due to their high dependency on agriculture, animal husbandry and natural resources (Hassan & Nhemachena, 2008; Soro et al., 2017). Indeed, Soro et al (2014) conducted a study on the occurrence of meteorological drought characterization at diverse timescales on the North-Western part of Côte d’Ivoire. In this study, three stations with longer rainfall series were analyzed and the standardized Precipitation Index (SPI) was determined. The results indicated that the most significant drought in term of intensity, duration and frequency occurred during the period 1970-1999 and regardless of the time scale considered. These dry spells have reached their peaks in 1983 and 1987 with extremely severe droughts type. The stations of Tengrela and Boundiali are the most affected by droughts. In addition, results showed that the time long-term scale seems more appropriate to describe with more details the dry spells.

Another study conducted by Soro et al (2010) on trends in annual maximum intensities of hourly rainfall events in Côte d’Ivoire. In this work, annual maximum intensity series from eight stations, over the period from 1957 to 2001 were analyzed using the Mann Kendall and the linear regression tests. Results showed a significant decrease in the annual maximum rainfall of short duration. The annual maximum rainfall of 2 h, 3 h and 4 h durations were most affected. However, the decrease in annual maximum intensities did not occur everywhere in Côte d'Ivoire.

Soro et al (2016) carried out a study that aimed to examine the trends in extreme rainfall from 10 sub-daily time series and 44 daily time series in Côte d’Ivoire. The methodology used was based on the conversion of rainfall data into indices. Globally, six indices were used for daily extreme rainfall (*CWD10, CWD20, R1day (annual), R1day (monthly), R10 mm and R20 mm*) and one index for sub-daily extreme rainfall. Then, two statistical tests for trend detection were used to evaluate the possible trend in these precipitation data. The first is a Mann-Kendall non-parametric trend test, used to evaluate the existence of monotonic trends. The second is a linear regression method, based on a parametric approach to trend detection. The results showed very few statistically significant decreasing trends at the sub-daily and daily timescales. Some decreasing trends in extreme rainfall events were located in the South and Southeast.

(Goula et al., 2012) has done a study on trends and changes in daily extreme rainfalls in Côte d’Ivoire. The aim of this study was to detect possible trends or changes in the statistical properties (mean) of daily extreme rainfall records using local and regional statistical tests. 44 rainfall time series for the period 1942–2002 were analyzed. To detect these changes, the indices characterizing the maximum annual daily rainfall (PJmaxan), the annual number of daily rainfall greater than 50 mm (NJsup50) and the contribution of daily rainfall greater than 50 mm in annual rainfall (R(PJsup50/Pan)) were defined. The result of the time series analysis did not show a change generalized for mean. However, by dividing Côte d’Ivoire into climatically homogeneous regions, downward trends were observed in regions I (North) and IV (South East).

In Burkina Faso, (Kabore et al., 2017) conducted a study on climate variability characterization in the North Central region. Daily rainfall data for eleven stations for the period 1961-2015 were used. The methodology used in this study was to perform the Standardized Precipitation Indices (SPI). Statistical tests were applied to analyze the rainfall variability and the ETCCDI (Expert Team on Climate Change Detection Indices) indices were used to characterize extreme rainfalls. The results showed that the period 1961-2015 is characterized by a wet and dry period with a decrease trend in the annual precipitation. Since

1960 a change in rainfall pattern is observed in this area. This change led to a decrease of rainfall amount and daily rainfall regime. This is significant in the Sahelian zone than the sudano-sahelian zone. The result showed also a strong spatial disparity in the rainy days distribution during these decades in this zone. The number of rainy days increased in five localities while decreasing is observed in the six other localities. The frequency of extremes rainfall is increased since the end of 1990 and 2000. The rainfall recovery in the North Central region is strongly linked to high intensity rainfall events. Despite this evolution, drought is recurrent in Kongoussi since 2005 and Bouroum in 2010.

A study on analysis of extreme rainfall events over Tordzie Watershed in the Volta Region of Ghana was carried out by (Nyatuame & Agodzo, 2017). The Standardized Precipitation Index (SPI) was employed to assess the extreme rainfall event on Tordzie watershed using precipitation data from 1984-2014. The SPI on the time scale of 3, 6, 9 and 12 months were determined using **DrinC** software. The drought was characterized in magnitude, duration, intensity, frequency at the time scales of SPI-3, SPI-6, SPI-9 and SPI-12. The Results indicated that the middle reaches (Kpetoe) of the watershed experienced less severe drought condition compared to the lower reaches (Tordzinu). Mann-Kendall (MK) test and Sen's slope revealed general increasing drought trends but insignificant at 95% confidence interval. The Sen's slope indicated change in magnitude of 0.016 mm/year, 0.012 mm/year, 0.026 mm/year and 0.016 mm/year respectively at the mentioned time scales at 95% confidence interval at the Tordzinu and that of Kpetoe were 0.006 mm/year, 0.009 mm/year, 0.014 mm/year and 0.003 mm/year. These changes could have an impact on agriculture and water resources management and lead to food insecurity among smallholder farmers.

(Ologunorisa & Tersoo, 2006) conducted a study on the changing rainfall pattern and its implication for flood frequency in Makurdi, northern Nigeria. Therefore, data on extreme daily rainfall and evapotranspiration were collected for analysis. The annual rainfall was analyzed for trends using spearman rank correlation coefficient. The annual rainfall variability was analyzed using standardized rainfall anomaly index while recurrence intervals were analyzed using Gumbell Extreme probability theory. The results of the analysis showed a significant continuous downward trend in annual rainfall amounts. Then, the period between 1996 and 2001 witnessed the highest frequencies of extreme rainfall events and flood frequencies.

(Babatolu et al., 2014) carried out a study on the variability and trends of daily heavy rainfall events over Niger River Basin (Development Authority Area in Nigeria) by using

Standardized Anomaly Index and Spearman Rank Correlation Coefficient. The study used daily rainfall records in eight stations for a period of 70 years. The results showed a significant temporal variability on interannual and decadal timescales, which was observed in the frequency of heavy rainfall events and annual heavy rainfall amount. The amount of annual heavy rainfall and the frequency of heavy rainfall events demonstrated no significant increase or decrease trend. However, more recent data that record from 1981 have shown an increasing trend.

(Lawan et al., 2014) conducted a study in the framework of ANADIA Niger project (Climate Change Adaptation, Disaster Prevention and Agricultural Development for Food Security Project). This study aimed to characterize the climate at regional level in the region of Tillabery from the period 1981 to 2010 in order to understand the variability. The methodology used in this work was to determine climate indices (SPI, R95p, R99p, R20mm, etc.) by using excel and to analyze the indices. The results showed that the monthly mean SPI for the month of July displayed a meaningful trend, especially during the year 2000 when a significant cumulative deficit of rainfall was observed. It also emphasized the severe drought of 1984 in the region.

(Bodian, 2014) carried out a study on Senegal. The objective of this study was to analyze the recent trend of annual rainfall series of 22 stations cover the period from 1940 to 2013. The approach included the calculation of the Standardized Precipitation Index (SPI), trends and breaks detection in annual rainfall series by applying three methods ((Pettitt, Lee and Heghinian, Segmentation). The results showed that the standardized indices calculated from all stations, as well as from stations grouped according to three climatic regions (South-Sahelian, South-Sudanian and North-Sudanian) appointed two break dates (significant at 1 % according to Student's t test). The first break ranges out between 1967 and 1969, and the second one occurs between 1986 and 1998 according to Pettitt test. According to the method of Lee and Heghinian, and Segmentation, the second break occurred between 1992 and 2007. Indeed, the annual rainfalls remain lower than pre 1970.

(Hountondji et al., 2000) conducted a study on trends in extreme rainfall events in Benin (West Africa) for the period 1960-2000. Global dataset of derived indicators has been compiled to clarify whether the frequency and / or the severity of rainfall extremes changed during the 1960-2000 period in the Republic of Benin. A total of 21 stations time series were extracted from national climate archives and collated into the unique dataset. In this study, 12 indicators of extreme climatic events that are based on daily totals of precipitation were calculated. The six first indicators are the annual total precipitation (RTOT); the annual total of wet days with daily rainfall >= 1mm (Rd); the simple day intensity index (SDII); the annual maximum rainfall recorded during 1, 5 and 30 days (Rx1d), (Rx5d) and (Rx30d). The other six indices are based on the 95th 99 th percentiles (R95p, R99p, R95pSUM, R99pSUM, R95pTOT, R99pTOT). The results showed that only the annual total precipitation, the annual total of wet days and the annual maximum rainfall recorded during 30 days present a significant decreasing trend while the other nine rainfall indicators appear to remain stable.

(Bedoum et al., 2013) carried out a study on the Republic of Chad. The aim of this study was to show the presence of climate variability. The method used was based on the Standardized precipitation index (SPI), Pettit test, bayésienne of Lee and Heghinian method over the period 1960-2008. The results of SPI on the time series showed a high interannual fluctuation. The period 1960-1970 was identified as a rainy season while the period 1971-1993 as a dry season. An increase of rainfall happened during the period 1994-2008. This long-term deficit over 22 years (1971-1993) resulted on a significant decrease in annual rainfall ranging between 2 and 37%. The percentage of this rainfall deficit was relatively high compared to the same type of studies undertaken in West and Central Africa (which showed 7%). Moreover, the result of Pettitt test showed a break around the period of 1969-1970 and 1980-1982. The results showed also a severe dryness over the period 1980-1990 which lead to enormous damage in agriculture and breeding’s.

Another study conducted by (Bedoum et al., 2017) on the evolution of climate extremes indices from 1960 to 2008 in Chad. An analysis of climate trends indices for the period of 1960-2008 was performed by RClimDex software. The results showed that almost all rainfall trends are decreasing, as in Central and Northern Africa. A significant decrease of 0.85 mm per decade in (R99p) was observed. However, the number of consecutive dry days (CDD) showed a slightly upward trend of 0.5 day per decade. All the Temperature indices are positive except for the frequencies of very hot days (TX90p) and very cold nights (TN10p), which decrease significantly by 0.39% day per year per decade, as in Central Africa. The sequences of hot or cold days decrease about 1% per year per decade.

A study conducted by (Elhagrsy et al., 2018) in Egypt on climate change effect on annual rainfall characteristics showed that the variability of annual rainfall characteristics in Egypt was investigated based on a statistical analysis of historical rainfall records at 31 stations. It also argued that, recently Egypt have become more vulnerable to extreme rainfall events which lead to some cases of severe flash floods. Therefore, parametric test (Pearson) and the non-parametric tests (Mann-Kendall and Spearman's Rho) were applied on four precipitation indices: Annual Maximum Precipitation (AMP), Annual Total Precipitation (ATP) and Annual Number of Rainy Days (ANRD). The results showed that about 29% of the analyzed stations present significant decreasing trends.

(Drouiche et al., 2019) conducted a study on Mitidja watershed (North of Algeria). The purpose of this research was to characterize this annual variability and determine its spatial extension in the watershed through the study of rainfall data measured at eight stations. An analysis of the long rainfall series of the Hamiz dam reference station (1905-2010) using several statistical tests was performed (Mann-Kendall, Pettitt, Buishand U, and the Bayesian procedure of Lee and Heghinian). The results showed that the period of drought occurred between 1973 and 2001 caused a decrease in annual rainfall varying between 16% and 24 % in the watershed. After this period of drought, a wet period settled in the Mitidja, causing annual rainfall to increase by 31.4%, particularly at the Réghaïa station.

(Hallouz et al., 2019) conducted a study on the analysis of the spatial and temporal variability of precipitation, temperature, and discharge in the wadi Mina watershed (Northwest of Algeria) for the period 1979-2013. Six indices related to temperatures and five to precipitations were performed using RClimDex. The results showed that the application of the non-parametric test of Kruskal-Wallis on rainfall indices has revealed that the total annual rainfall and the maximum number of consecutive rainy days showed a large spatial variability. The number of days with high discharge decreases from the north to the south of the basin. The Mann-Kendall test showed a decreasing trend on the total annual rainfall. Therefore, the maximal and minimal temperatures, consecutive dry days, rainfall intensities and extremely rainy days increased significantly. Finally, the decrease in rainfall and the increase in temperature have generated a decline in water resources.

(Khomsi et al., 2015) conducted a study on trends in rainfall and temperature extremes in Morocco. The aim of this work was to analyze the frequency and the trends of temperature and rainfall extreme events in two contrasted Moroccan regions (the Tensift in the semi-arid South, and the Bouregreg in the sub-humid North), during the second half of the 20th century. This study considered long time series of daily extreme temperatures and rainfall, recorded in the stations of Marrakech and Safi for the Tensift region, and Kasba-Tadla and Rabat-Sale for the Bouregreg region. Data from four other stations (Tanger, Fes, Agadir and Ouarzazate) and from other regions, were added. Extreme indices were defined by using as thresholds the 1st, 5th, 90th, 95th, and 99th percentiles as they are recommended by STARDEX (Statistical and

Regional dynamical Downscaling of Extremes for European regions) and the ETCCDI (Expert Team on Climate Change Detection and Indices). The Results showed upward trends in maximum and minimum temperatures of both regions and no generalized trends in rainfall amounts. Changes in cold events were larger than those for warm events, and the numbers of very cold events decrease significantly in the whole studied area. The southern region was the most affected with changes in the temperature regime. Most of the trends founded in heavy rainfall events are positive with weak magnitudes even though no statistically significant generalized trends were identified during both seasons.

The observation of all these studies highlighted that the period after 1970 was the driest period at regional level. However, an increasing of rainfall was observed around the year 1990. We noticed that the annual total precipitation and the maximum consecutive wet days were decreasing.

2.4 Previous studies on hydrological modeling

Hydrological rain-flow modelling has become an essential tool for flood forecasting. To improve the quality of forecasts, hydrologists have proposed numerous data assimilation approaches. Hydrologists have therefore adopted different approaches and developed many different models. It should be noted that a large number of models are similar and share the same concepts. These models are classified on the basis of their approach (ranging from reductionism to elementary physical processes to empiricism) and their complexity: there are the physics-based distributed models, conceptual models and empirical models. These models are also distinguished by their spatial resolution by considering the catchment area as a spatial unit. Nowadays, the simulation of the transformation of rainfall into flow at the scale of the catchment area by mathematical models has been expanding rapidly since the beginning of the 1960s due to the increase in computing capacity (Belaroui & Haouchine, 2017). There are many existing models today, including global empirical conceptual models that represent the link between rainfall and flow through various reservoir arrangements. (Belaroui & Haouchine, 2017) have carried out hydrological modelling studies of the catchment area of Oued el Harrach upstream using global models (Rain-Discharge), in the work the GR2M and GR4j models were used to determine the characteristics of the latter for the catchment area of Oued el Harrach upstream having a surface area of 388 km2 and used them in the characterization of surface water flows and in the evolution of water resources based on climatic data (rainfall and evapotranspiration). The results obtained indicate that the quality criteria of the models with annual, monthly and daily time step are satisfactory.

2.5 Relevance of the study

In view of the extreme events studies characteristics limitations in the current context of climate change and the increased vulnerability of farmers, this research is vital for Côte d’Ivoire, as it will characterize extreme event. This will help water resources engineers to model, simulate with R software and contribute to tackle farmer’s vulnerability to rainfall hazards. This study will guide decision makers to know which extreme event is more frequent in term of frequency, intensity and duration in Côte d’Ivoire and on which region the mitigation measures may be emphasized to reduce the risk. Furthermore, the results will be also used by some stakeholders in the region for the strategic plan. Indeed, one of the aspirations of the African Union's (AU) Agenda 2063 also states: "Dynamic cities, urban and rural peri-urban municipalities equipped with sanitation infrastructure and preparedness for natural disaster reduction". This work based on climate variability from 1961-2000 will contribute to the achievement of this aspiration.

CHAPTER THREE

3 METHODOLOGY

3.1 Description of the study Area

3.1.1 Location

Côte d’Ivoire is a country located in West Africa on the edge of the Gulf of Guinea. It covers an area of 322,462 Km² and it lies within a latitude of 4°30’- 10°30’N and a longitude of 2°30’-8°30 W (PNCC, 2015). It comprises of fourteen districts (**Figure 2**) namely: **Abidjan, Yamoussoukro, Bas-Sassandra, Comoé, Denguelé, Goh-Djiboua, Lacs, Lagunes, Montagnes, Sassandra-Marahoue, Savanes, Vallee du Bandama, Woroba, Zanzan**, with Abidjan as Capital. It is bordered on the North by Mali and Burkina Faso, on the West by Guinea and Liberia, on the East by Ghana and in the South by Atlantic Ocean. Our study focuses on all the country due to the spatial representation of the stations that we have.

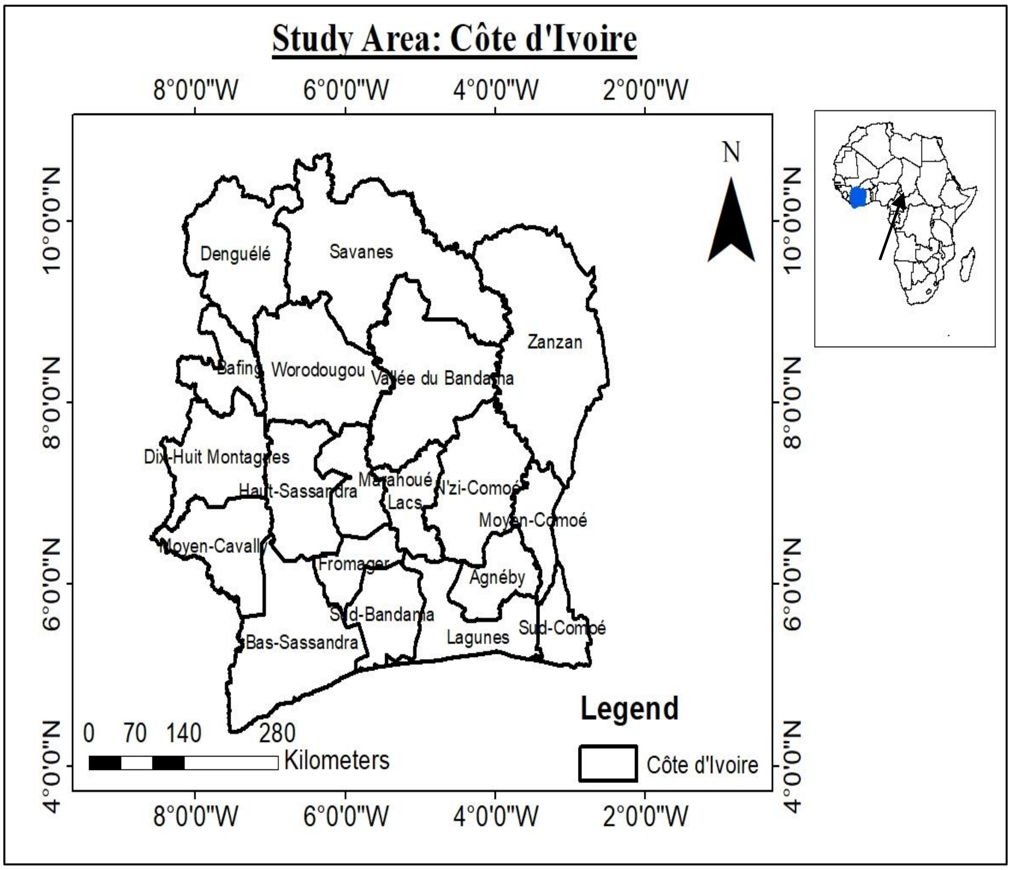


Figure 2: Study Area Côte d’Ivoire

3.1.2 Topography

The relief of Côte d'Ivoire is generally flat, varying from about **500 m** on the north to less than **0 m** in the south. Highlands that rise to **1000 m** above the mean sea level are in the northwestern parts of the country (Nimba and Man hills).

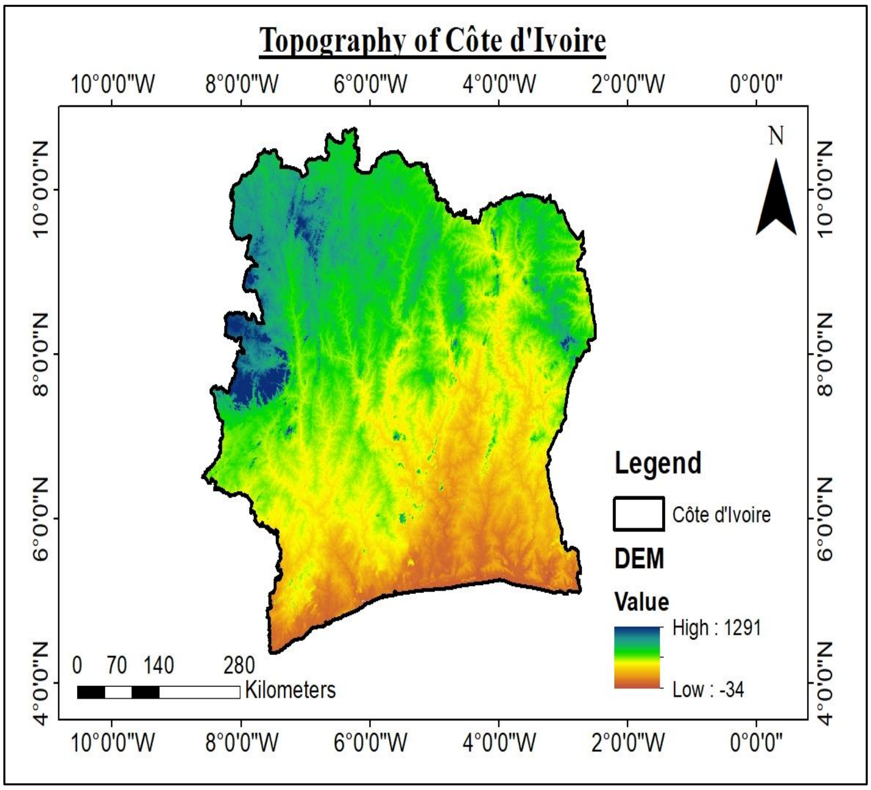


Figure 3: Topography of Côte d'Ivoire

3.1.3 Climate

The movement of the **Inter-Tropical Convergence Zone (ITCZ)** is a factor which influence the seasonal climate of Côte d'Ivoire (Eldin, 1971; Kouadio et al., 2011). According to (Jourda et al., 2015) , Côte d'Ivoire is divided into three climatic zones, North, Central and South (**Figure 4**) . The Central zone includes the mountainous area found on the West (Jourda et al., 2015; UNICEF, 2009).

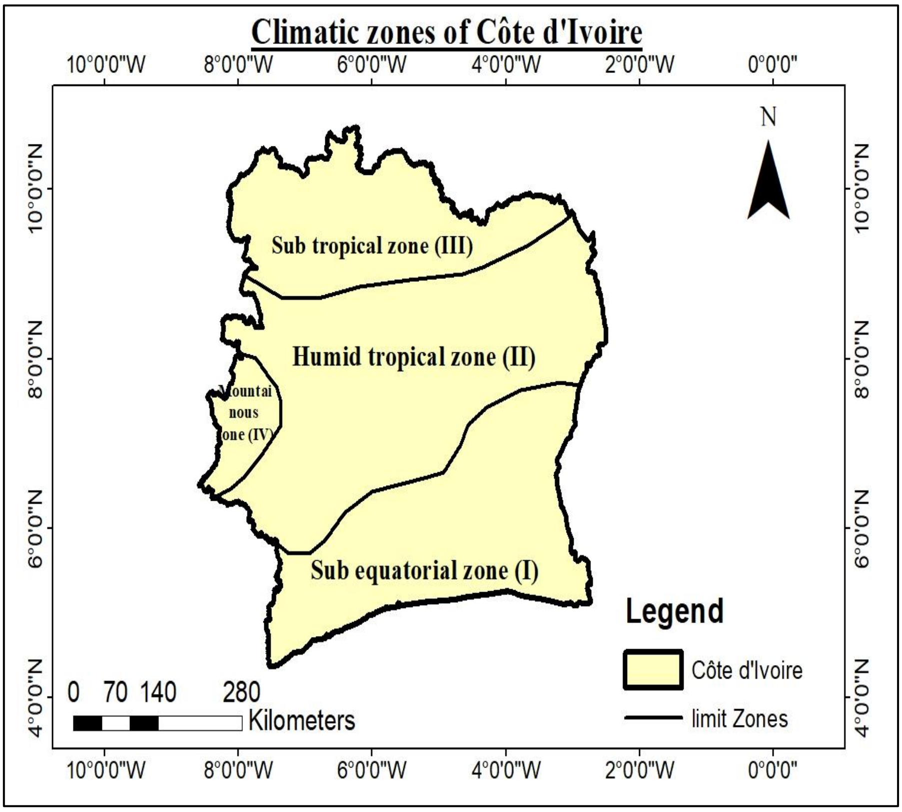


Figure 4: Climate zones of Côte d'Ivoire (Goula et al, 2006)

<u>The South zone</u>

The south zone **(sub-equatorial** or Attien climate) is characterized by four seasons (PNCC, 2015) with low temperatures range from 25 °C to 30 °C, high humidity 80 to 90 % , an average annual rainfall greater than 1800mm and covers the southern parts of the country **Figure 5**:

- a long dry season from December to March with few rainy days and characterized by high temperatures.
- a long rainy season from April to the mid of July.
- a short dry season from mid-July to the mid of September.
- a short rainy season from mid-September to November.

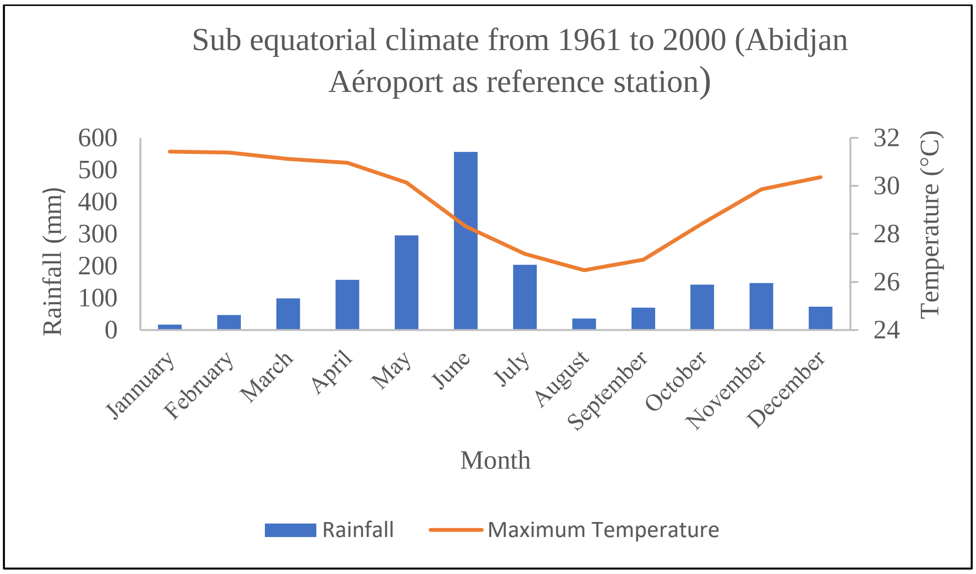


Figure 5: Average monthly rainfall and temperature of sub equatorial climate from 1961 to 2000

<u>The Central zone</u>

The Central zone (humid tropical or Baoulean climate) is the transition between the Sudanian zone on the North and the Sub equatorial zone in the South. It is characterized by four seasons (Kouadio et al., 2011; PNCC, 2015) **Figure 6**:

- a long dry season from November to February.
- a long rainy season from March to June.
- a short dry season from July to August.
- a short rainy season from September to October.

This humid tropical climate is closer to the sub-equatorial climate by the abundance of rainfall. The average annual rainfall ranges between 1200 and 1600 mm, temperature (14°C-33°C).

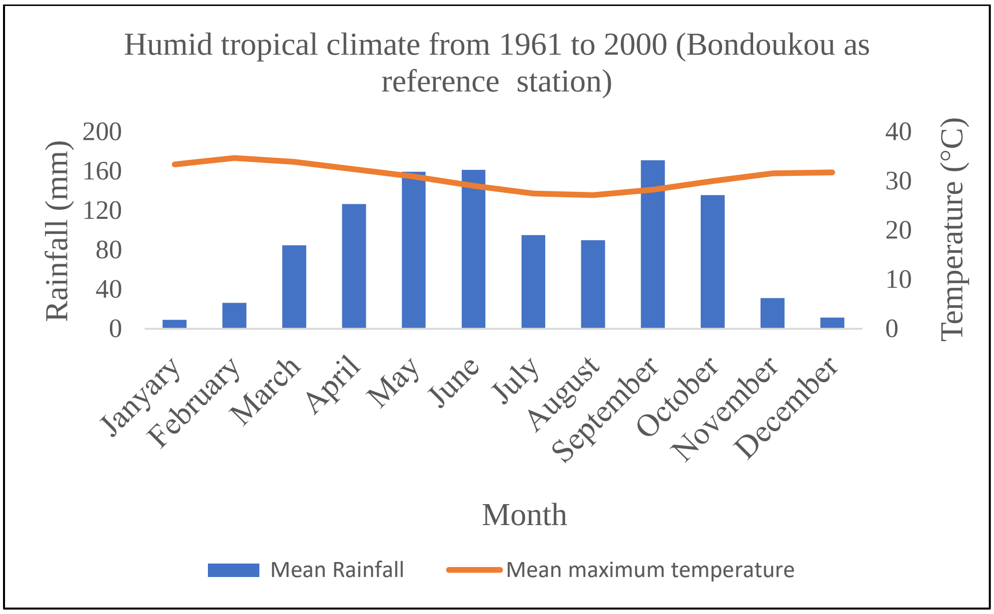


Figure 6: Average monthly rainfall and temperature of humid tropical

<u>The Northern zone</u>

The Northern Zone (**Subtropical** or Sudanian climate) is characterized by a rainfall distribution with two seasons with an average annual rainfall less than 1200 mm (Kouadio et al., 2011; PNCC, 2015) **Figure 7**:

- a rainy season from June to October.
- a dry season from November to May.

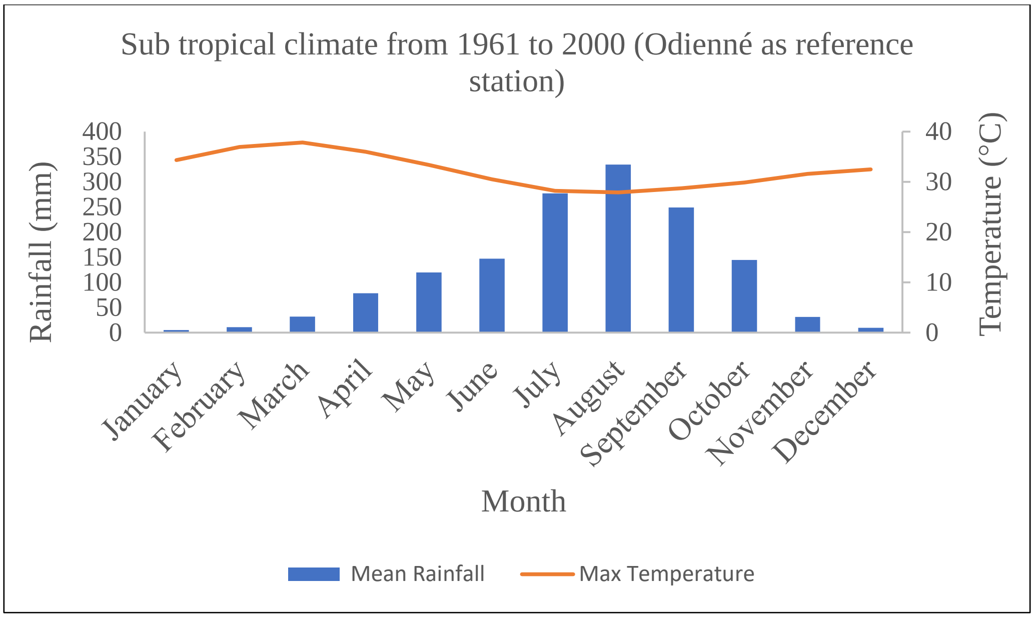


Figure 7: Average monthly rainfall of sub-tropical climate from 1961 to 2000

3.1.4 Geology

According to (Jourda et al., 2015), geological formations of Côte d'Ivoire are divided between two chronological distinct entities. Firstly, there is a sedimentary basin ranging from secondary to quaternary finite age in the South. Secondly, a Precambrian basement which constitutes the major part of the country (97.5%). This basement belongs to the Man dorsal of the West African craton. It is subdivided into two parts of unequal areas, separated by the Sassandra Fault zone (an Archean and a Proterozoic domain).

3.1.5 Hydrology of Côte d'Ivoire

The hydrological network of Côte d'Ivoire comprises of four main rivers (Eldin, 1971; UNICEF, 2009) which are, from west to east:

- Cavally: with a length of 700 km takes its source in Guinea, north of Mount Nimba, with an altitude of approximately 600 m. The watershed covers an area of 28,800 km² which is 15,000 km² in Côte d'Ivoire;
- Sassandra: taking its source in Fouta Djalon in Guinea, drains in Côte d'Ivoire a basin of 75,000 km² with a length of 650 km;
- Bandama: It is completely within the interior limits of Côte d’Ivoire formed by the White Bandama, the Red Bandama or Marahoué and the N'zi. It covers a total catchment area of 97, 000 km² with a length of 1,050 km;
- Comoé: The longest river in Côte d'Ivoire which takes its source from Banfora (Burkina Faso) and drains a catchment area of 78,000 km² with a length of 1,160 km.

Apart from these rivers, there are small coastal rivers from West to East, which are:

Tabou, San-Pédro, **Niouniourou, Boubo** (5,100 km²), **Agnéby** (8,900 km² and 200 Km of length), **Mé** (4,300 km² for a length of 140 km) and **Bia** which gets its source in Ghana.

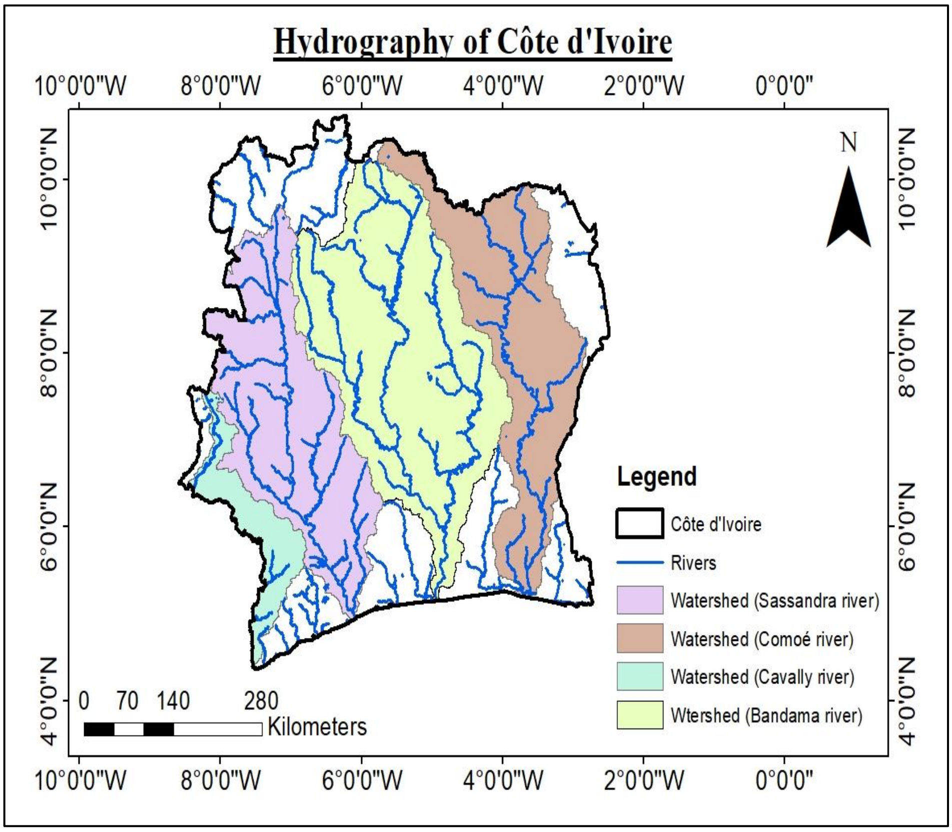


Figure 8: Hydrography of Côte d'Ivoire

3.2 Data collection

The Hydro-meteorological data is a critical input for this research. Indeed, rainfall data were obtained from **Environmental Information System on Water Resources and their Modeling** (*Systeme d'Information Environmentale sur les Ressources en Eau et leur Modélisation* (SIEREM http://www.hydrosciences.fr/SIEREM/, Boyer et al., 2006) database and other database collected by ORSTOM/IRD researchers with a daily time step. These daily rainfalls are collected from twenty-seven meteorological stations (Abidjan-Aéroport, Adiaké, Bondoukou, Dimbokro, Gagnoa, Man aero, Sassandra, Tabou, Toulepleu, Soubré, Guiglo, Oumé, Beoumi, Bouna, Mankono, Adzope, Lakota , Tai, Odienné, Dembasso, Kouto, Madiani, Manignan, Ouangolodogou, Sanhala, Tengrela and Tiemé) from South to North and cover different period. The choice based on these stations (stations listed above) is due to the long time series observations with a low percentage of missing data. The stream flow and evapotranspiration data at monthly time step at five stations (Semien, Soubré, Mbasso, Bada and Nzienoa) were obtained from SIEREM database. The Digital Elevation Model (DEM) was downloaded from http://www.diva-gis.org/gdata.

3.2.1 Rainfall stations in Côte d'Ivoire

Côte d'Ivoire has several operational stations (rain gauge, agro climatic, etc.) for climatic data collection. Most rain gauge data stations located in the North have incomplete datasets ranging from rainfall, temperature, and relative humidity. This is due to the political issue that the Country faced during the periods (1993-1994 and 2000-2002).

The **Figure 9** and **Table 1** below shows respectively the spatial distribution and the summary of meteorological stations used in this study.

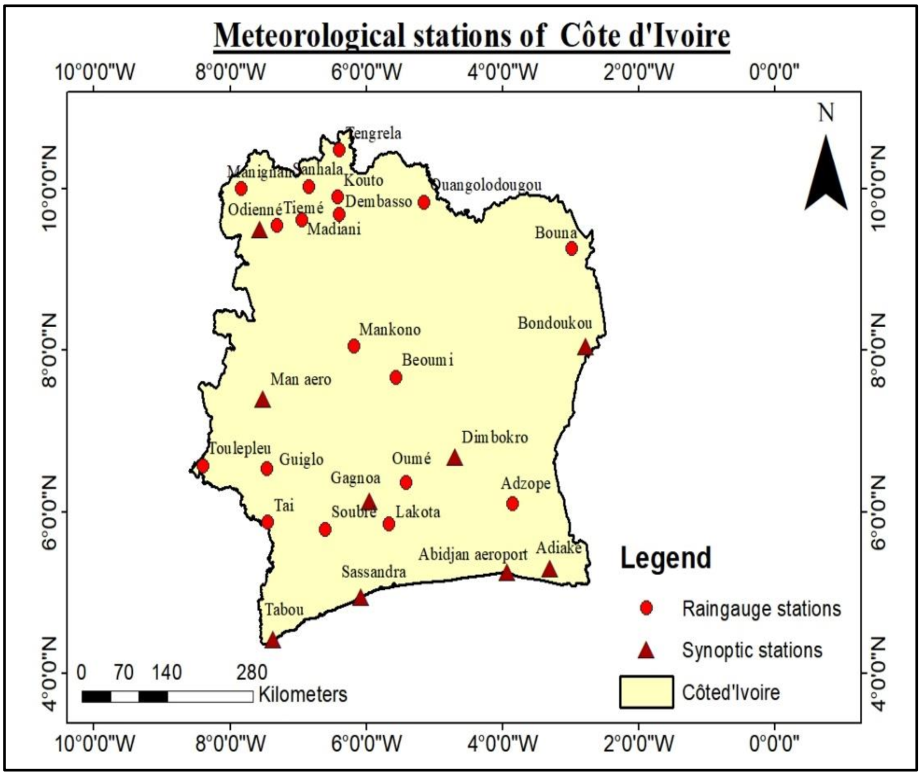


Figure 9: location of the mmeteorological stations in Côte d'Ivoire

Table 1: Meteorological stations in Côte d'Ivoire

Stations code	Stations Name	Coordinates (decimal degree)		Altitudes (m)	Period	(% NA)
		Latitudes	Longitudes			
1090000100C	Abidjan aéroport	5.25	-3.9333	8	1936-2000	6
1090001300C	Adiaké	5.3	-3.3	35	1944-2005	1
1090001900	Adzope	6.1	-3.85	125	1944-2000	2
1090003700	Beoumi	7.6667	-5.5667	223	1939-2000	2
1090004600	Bondoukou	8.05	-2.7833	371	1919-2000	16
1090006100	Bouna	9.2667	-2.9833	319	1920-2000	3
1090008800C	Dembasso	9.6833	-6.4	348	1961-2000	8
1090009100	Dimbokro	6.68	-4.7	92	1921-2000	1
1090010300	Gagnoa	6.1333	-5.95	205	1919-2000	3
1090011200	Guiglo	6.5333	-7.4667	217	1924-2000	5
1090012700C	Kouto	9.9	-6.4167	360	1961-2000	8
1090013000	Lakota	5.85	-5.6667	200	1945-2000	2
1090013900C	Madiani	9.6167	-6.95	516	1961-2000	6
1090014200	Man aero	7.4	-7.5167	340	1922-2000	0
1090014500C	Manignan	10	-7.8333	393	1950-2000	3
1090014800	Mankono	8.05	-6.1833	329	1937-2000	4
1090016000C	Odienné	9.5	-7.5667	432	1921-2002	3
1090016300C	Ouangolodougou	9.8333	-5.15	309	1950-2000	6
1090016900	Oumé	6.3667	-5.4167	207	1944-2000	1
1090017200	Sassandra	4.95	-6.0833	62	1922-2000	1
1090017900C	Sanhala	10.0333	-6.85	380	1961-1996	8
1090018100	Soubré	5.7833	-6.6	134	1940-2000	1
1090018400	Tabou	4.4167	-7.3667	20	1919-2000	4
1090019000	Tai	5.8667	-7.45	123	1924-2000	24
1090019300C	Tengrela	10.4833	-6.4	356	1953-2000	15
1090020100C	Tiemé	9.55	-7.3167	451	1961-1999	7
1090020800	Toulepleu	6.5667	-8.4	270	1924-2000	2

3.3 Data processing

In order to reconstitute the reference time series, SIEREM and other database collected by ORSTOM/IRD researchers in “txt “ format was used. This task was carried out by Excel 2016 and takes a lot of time to complete. After this process, R software was used to perform descriptive statistics for the time series. Indeed, the descriptive statistics allowed us to compare the two databases (SIEREM and ORSTOM/IRD), to see the gap between the datasets and then reconstitute the reference series. Once the reference series were obtained, statistical tests were applied at 5% significance level to identify the trend and break in time series. RClimDex and RDIT software was used to determine climates indices. The rainfall/runoff modeling was done by airGR package.

3.3.1 Statistical Analysis (Descriptive statistics)

The R software with its **Stats package** was used to calculate the descriptive statistics for annual rainfall data from 1961 to 2000. Indeed, statistical analyses were performed to assess any significant differences among the twenty-seven stations within the years. The statistical analysis was used to establish the measures of central tendency (mean, median, maximum, minimum, etc.); the measures of dispersion such as standard deviation as well as coefficient of variation and skewness and kurtosis coefficients.

3.3.2 Trend analysis methods

Tests for the detection of significant trends in climatologic time series can be classified as parametric and non-parametric methods. **Parametric trend** tests require data to be independent and normally distributed, while **non-parametric** trend tests require only that the data be independent. In this study, the lag-1 serial correlation coefficient (r1) was calculated using R software namely with **acf** function for each time series before applying the trend analysis test. Indeed, when the correlation coefficient is within the interval $\left\{\frac{(-1\mp1.645\sqrt{n}-2)}{n-1}\right\}$ so the time series are not significantly auto correlated and we carried out the **Mann-Kendall** test. Otherwise, **Modified Mann Kendall** can be used. In this study, after testing the serial autocorrelation, we notice that all the stations are not significantly autocorrelated, so Mann Kendall test was done.

3.3.3 Trend Analysis based on Mann Kendall Test

The Mann-Kendall test is a non-parametric technique which tests trends whether they are **decreasing**, **increasing**, or **none**. In this study, the annual rainfall time series were analysed using **Trend** package in R with mkttest (x) function. The Mann-Kendall test statistic S (Mann, 1945; Kendall, 1975) is calculated as follow:

$$\boldsymbol{S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n} Sign(xj - xi)\right]} \qquad \text{Equation 1}$$

Where n is the number of data, xi and xj are the data values in time series i and j (j > i), respectively and sign (xj−xi) is the sign function.

The sign function is given as:

$$\boldsymbol{Sign}(\boldsymbol{xj}-\boldsymbol{xi}) = \begin{cases} +\mathbf{1}, \boldsymbol{if}\ (\boldsymbol{xj}-\boldsymbol{xi}) > 0 \\ \mathbf{0}, \boldsymbol{if}\ (\boldsymbol{xj}-\boldsymbol{xi}) = \mathbf{0} \\ -\mathbf{1}, \boldsymbol{if}\ (\boldsymbol{xj}-\boldsymbol{xi}) < 0 \end{cases} \qquad \text{Equation 2}$$

In order to determine the level of the significant trend, the probability linked to S and the number of data n was established. The variance of the datasets Var(S) and the standard normal test statistic Zs is computed using the equations below (Azizzadeh & Javan, 2018):

$$\boldsymbol{Var}\ (\boldsymbol{S}) = \frac{\boldsymbol{n}(\boldsymbol{n}-\mathbf{1})(\mathbf{2}\boldsymbol{n}+\mathbf{5})-\sum_{i}^{m} \boldsymbol{ti}(\boldsymbol{ti}-\mathbf{1})(\mathbf{2}\boldsymbol{ti}+\mathbf{5})}{\mathbf{18}} \qquad \text{Equation 3}$$

$$\boldsymbol{Zs} = \begin{cases} \frac{(\boldsymbol{S}-\mathbf{1})}{\sqrt{\boldsymbol{Var}\ (\boldsymbol{S})}},\ \boldsymbol{if}\ \boldsymbol{S} > 0 \\ \mathbf{0},\ \boldsymbol{if}\ \boldsymbol{S} = \mathbf{0} \\ \frac{(\boldsymbol{S}+\mathbf{1})}{\sqrt{\boldsymbol{Var}\ (\boldsymbol{S})}}, \boldsymbol{if}\ \boldsymbol{S} < 0 \end{cases} \qquad \text{Equation 4}$$

where n is the number of data points, m is the number of tied groups and ti denotes the number of ties of extent i. Trend qualification as decreasing, increasing or no trend was based on whether **S < 0, S > 0 and S = 0** respectively. Indeed, the null hypothesis (H0) is: the stationarity hypothesis of the time series (no trend). The alternative hypothesis (H1) is: the non-stationarity hypothesis of the series. Testing trends is done at the specific α significance level. When $|\boldsymbol{Zs}| > \mathbf{Z_{1-\alpha/2}}$, the null hypothesis is rejected. $\mathbf{Z_{1-\alpha/2}}$, is obtained from the standard normal distribution table. In this study, significance level **α = 0.05** were used. At the **5%** significance level, the null hypothesis **(H0)** is rejected if $|\mathbf{Z_S}| > \mathbf{1.96}$.

3.3.4 Break analysis test (Pettitt test)

The Pettitt method (Pettitt 1979) is a rank-based nonparametric statistical test method which is derived from the Mann -Whitney test and useful for evaluating the occurrence of abrupt changes in climatic records (Jaiswal et al., 2015). In this study, Pettitt test was done on annual rainfall time series from 1961-2000 using R software particularly with trend package and pettitt.test(x) function. Indeed, the test was applied at 5% significance level. Once the p-value is less than the pre-assigned significance level (α =0.05), we reject the null hypothesis and an estimation of the date of the break is provided by K.

The null hypothesis **(H0)** as being that the T variables follow the same distribution F; the alternative hypothesis (H1) is that the distribution function F1(x) of the random variables from X1 to Xt is different from the distribution function F2(x) of the random variables from

X_{t+1} to X_T (i.e. at a time t there is a change of distribution). The variable that is to be tested is K_T, the maximum in absolute terms of the variable $U_{t,T}$ defined by (Mallakpour & Villarini, 2016) :

$$Dij = sgn(Xi - Xj) = \begin{cases} -1 \ (Xi - Xj) < 0 \\ 0 \ (Xi - Xj) = 0 \\ +1 \ (Xi - Xj) > 0 \end{cases} \qquad \text{Equation 5}$$

where Xi and Xj are random variables. The test statistic Ut,T depends on Dij as:

$$Ut, T = \sum_{i=1}^{t} \sum_{j=t+1}^{T} Dij \qquad \text{Equation 6}$$

The test statistic K and its probability of exceeding are given approximatively by:

$$KT = max1 \leq t < T|Ut, T|$$

$$\rho = \left(\frac{-6K_T^2}{T^2+T^3}\right) \qquad \text{Equation 7}$$

ArcGIS 10.4 was used in order to perform the interpolation method namely with **Kriging function**. This function was chosen among the others function due to the spatial representation of the studied stations. The results of the statistical test (Mann Kendall and Pettitt test) were represented spatial by using this interpolation technique listed above. However, the result of the climates indices from the ETCCDI was represent spatially with ArcGIS 10.4 but using classification tools specially **symbology** function. For the watersheds delineation the same software was used with the **Hydrology tools**.

3.3.5 Climate indices calculation

RClimDex 1.0 software was used to calculate climate indices in this study. Indeed**,** these indices are used to characterize the frequency, intensity of the extreme climates. Some of these indices were chosen from the list established by the Expert Team on Climate Change Detection and Indices (ETCCDI) but adapted to the study area. Annual and seasonal values of the indices were calculated on a daily basis for each time series for the period from 1961–2000 and a trend test were performed on the time series thus generated. Considering the way, the indices were computed, they may be divided into three categories (Zhang et al., 2018):

- Indices based on fixed thresholds: are those defined on a certain fixed threshold of recorded precipitation amount. Five fixed threshold defined indicators were used:

Heavy precipitation days (R10)

Daily precipitation amount on day i in period j. Count the number of days where: RR_{ij} (rainfall rate) ≥ 10mm.

Very heavy precipitation days (R20)

Daily precipitation amount on day i in period j. Count the number of days where: $RR_{ij} \geq$ 20mm

R_{nn} extremely heavy precipitation days

RR_{ij} is the daily precipitation amount on day i in period j; nn represents any reasonable daily precipitation value then, count the number of days where:

$RR_{ij} \geq$ nn mm

Consecutive dry days (CDD)

Daily precipitation amount on day i in period j. Count the largest number of consecutive days where: $RR_{ij} \leq 1$ mm

Consecutive wet days (CWD)

Daily precipitation amount on day i in period j. Count the largest number of consecutive days where: $RR_{ij} \geq 1$ mm

This category of indices is considered to define frequency since they express the changes in the annual number of days.

- Indices based on station-related thresholds are those indices defined on a percentile-based threshold. In this study, two indices were analyzed:

Very wet days (R95p)

RR_{wj} is the daily precipitation amount on a wet day where RR ≥ 1mm in period j and $RR_{nn}95$ be the 95^{th} percentile of precipitation on wet days in the 1961-2000 periods. If W represents the number of wet days in the period, then:

$R95pj = \sum_{w=1}^{W} RRwj$ where RRwj > RRnn95.

Extremely wet days (R99p)

RR_{wj} is the daily precipitation amount on a wet day where RR (rainfall rate) ≥ 1mm in period j and $RR_{nn}99$ be the 99^{th} percentile of precipitation on wet days in the 1961-2000 period. If W represents the number of wet days in the period, then:

$R99pj = \sum_{w=1}^{W} RRwj$ where RRwj > RRnn99.

- Non-threshold indices class includes those indices computed considering the absolute values recorded in the area yet not considering any threshold. They are focused on the monthly absolute values of the precipitation recordings. Four indices were considered:

Maximum 1-day precipitation amount (Rx1day)

RR be the daily precipitation amount on day i in period j. Then maximum 1-day values for period j are:

$R * 1dayj = \max(RRij)$

Maximum 5-days precipitation amount (Rx5days)

RR be the daily precipitation amount on day i in period j. Then maximum 5-day values for period j are:

$$R * 5dayj = \max(RRij)$$

Simple daily intensity index (SDII)

RR_{wj} (rainfall rate) be the daily precipitation amount on wet days, where RR ≥ 1mm in period j. If W represents number of wet days in j, then:

$SDII = \frac{\sum_{w=1}^{W} RRwj}{W}$ *Equation 5*

Annual total wet-day precipitation (PRCPTOT)

RR (rainfall rate) be the daily precipitation amount on day i in period j. If i represent the number of days in j, then

$$PRCPTOPj = \sum_{i=1}^{I} RRij$$

3.3.6 SPI

The Standardized Precipitation Index is the most popular drought index (Karabulut, 2015; Salehnia et al., 2017) and is a widely recognized index for characterizing meteorological droughts (Hayes et al., 2011; Salehnia et al., 2017). SPI is a useful index for drought monitoring at a given region. Calculation of the SPI is easier than other drought indices and it requires only precipitation as an input. (Mckee et al., 1993) defined SPI suitable for different timescales (1, 3, 6, 12, 24 and 48 months), and the output values ranged from −2.0 to 2.0. The Standardized Precipitation Index for a short period (3 and 6 months) refers to meteorological and agricultural drought, while the longest period (12, 24 etc.) refers to hydrological (surface and subsurface water deficit) and socio-economic drought (impact on supply and demand). However, monthly precipitation data for each time series were applied to determine the SPI at different time scales (6 and 12) months using RDIT software. The severity threshold in order to characterize the index (by duration, severity and frequency) was taken as **-0.99** in the RDIT software. Indeed, the table shows the SPI classification according to (Mckee et al., 1993).

Table 2: SPI classification

SPI value	Dry/Wet category
≥ 2	Extremely wet
1.5 to 1.99	Very wet
1 to 1.49	Moderately wet
_-0.99 to 0.99	Near to normal
-1 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
≤ -2	Extremely dry

Source (Mckee et al., 1993)

SPI is calculated by the equation below:

$$SPI = \frac{(\boldsymbol{Xij} - \boldsymbol{Xim})}{\boldsymbol{\sigma}} \quad \text{Equation 8}$$

Where $\boldsymbol{X}_{ij}$ is the seasonal rainfall at the station i and observation j, $\boldsymbol{X}_{im}$ is the long-term seasonal mean and **σ** is the standard deviation.

The SPI is calculated using a probability density function of the gamma distribution:

$$g(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} x^{\alpha-1} e^{-x/\beta} \; (x > 0) \quad \text{Equation 9}$$

Where $\tau(\alpha)$is the gamma function; x (mm) is the precipitation amount (x > 0); **α** is the shape parameter (α > 0); and **β** is the scale parameter (β > 0). These parameters are given by the following equations:

$$A = \ln(\bar{\bar{x}}) - \frac{\sum \ln(x)}{n} \quad \text{Equation 10}$$

$$\tau(\alpha) = \int_{0}^{\infty} y^{\alpha-1} e^{-y} dy \quad \text{Equation 11}$$

$$\alpha = \frac{1}{4A} * \left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad \text{Equation 12}$$

$$\beta = \frac{\bar{\bar{x}}}{\alpha} \quad \text{Equation 13}$$

The table 3 summarizes the indices used in this study

Table 3: Summary of all the indices used in this study

Indices	Definition	Unit
SPI	Standard Precipitation Index	Without unit
R10	Annual count of days when PRCP≥10m	day
R20	Annual count of days when PRCP≥ 20mm	day
R40	Annual count of days when PRCP≥ 40m	day
R50	Annual count of days when PRCP≥50m	Day
R*1day	Monthly maximum 1-day precipitation	mm
R*5day	Monthly maximum consecutive 5-day precipitation	mm
CDD	Maximum number of consecutive days with RR<1mm	day
CWD	Maximum number of consecutive days with RR ≥1mm	day
SDII	Annual total precipitation divided by the number of wet days (defined as PRCP ≥1mm) in the year	mm
R95p	(Annual total PRCP when RR > 95th percentile	mm
R 99p	Annual total PRCP when RR > 99th percentile	mm
PRCPTOT	(Annual total precipitation in wet days RR ≥1mm	mm

3.4 Software

The climates indices summarize in table 3 were determined by RDIT 1.0 and RclimDex 1.0 software respectively.

3.4.1 Description of R software

R is a free open source software and programming language for statistical computing, graphics, and data analysis. It was developed in 1995 by Ross Ihaka and Robert Gentleman in the Department of Statistics at the University of Auckland (Ross & Robert, 1996). A major advantage that R has over many other statistical packages is that it's flexible and powerful. It has also wide range of packages for data access, performing analysis, statistical modelling, linear regression, time series, GIS capabilities, analysing data and creating reports. Indeed, RStudio is an integrated development environment (IDE) that allows user to interact with R more readily. It has more drop-down menus, windows with multiple tabs, and many customization options (Source, Console, Environment and History, Files, Plots, Packages, and Help).

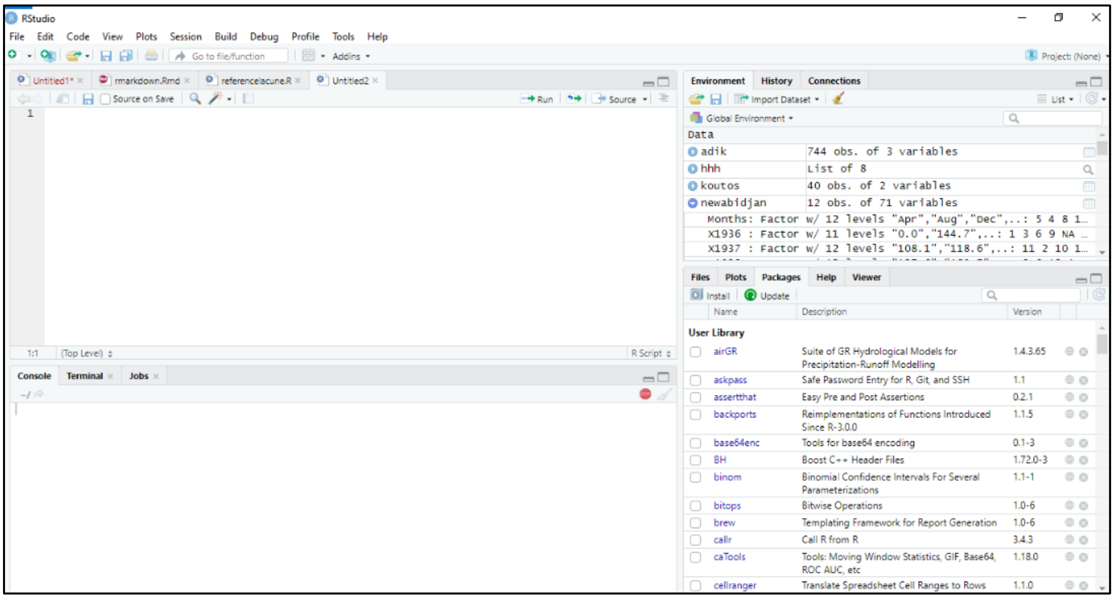


Figure 10: R studio interface

3.4.2 Description of RClimDex 1.0

RClimDex 1.0 is a software package based on **R**. It was developed and maintained by Xuebin Zhang and Yang Feng at the Climate Research Branch of Meteorological Service of Canada (Zhang et al., 2018). It is designed to provide a user-friendly interface to compute indices of climate extremes. It computes all 27 core indices recommended by the CLIVAR Expert Team for Climate Change Detection and Indices (ETCCDI) as well as some other temperature and precipitation indices with user defined thresholds. The main objective of constructing climate extremes indices is used for climate change monitoring and detection studies.

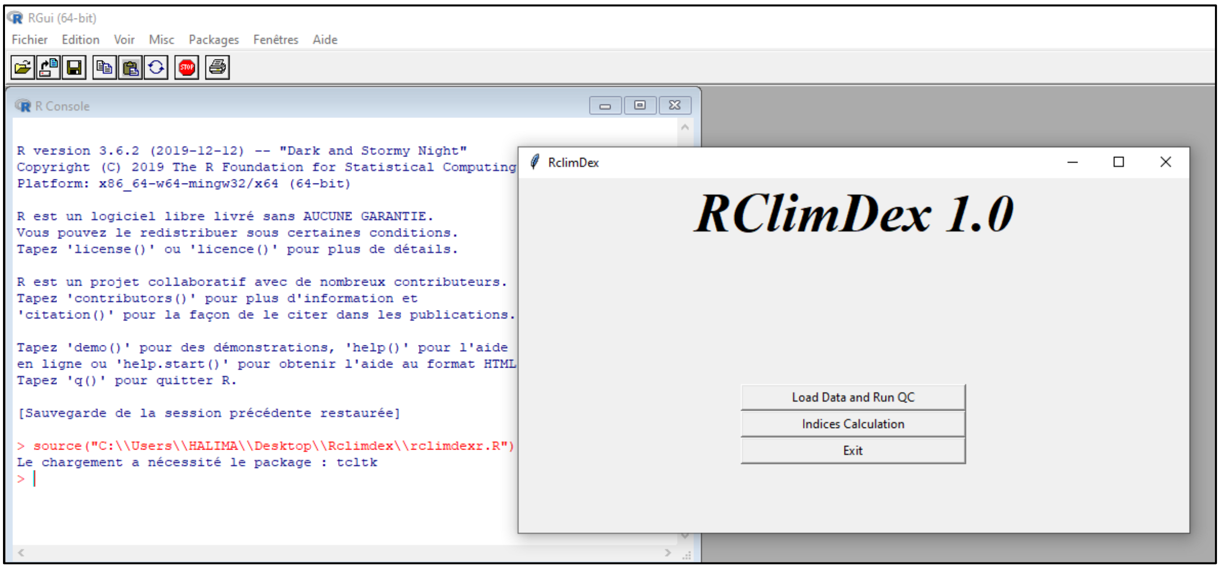


Figure 11: RClimDex interface

RClimDex requires a daily data as an input for the climate indices calculation. However, some steps are important before the computation of indices:

load data and run QC (quality control of the data), used in order to check for inaccurate data such as:

- daily negative precipitation,
- maximum daily temperature less or equal to minimum daily temperature,
- examinations for outliers data.

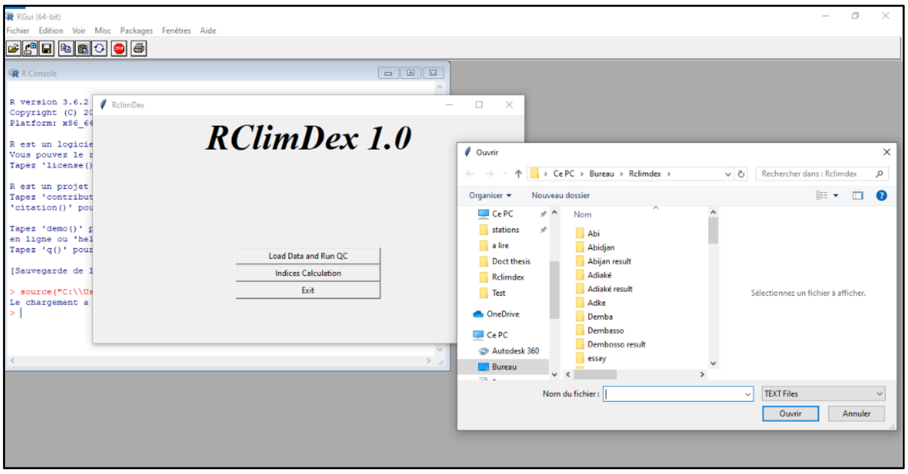


Figure 12: Load data in RClimDex

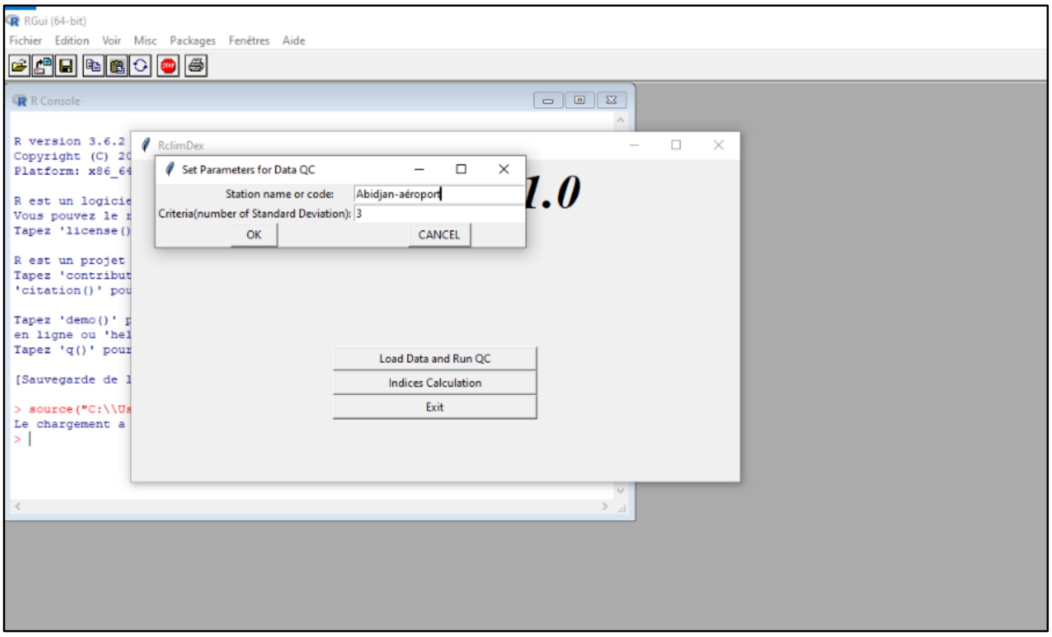


Figure 13: Quality control of data

- After quality control, RClimDex was used to compute climate indices from the daily data. Indeed, the twelve indices summarize in (Table 3) were calculated.

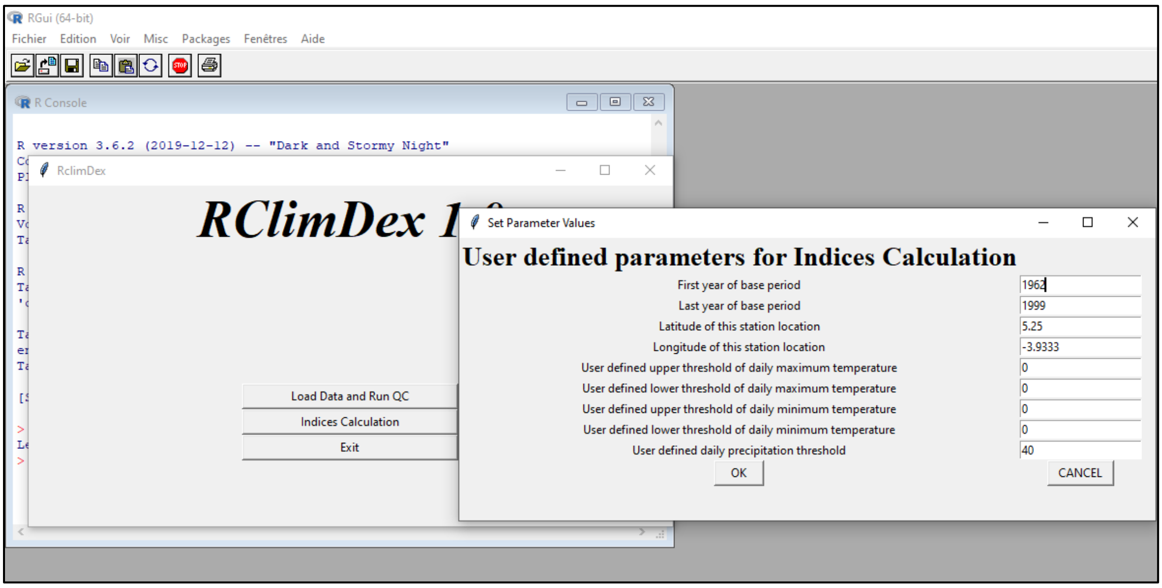


Figure 14: Parameters for Indices calculation

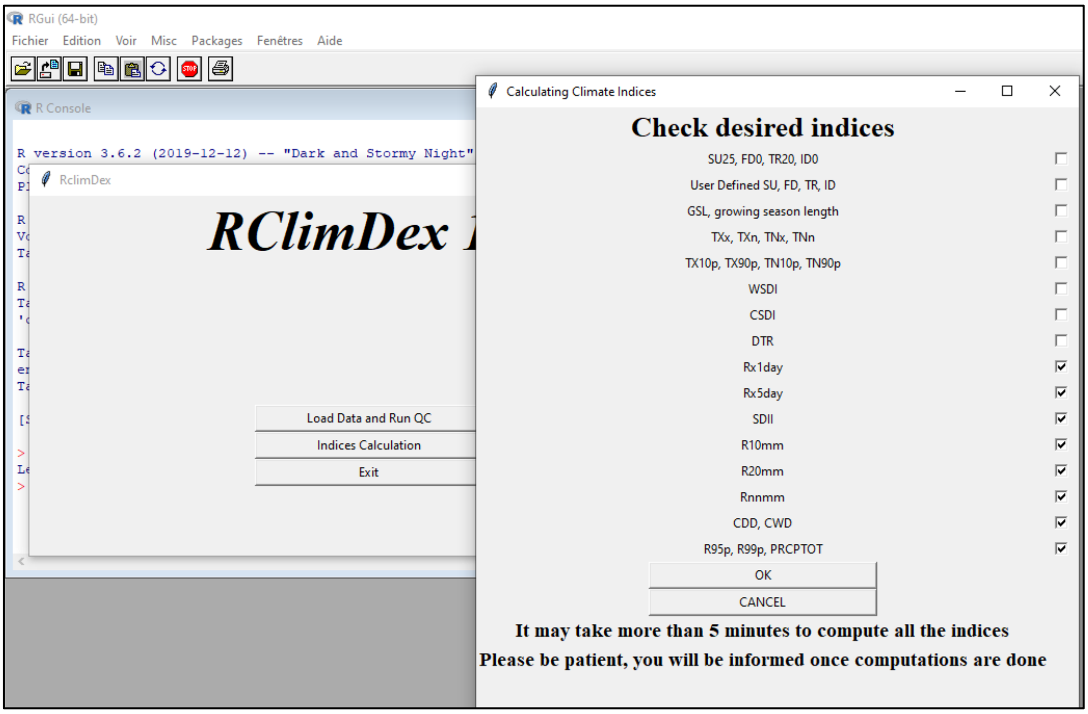


Figure 15: Indices calculation

3.4.3 Description of RDIT 1.0 software

RDIT (Rainfall Drought Indices tool) is a user-friendly software developed by Agriculture and meteorological software (AMS software for crop yield forecasting initiated by the Food and Agriculture Organization of the United Nations (https://agrimetsoft.com/)) for assessing and monitoring drought indices. This software performs and run eight indices of meteorological drought, plotting various graphs and estimates the severity, onset, and end of each period's drought. Input and output data are in excel format file. For input data, RDIT can assess the data and check blank cells and produce data for "null" cells. It calculates SPI (Standardized Precipitation Index), DI (deciles index), PN (Percent of Normal Index), RAI (Rainfall Anomaly Index), EDI (effective drought index), CZI (China-Z index), MCZI (modified CZI), ZSI (Z-Score Index) in form of yearly, seasonally, monthly and moving average for 3, 6, 9, 12, 18, 24, 48 months (https://agrimetsoft.com/rdit).

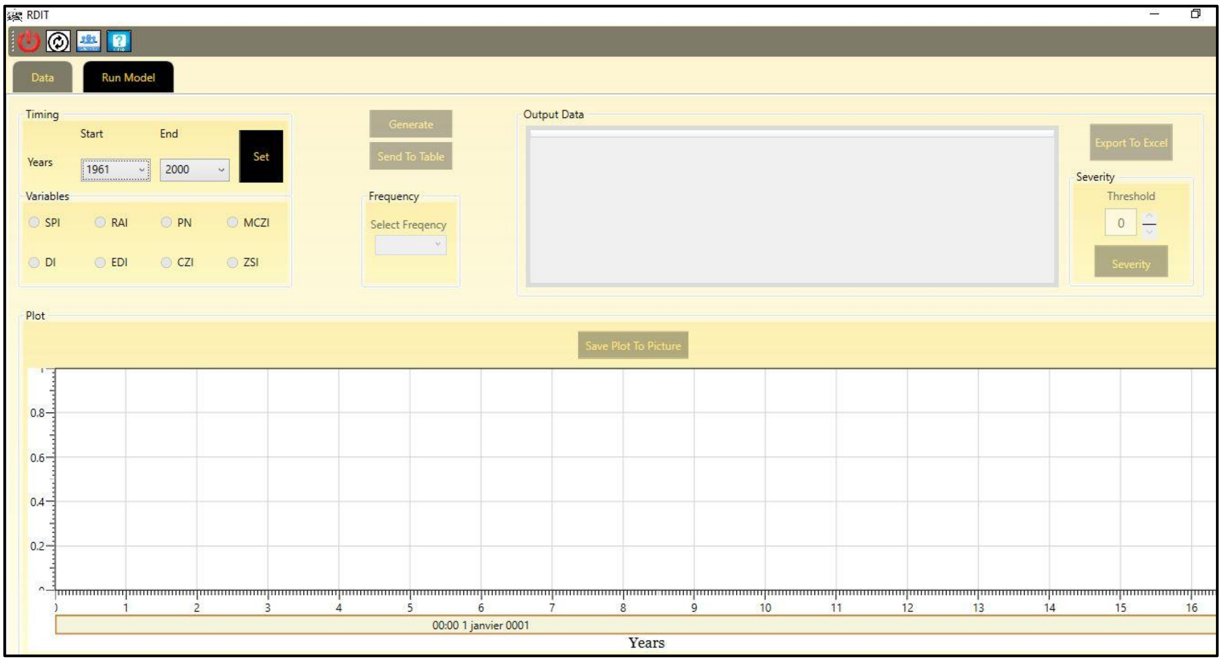


Figure 16: RDIT 1.0 interface

3.5 Modeling Approach

Hydrological models have emerged as essential tools to support water resources management and planning initiatives due to its ability to facilitate the understanding of physical processes operating within the catchment. Indeed, understanding and modeling hydrological behaviour is an important challenge for water resources management and investigation of extreme hydrological events, such as floods and droughts. Rainfall -Runoff modelling is an essential way to simulate the hydrological behaviour of the basin for a good evaluation in term of water production. Many approaches are actually in use. Two types of hydrologic models have been used in most applications: lumped-conceptual models and physically-based models (Ficchí, 2017).

In physically distributed models, deterministic relations issued from conservation laws of physics (mass conservation, momentum conservation) are solved to describe the hydrological processes generating flow and their interaction (Traore et al., 2014). Complexity of the equations to be solved and the huge amount of required data make these models of limited use. Conceptual rainfall-runoff models are often preferred by hydrologists. Conceptual models use simplified mathematical relationships to represent the hydrological processes in the catchment. These models have a simple structure, and their data requirements are lower. The application of these models is easy, what make them important for flood forecasting, water resources planning and management (Amir et al., 2013).

In this study, the **GR2M model** at monthly time step was used to describe the hydrological behaviour of the basins. This model has been developed by a French research Office the CEMAGREF (formerly IRSTEA and nowadays INRAE). It is widely use and required few inputs parameters and is very easy to calibrate and validate (Kabouya, 1990). GR2M model have been also widely employed in some study for predicting and simulating different hydrological processes: drought forecasting (Belarbi et al., 2017) and assessing hydrologic changes (Lyon et al., 2017).

3.5.1 Description of the study area

For the hydrological modelling five basins at **Soubré, Semien, Bada, Mbasso** and **Nzienoa** stations was used. Soubré and Semien are the sub basins of the Sassandra River and cover respectively an area of **62,173km²** and **29,900 km².** These sub basins lie between the altitude of **1,260 m** to **112 m** at Soubré and **1,067 m** to **241 m** at Semien. In these sub basins, agriculture is considered as the major activity. Indeed, the Sassandra basin is subdivided into four climatic zones according to rainfall patterns (Santé et al., 2019). The equatorial climate with four seasons and an average rainfall of 1,441.5mm; the equatorial climate of attenuated transition with two seasons and an interannual rainfall of 1,305.2 mm; the tropical transitional climate (characterized by interannual rainfall of 1,578.5 mm and the highest rainfall peak is recorded in September (279mm)).

However, the Sassandra basin is full of infrastructures such as hydroelectric (Buyo) and agricultural dams. These structures have a great impact on Soubré a station at downstream of the confluence of the Sassandra and Lobo rivers. **Nzienoa** and **Bada** are the sub basins of the Bandama river and covers respectively an area of **35, 340 Km²** and **23, 809 Km².** The relief of these sub basins varies from **575** m to **41 m** at Nzienoa and **564 m** to **201 m** at Bada. The Bandama River takes its source in the north of Côte d'Ivoire and flows generally in a north-south direction. Indeed, the Central part of the Bada basin is characterized by tropical climate while the southern part of Nzienoa is characterized by a subequatorial climate with mean rainfall above 1,600 mm/year (G. E Soro et al., 2017). **Mbasso** is the sub basin of the Comoé River and has an area of **70,500 Km².** Its relief varies from 704 m to 103m. Comoé River has its source in Banfora region (South of Burkina Faso) and flows into the Atlantic Ocean at Grand-Bassam in Côte d'Ivoire, following the North-South direction. The Comoé River is characterized by three climatic zones (tropical in the North, sub equatorial in the South and humid tropical in the Centre).

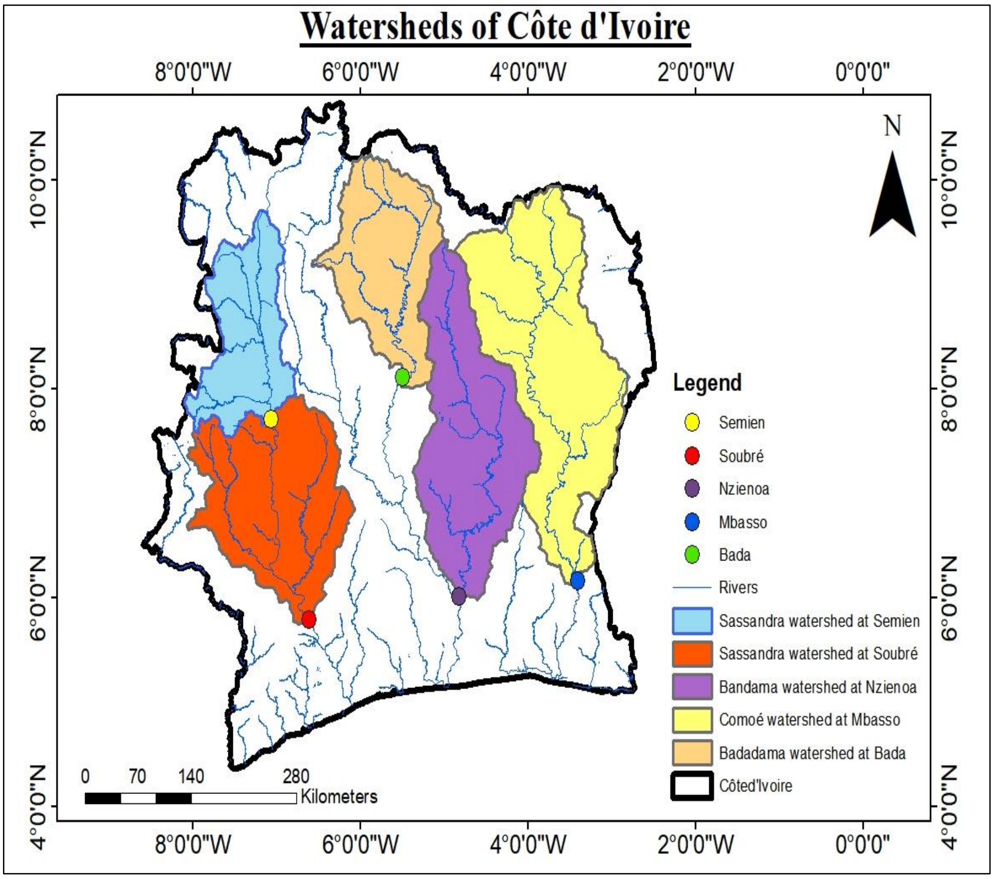


Figure 17: Presentation of the studied watersheds of Côte d'Ivoire

The **Table 4** below summarizes the description of the basins used in this study

Table 4: summary description of the of basins

Basin Name	Station Name	Station Code	Latitude (Decimal degree)	Longitude (Decimal degree)	River	Areas (km²)
Bandama	Bada	1090100103	8.1069	-5.4972	Bandama	23,809
	Nzienoa	1090102515	5.9964	-4.8125	Nzi	35,340
Comoé	Mbasso	1090400112	6.125	-3.48	Comoé	70,500
Sassandra	Semien	1092500109	7.7083	-7.0669	Sassandra	29,900
	Soubré	1092500115	5.7833	-6.6131	Sassandra	62,173

3.5.2 Description of the GR2M model

In this study, due to the available data, the use of conceptual hydrological model is more suitable. One of these models is the GR2M.

GR2M is an empirical lumped monthly hydrologic model with two parameters developed by the CEMAGREF (France) for the use in the field of water resources. This model has known several versions, proposed successively by (Kabouya 1990; Makhlouf 1994; Mouelhi 2003; Mouelhi et al., 2006). The version used in this study is that of Mouelhi et al. (2006) which appears the best performing. Indeed, the inputs of the model are monthly rainfall (P) and potential evapotranspiration (E) for a given month and output is monthly runoff at the outlet of the basin Q. Even so, the model working with two stores (**Figure 18**): a production store whose capacity is the parameter X1 and actual contents is S; and a routing store whose capacity is set to 60 mm and actual contents is R (Traore et al., 2014). A part Ps of rainfall (P) is directed to production store (equation 14), whose content becomes S' given by (equation 16). The excess part P1 is directed to the routing store (equation 15).

$$\boldsymbol{Ps} = \frac{\boldsymbol{X1} * \left\{1 - \left(\frac{S}{X1}\right)^2\right\} * \boldsymbol{tanh}\left(\frac{P}{X1}\right)}{1 + \left(\frac{S}{X1}\right) * \boldsymbol{tanh}\left(\frac{P}{X1}\right)}$$ Equation 14

$$P1 = P - Ps$$ Equation 15

$$\boldsymbol{S'} = \boldsymbol{S} + \boldsymbol{Ps}$$ Equation 16

To take account of the evapotranspiration in the production store, a part Es (equation 17) of E (is the mean potential evapotranspiration for a given calendar month) is extracted from this store, whose content is updated by (equation 18). This new content of production store loses a quantity P2 of water through Percolation (equation 19) given by:

$$Es = \frac{S * \left(2 - \frac{S'}{X1}\right) * tanh\left(\frac{E}{X1}\right)}{1 + \left(1 - \frac{S\prime}{X1}\right) * tanh\left(\frac{E}{X1}\right)} \qquad \text{Equation 17}$$

$$S" = S' - Es \qquad \text{Equation 18}$$

$$P2 = S" * \left\{1 - \left[1 + \left(\frac{S"}{X1}\right)^{1/3}\right]\right\} \qquad \text{Equation 19}$$

P2 is added to the routing store. Total water P3 input of the routing store is then given by (equation 20), and its content pass to R’ given by (equation 21). At this step, a fraction X2R’ of R’ is reserved for the routing store, and the difference F (equation 22) is taken away from the basin as groundwater exchange.

$$P3 = P1 + P2 \qquad \text{Equation 20}$$

$$R' = R + P3 \qquad \text{Equation 21}$$

$$F = (X2 - 1) * R' \qquad \text{Equation 22}$$

The level in the routing store becomes R” (equation 23). Then the output runoff Q is estimated by (equation 24)

$$R" = R' + F \qquad \text{Equation 23}$$

$$Q = \frac{(R")^2}{R" + 60} \qquad \text{Equation 24}$$

(X1) is the maximum capacity of the soil reservoir and (X2) is the exchange parameter in the underground “free water” reservoir.

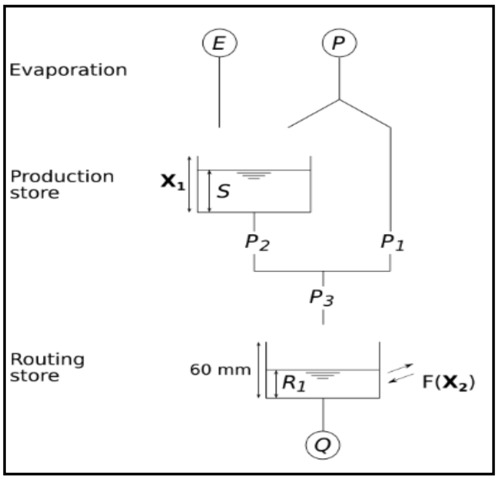


Figure 18: Structure of GR2M model (Mouelhi et al., 2006)

airGR is a package which brings into the R software the hydrological modelling tools used and developed at the Catchment Hydrology Research Group of INRAE (France). It is including the GR rainfall-runoff models, a snowmelt and accumulation model, CemaNeige. Each model core is coded in Fortran to ensure low computational time. The other package functions (i. e the calibration algorithm and the efficiency criteria calculation) are coded in R. The airGR package has been also designed to fulfill two major requirements: to facilitate the use by non-expert users and to allow flexibility regarding the addition of external criteria, models or calibration algorithms. airGR contains six hydrological models, one snowmelt and accumulation model (https://hydrogr.github.io/airGR/).

3.5.3 Model Calibration and validation

The successful application of a hydrologic watershed model depends on how well the model is calibrated (Traore et al., 2014). Indeed, calibration is required in any empirical model because it is the process of choosing best sets of model parameters (X1 and X2), by adjusting manually or automatically their numerical values. The calibrated model parameters should necessarily be validated. The validation of a model consists in verifying the reproducibility of the results by the calibrated parameters on a new period of data different from that in the period of the calibration.

The optimization criterion used to evaluate the model is the Nash-Sutcliffe criterion **(NSE)** (Nash and Sutcliffe, 1970), which is a dimensionless criterion for judging the goodness of fit and which facilitates the comparison of the fits of various watersheds whose flows are of different orders of magnitude. This criterion is calculated by (Knoben et al., 2019):

$$NSE(Q) = 1 - \frac{\sum_i^n (Q_{obsi} - Q_{cali})^2}{\sum_i^n (Q_{obsi} - \bar{Q}_{obs})^2} \qquad \text{Equation 25}$$

Where Q_{obsi} and Q_{cali} are respectively the monthly observed and simulated flows at time i and $\bar{Q}_{obs}$ the mean monthly flow.

NSE ranges between $-\infty$ and 1 (Mathevet et al., 2006), with NSE = 1 being the optimal value. A value of Nash equal to 0 or less than 0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. A value of Nash equal to 1 corresponds to a perfect model, which reproduces reality and show complete adequation between observed mean and simulated mean. Indeed, the table shows the performance rating classification of the NSE criterion for monthly time steps (D. N. Moriasi et al., 2007).

Table 5: Classification of NSE criterion (D. N. Moriasi et al., 2007)

Performance Rating	NSE
Very good	0.75 < NSE ≤1
Good	0.65 <NSE ≤ 0.75
Satisfactory	0.50 < NSE ≤ 0.65
Unsatisfactory	NSE ≤ 0.50

3.5.4 Methodology applies for the model

The model GR2M applied in this study use a monthly rainfall, evapotranspiration and stream flow data. All the inputs data listed above must be on the same unit **(mm)** and the rainfall and evapotranspiration time series should not contain any missing data (NA) in order to run the model. The inputs data should also be range in this order first column the **date** then followed by **rainfall** thereafter **evapotranspiration** and finally the last column **stream flow** data. The **R software** with its package **airGR** was used to carry out set of parameters and Nash criterion for GR2M model. For all the calibration and validation period, a warm -up period of one year was taken and it is considered as first year of initialization. The monthly data for the period **1949 to 2000** for the five basins were subjected to descriptive analysis using **R software**. The method of sample test proposed by (KlemeŠ, 1986) was used.

KlemeŠ proposed different tools to test the robustness of the model. These tests are:

- Split-sample test
- Differential split-sample test
- Proxy-basin test
- Proxy- basin differential split-sample test

The objective of the tests proposed by KlemeŠ is to examine the question of the temporal and spatial transferability of the parameters that have been calibrated on a basin to test the robustness of the hydrological model. But also, to test the spatial and temporal transposability of the parameters from one model to another. The question is: which period the model must be calibrated in order to be able to reproduce the flows as well as possible?

Split-sample test

The split simple test is used for the separation of a period with observed stationary of the available conditions into two independent sub-periods. The model was calibrated on the first period and validated test on the second period. In this study, all the stream flow series were divided in two periods (**before 1970** and **after 1970**). So, for this test both calibration and validation methods were done on the same period before 1970 and after 1970.

Differential split-sample test

Application of test n°1 (split-sample test) but with non-stationary conditions (different climate characteristics from one period to another). In this test, the model was calibrated for the all basins on the period before 1970 consider as humid period and validated in the period after 1970 considered as dry period according to (Paturel et al., 1998). Once this process was done, we exchanged the role by calibrating the model after 1970 and validated in the period before 1970.

Proxy-basin test

In this test, the calibration was performed in the period **before** and **after 1970** in Sassandra basin at **Semien** and then validated respectively in Sassandra basin at **Soubré**. Indeed, if the results are satisfactory in both cases, the model can be transposed to an ungauged **C** basin.

Proxy- basin differential split-sample test

Application of test n°2 (Differential split-sample test) was conducted with non-stationary conditions (different climate characteristics from one period to another). Calibration was done in Sassandra basin at Semien **before 1970** and then validated in Soubré **after 1970**. Indeed, we repeated the same operation but with a calibrated model **after 1970** in **Semien** and validation in **Soubré before 1970**.

<u>Script wrote for all the calibration and validation of the model (Example in Sassandra basin at Semien)</u>

Import data to csv format

```
setwd ("C:/Users/HALIMA/Desktop/modelisation doc/Periode glissants")
data<-read.csv2("Semien.csv", dec = ".")
```

Convert the date variable as. POSIXct

```
date<- as. POSIXct (as. character(data$Date), tz="UTC",format="%m/%d/%Y")
```

Preparation of the Inputs Model object

```
library(airGR)
InputsModel<-CreateInputsModel (FUN_MOD = RunModel_GR2M, DatesR = date, Pre
cip = data$P_mm,PotEvap = data$ETP_mm)
```

Calibration period selection

```
Ind_Cal<-seq (which(format (date, format = "%Y/%m/%d")=="1954/01/01"),which
(format(date, format = "%Y/%m/%d")=="1958/12/01"))
```

Calculation of the Ind_Wup (Warm up period)

```
Ind_Wup = seq(Ind_Cal[1]-12, Ind_Cal[1]-1)
```

Preparation of the RunOptions period

```
RunOptions_Cal <- CreateRunOptions(FUN_MOD = RunModel_GR2M, InputsModel = I
nputsModel, IndPeriod_Run = Ind_Cal,IndPeriod_WarmUp = Ind_Wup)
```

Calibration criterion: preparation of the InputsCrit object

```
InputsCrit<-CreateInputsCrit(FUN_CRIT = ErrorCrit_NSE, InputsModel = Inputs
Model, RunOptions = RunOptions_Cal,Obs=data$Q_mm[Ind_Cal])
```

Preparation of CalibOptions object

```
CalibOptions<-CreateCalibOptions(FUN_MOD = RunModel_GR2M,FUN_CALIB = Calibr
ation_Michel)
```

Calibration

```
OutputsCalib<-Calibration(InputsModel = InputsModel,RunOptions = RunOptions
_Cal,InputsCrit = InputsCrit, CalibOptions = CalibOptions,FUN_MOD = RunMode
l_GR2M,FUN_CRIT = ErrorCrit_NSE,FUN_CALIB = Calibration_Michel)

## Grid-Screening in progress (0% 20% 40% 60% 80% 100%)
##   Screening completed (9 runs)
```

```
##       Param =  184.934,    0.712
##       Crit. NSE[Q]       = 0.7182
## Steepest-descent local search in progress
##   Calibration completed (66 iterations, 320 runs)
##       Param =  417.121,    1.328
##       Crit. NSE[Q]       = 0.8259

OutputsCalib<-Calibration(InputsModel = InputsModel,RunOptions = RunOptions
_Cal,InputsCrit = InputsCrit, CalibOptions = CalibOptions,FUN_MOD = RunMode
l_GR2M,FUN_CRIT = ErrorCrit_NSE,FUN_CALIB = Calibration_Michel)
```

Determination of X1 and X2 Parameters

```
Param<-OutputsCalib$ParamFinalR
```

Output of the model

```
OutputsModel <- RunModel(InputsModel = InputsModel, RunOptions = RunOptions
_Cal,Param = Param, FUN = RunModel_GR2M)

OutputsCrit <- ErrorCrit_NSE(InputsCrit = InputsCrit, OutputsModel = Output
sModel)

## Crit. NSE[Q] = 0.8259
```

Validation

```
Ind_val<-seq(which(format(date,format = "%Y/%m/%d")=="1963/01/01"),which(fo
rmat(date,format = "%Y/%m/%d")=="1967/12/01"))

Ind_warmp_val=seq(Ind_val[1]-12, Ind_val[1]-1)

RunOptions_val <- CreateRunOptions(FUN_MOD = RunModel_GR2M, InputsModel = I
nputsModel, IndPeriod_Run = Ind_val,IndPeriod_WarmUp =Ind_warmp_val)

InputsCrit_val<-CreateInputsCrit(FUN_CRIT = ErrorCrit_NSE, InputsModel = In
putsModel,RunOptions = RunOptions_val,Obs= data$Q_mm[Ind_val])
param_val<- c(417.121222,1.328117)

OutputsModel_val <- RunModel(InputsModel = InputsModel, RunOptions = RunOpt
ions_val,Param = param_val, FUN = RunModel_GR2M)
OutputsCrit_val <- ErrorCrit_NSE(InputsCrit = InputsCrit_val, OutputsModel
= OutputsModel_val)

## Crit. NSE[Q] = 0.7325
```

5-years sliding period

Beside the tests of KlemeŠ, we try to see how the parameters (X1 and X2) and Nash (Q) criterion for the model are evolved for all the basins. We also have to verify whether there is a trend in the evolution of these parameters that can transcribe somewhere the modification that may exist between the runoff-rainfall relations between two different periods. For performing this analysis, 5-years sliding calibration was done on all the time series for the period mentioned above. For example, at Semien, calibration was made for the period 1950 to 1954 then 1951 to 1955 by following this logic until the end of the stream flow time series.

Summary of all the methodology used in this study

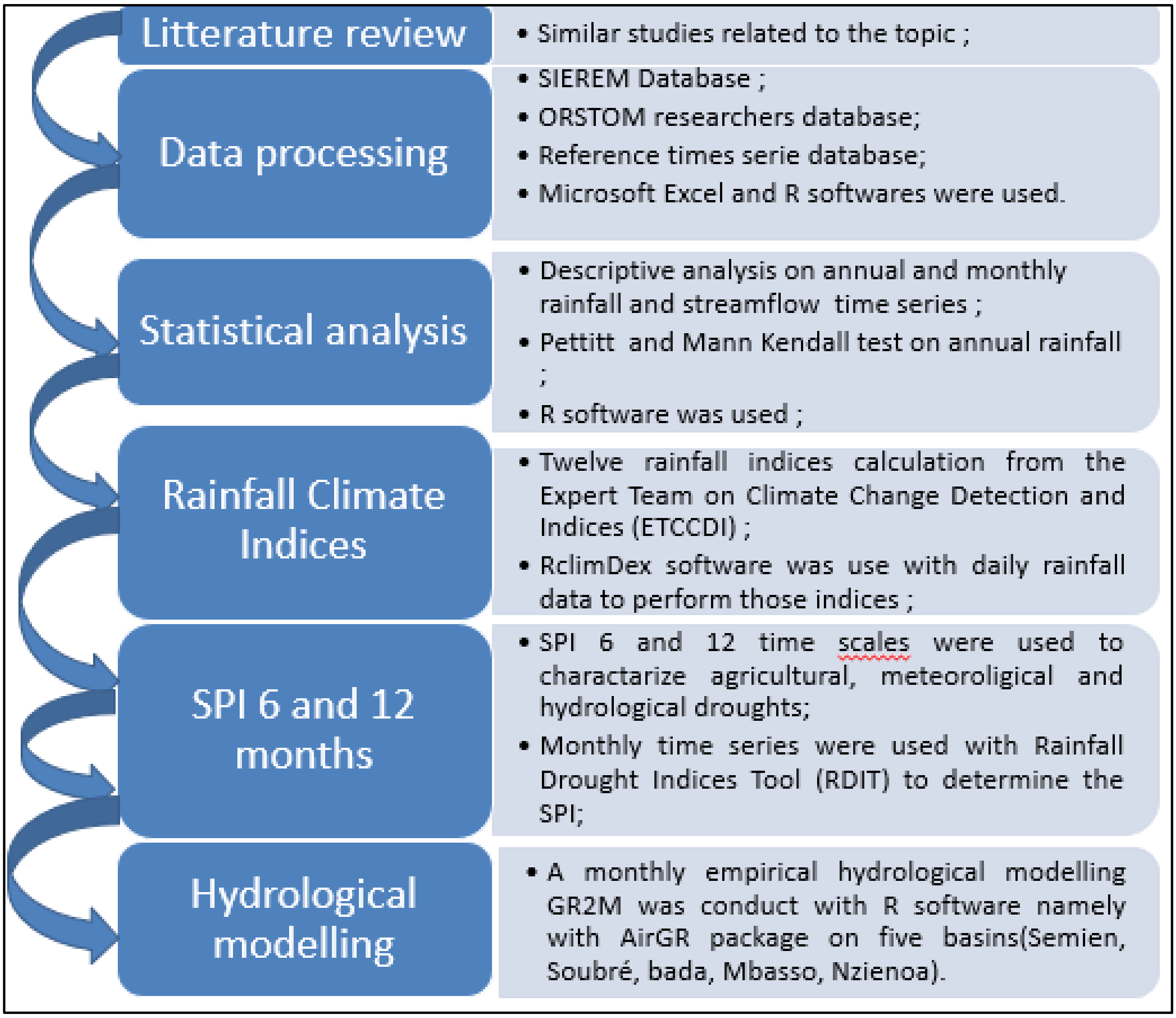


Figure 19: Summary of all the methodology used in this study

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Statistical analysis

4.1.1 Descriptive analysis of annual time series

The descriptive statistics computed are minimum, maximum, mean, standard deviation, coefficient of variation, skewness and kurtosis coefficient for each station.

The **Table 6** summarize the statistical analysis of annual rainfall data in Côte d'Ivoire for the period 1961 to 2000. The mean annual rainfall varies from **895.2 mm** for Bouna to **2,246 mm** for Tabou. It shows that all the stations located in the South western and eastern part of the country (Tabou, Adiaké, Abidjan, Tai, Toulepleu, Sassandra, Soubré, Man aero, Guiglo, Oumé, Adzope) receive on average the highest rainfall compare to those on the North eastern and southern part (Bouna, Ouangolodougou, Bondoukou, Odienné, Tengrela etc.).

The lower rainfall recorded in the North portion can be explain by an increase of temperature and decrease of rainfall since 1970 that mostly affected the North region (Bra et al., 2018; Kouadio et al., 2011)

The coefficient of variation in all the stations in the North (expect Odienné) shows that the annual rainfall in the region is highly variable compare to those in the South and central of the region which are moderately variable. The Sanhala station displays the highest coefficient of variation (**0.63**) while the Man aero has the lower value of coefficient of variation (**0.15**). However, the average coefficient of variation over the Côte d'Ivoire is **0.27**. Indeed, the variability of the rainfall time series in this study are markedly equal to the values reported by (Faria Filho et al., 2010) categorized the variability and the reliability using the coefficient of variations (CV). The higher value of the CV, the lower reliability of the distribution.

Furthermore, the standard deviation for all the stations is ranged from **200.25 mm** per year to **828.23 mm** per year. The high values of standard deviation also suggest annual rainfall fluctuations and high variability of rainfall in the region. As the table shows, the coefficient of skewness varied from **-2.07** to **3.68**; kurtosis varied between **-0.96** and **17.64**. Indeed, for time series data to be considered normally distributed, the coefficient of skewness and kurtosis must be equal to 0 and 3, respectively. The **Table 6** indicates, therefore, that the data are negatively skewed and not normally distributed.

Table 6: Summary of descriptive statistics for annual precipitation from 1961-2000 (NA: data not available)

Stations Name	Coordinates (dd)		Min (mm)	Max (mm)	Mean (mm)	Standard deviation (mm)	Coefficient of variation	Skewness	Kurtosis	% of NA
	Latitudes	Longitudes								
Abidjan aéroport	5.25	-3.9333	1059	2756	1804	409.12	0.23	0.13	-0.96	10
Adiaké	5.3	-3.3	1181	2563	1844	370.94	0.20	0.18	-0.92	0
Adzope	6.1	-3.85	608	2186	1314	312.33	0.24	0.47	0.81	2
Beoumi	7.6667	-5.5667	0	1564.7	1038.2	258.41	0.25	-1.34	4.87	2
Bondoukou	8.05	-2.7833	749.8	1601.3	1087	211.90	0.19	0.62	-0.25	8
Bouna	9.2667	-2.9833	0	1500.8	895.2	339.09	0.38	-0.96	1.36	7
Dembasso	9.6833	-6.4	0	1660.4	1145.3	364.37	0.32	-1.72	2.94	8
Dimbokro	6.68	-4.7	815.9	1949.2	1128.5	200.25	0.18	1.68	5.07	0
Gagnoa	6.1333	-5.95	1006	2048	1372	217.77	0.16	0.96	1.17	0
Guiglo	6.5333	-7.4667	886	2446	1565	305.68	0.20	-0.01	0.80	7
Kouto	9.9	-6.4167	0	1616	1133	368.28	0.33	-1.71	2.85	8
Lakota	5.85	-5.6667	133.5	1774	1218.7	281.01	0.23	-1.01	3.69	2
Madiani	9.6167	-6.95	0	1781	1278	386.65	0.30	-1.95	4.14	6
Man aero	7.4	-7.5167	1150	2190	1619	249.09	0.15	0.21	-0.73	0
Manignan	10	-7.8333	0	2414	1356	471.45	0.35	-0.66	1.58	4
Mankono	8.05	-6.1833	0	1632	1160	346.44	0.30	-1.75	3.75	4
Odienné	9.5	-7.5667	991.7	1796.6	1434.7	226.70	0.16	-0.40	-0.93	3
Ouangolodougou	9.8333	-5.15	0	1339.6	956.9	331.95	0.35	-1.52	1.74	8
Oumé	6.3667	-5.4167	604.2	1816.5	1220.6	260.07	0.21	-0.15	-0.17	0
Sanhala	10.0333	-6.85	0	5612	1307	828.23	0.63	3.68	17.64	8
Sassandra	4.95	-6.0833	704.5	2249.3	1429.2	357.69	0.25	0.37	-0.60	0
Soubré	5.7833	-6.6	382	2144	1352	306.62	0.23	-0.33	1.74	2
Tabou	4.4167	-7.3667	1219	3351	2246	427.43	0.19	0.29	0.05	0
Tai	5.8667	-7.45	131.4	3192.5	1833.3	518.00	0.28	-0.17	2.29	8
Tengrela	10.4833	-6.4	0	1779.7	1038.1	392.44	0.38	-0.98	1.33	16
Tiemé	9.55	-7.3167	0	1861	1314	427.97	0.33	-2.07	4.03	7
Toulepleu	6.5667	-8.4	256.1	2651.4	1632.1	407.04	0.25	-0.48	2.45	2

4.1.2 Monthly descriptive analysis

The descriptive statistics for the stream flow at monthly timescales from the period 1949-2000 for all the stations was summarize in the tables (7, 8, 9, 10 and 11). The **summary** function used in R software to compute the descriptive statistics did not take the not available data (NA) in the calculation.

Table 7: Monthly stream flow descriptive statistics (Bada)

Months	Monthly mean (m^3/s)	Median (m^3/s)	Standard deviation (SD)	Coefficient of variation (CV)	Min (m^3/s)	Max (m^3/s)	% of NA
January	10.55	5.31	14.047	0.75	0	68.69	42
February	5.0319	1.495	7.956	0.63	0.01	35.76	50
March	3.464	1.36	4.561	0.76	0	16.68	48
April	4.192	3.38	4.156	1.01	0	16.21	48
May	8.252	6.86	5.234	1.58	0.76	22.54	44
June	17.89	12.61	18.419	0.97	2.92	86.37	44
july	50.39	34.91	49.007	1.03	6.87	223.22	46
August	190.76	176.38	131.317	1.45	9.32	470.41	42
September	382.77	414.56	213.733	1.79	6.33	801.16	38
October	261.84	226.77	182.664	1.43	16.07	655.77	40
November	90.07	53.28	81.572	1.10	1.52	335.13	46
December	26.849	12.91	29.181	0.92	0.93	128.54	48

Table 8: Monthly stream flow descriptive statistics (Nzienoa)

Months	Monthly mean (m^3/s)	Median (m^3/s)	Standard deviation (SD)	Coefficien t of variation (CV)	Min (m^3/s)	Max (m^3/s)	% of NA
January	4.402	2.36	5.703	0.77	0.01	25.35	21
February	1.489	0.59	2.584	0.58	0.07	13.88	19
March	1.511	0.47	2.144	0.70	0	9.89	21
April	6.688	5.76	6.694	1.00	0	32.56	19
May	19.93	18.23	16.268	1.23	0.04	69.08	19
June	69.61	47.2	63.079	1.10	3.46	245.07	19
july	90.44	62.51	85.629	1.06	5.66	356.48	15
August	83.11	39.57	103.569	0.80	1.13	525.96	13
Septembe r	166.72	158.26	153.702	1.08	0.23	695.53	15
October	238.46	210.35	198.378	1.20	0.33	805.58	17
November	82.56	52.55	98.184	0.84	0.03	481.4	25
December	16.371	11.06	18.906	0.87	0.07	88.59	27

Table 9: Monthly stream flow descriptive statistics (Mbasso)

Months	Monthly mean (m^3/s)	Median (m^3/s)	Standard deviation (SD)	Coefficient of variation (CV)	Min (m^3/s)	Max (m^3/s)	% of NA
January	10.23	5.81	11.11	0.92	0.27	48.41	37
February	4.945	2.92	5.23	0.95	0.09	19.57	44
March	4.565	2.31	5.23	0.87	0.01	20.76	35
April	9.785	8.15	8.35	1.17	0.03	35.41	29
May	20.396	13.05	19.16	1.06	0.3	83.56	33
June	69.71	39.37	63.64	1.10	5.45	261.46	33
july	121.77	68.99	128.48	0.95	1.71	652.9	33
August	289.94	252.38	224.90	1.29	37.56	979.67	25
September	670.8	570.1	413.42	1.62	64.6	1661.7	31
October	568.66	529.39	375.71	1.51	50.15	1671.87	38
November	149.27	104.09	129.76	1.15	6.52	588.73	37
December	35.14	22.24	33.24	1.06	1.57	150.03	40

Table 10: Monthly stream flow descriptive statistics (Semien)

Months	Monthly mean (m^3/s)	Median (m^3/s)	Standard deviation (SD)	Coefficient of variation (CV)	Min (m^3/s)	Max (m^3/s)	% of NA
January	49.11	39.82	30.13	1.63	10.05	131.97	19
February	29.91	25.04	20.70	1.45	5	80.76	17
March	27.1	23.17	18.25	1.48	5.29	78.81	19
April	44.13	39.19	26.31	1.68	7.53	119.97	13
May	61.59	61.76	25.23	2.44	9.75	106.07	15
June	105.21	93.63	53.88	1.95	28.02	239.18	13
july	211.94	178.09	107.63	1.97	55.12	519.09	13
August	480.5	450.9	182.49	2.63	190.1	864.9	15
September	767.7	769.6	220.42	3.48	361.1	1221.7	17
October	494.1	440.7	220.36	2.24	155.1	1063.5	15
November	220.18	180.06	129.39	1.70	69.56	593.26	13
December	94.62	84.42	48.22	1.96	32.6	209.22	23

Table 11: Monthly stream flow descriptive statistics (Soubré)

Months	Monthly mean (m^3/s)	Median (m^3/s)	Standard deviation (SD)	Coefficient of variation (CV)	Min (m^3/s)	Max (m^3/s)	% of NA
January	195.33	160.98	146.07	1.34	38.4	598.06	35
February	176.07	103.15	161.75	1.09	21.2	593.17	40
March	173.77	90.29	167.54	1.04	17.79	565.74	23
April	169.7	96.28	137.01	1.24	15.47	478.86	38
May	185.45	128.1	132.83	1.40	35.99	518.35	27
June	318.53	294.23	171.49	1.86	48.64	660.93	33
july	393.38	281.61	264.14	1.49	61.25	868.54	38
August	619.49	464.9	465.15	1.33	94.89	1760.96	33
September	1141.66	1016.76	759.49	1.50	98.75	2696.66	33
October	1078.7	1054	673.61	1.60	127.4	2745.5	31
November	530	432.8	301.97	1.76	148.2	1324	29
December	279.3	288.4	137.22	2.04	60.1	538.4	29

The **Table 7** to **Table 11** summarise the statistical analysis for monthly stream flows data from 1949 to 2000 in Soubré, Semien, Mbasso, Bada and Nzienoa. According to these results, the month of August, September and October received the highest amount of stream flow (Q = 335.13 to 2,745.5 m^3/s but the highest amount is observed in Semien and Soubré. The mean annual flow varies from **87.67** m^3/s for Bada to **162.93** m^3/s for Mbasso; from **65.11** m^3/s for Nzienioa to **215.51** m^3/s for Semien and **438.45** m^3/s for Soubré. We notice that all stations receive a considerable amount of flow for the period from July to October consider as high-water period and less amount during January to June. The coefficient of variation shows that the monthly flow in all stations during the summer period is highly variable than the winter. Indeed, the **Figure 20** shows the mean monthly stream flow in these stations. According to this result, all the stations receive the maximum amount of flow in September and the period between December and May is show the dry period in Mbasso, Nzienoa and Bada.

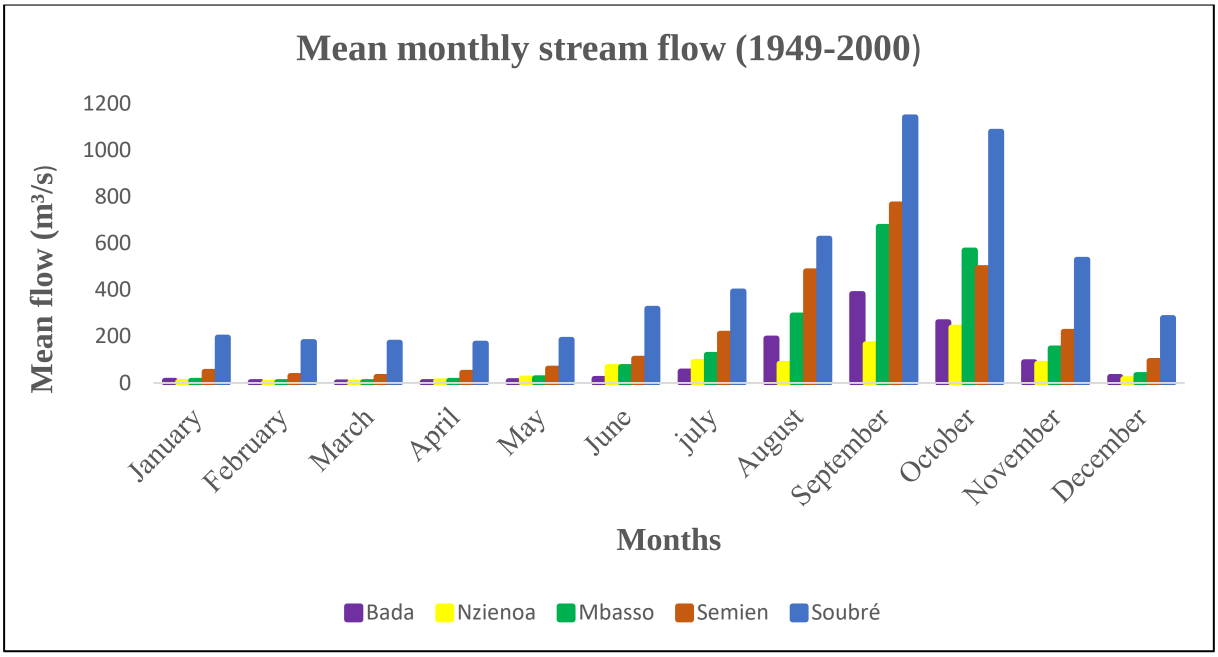


Figure 20: Mean monthly stream flow (1949-2000)

4.2 Trend Analysis using Mann Kendall test

In this study, trend analysis of yearly rainfall from the period 1961 to 2000 was done using Mann Kendall test. The null hypothesis **H0** for the test is: there is no trend in the time series. Testing trends is done at 5% significance level (α = 0.05). However, the null hypothesis is rejected if $|Z_S| > 1.96$. The Sen's slope estimator (Q) is also used to estimate the magnitude of trend for time series data. The annual rainfall trend and the Sen's slope estimator are given in **Table 6**. The result of this table show that all the stations located in the centre zone (i.e. in humid tropical climate) does not present any trend at 95% while significant trend are observed in all stations in the North and South zones (sub-tropical and sub-equatorial climates) except some stations (Dembasso, Soubré, Adzope and Tabou). The **Figure 21** shows the level of significance at 95% and the trend rainfall respectively. The result highlighted that only four stations out twenty-seven show an increasing trend while the others stations show a decreasing trend in annual rainfall. An increasing trend was observed in the Central western part of the country but they are not statistically significant at **95%** (**Figure 21**).

Furthermore, understanding temporal and spatial pattern of rainfall trends analysed in this study is crucial for mobilizing and planning water resources. The table below summarize the results of Mann Kendall test and the figures show the spatial significance trend.

Table 12: Mann Kendall test result for annual precipitation at 5% significance level (Z: Standard normal test statistic; Q: Sen slope estimator)

Climatics zone	Stations Name	Z	P-value	Ho test significance level 5%	Q sen
Sub-tropical	Dembasso	-1.352	1.76E-01	Accepted	-5.81
	Kouto	-2.738	6.17E-03	Rejected	-8.641
	Madiani	-2.26	2.38E-02	Rejected	-8.462
	Manignan	-4.906	9.31E-07	Rejected	-25.494
	Odienné	-3.204	1.36E-03	Rejected	-10.331
	Ouangolodougou	-2.773	5.55E-03	Rejected	-8.81
	Sanhala	-2.506	1.22E-02	Rejected	-12.245
	Tengrela	-3.589	3.31E-04	Rejected	-15.518
	Tiemé	-3.182	1.46E-03	Rejected	-8.514
Humid tropical	Bouna	-1.375	1.69E-01	Accepted	-6.049
	Beoumi	-0.874	3.82E-01	Accepted	-2.31
	Bondoukou	-0.618	5.37E-01	Accepted	-2.349
	Man aero	0.536	5.92E-01	Accepted	2.8
	Mankono	0.396	6.92E-01	Accepted	1.363
	Guiglo	0.198	8.43E-01	Accepted	0.943
	Tai	0.291	7.71E-01	Accepted	1.75
	Toulepleu	-0.128	8.98E-01	Accepted	-0.94
Sub-equatorial	Abidjan aéroport	-3.274	1.06E-03	Rejected	-17.13
	Adiaké	-4.089	4.32E-05	Rejected	-20.087
	Dimbokro	-2.319	2.00E-02	Rejected	-5.703
	Sassandra	-4.299	1.71E-05	Rejected	-19.421
	Oumé	-3.693	2.21E-04	Rejected	-11.964
	Gagnoa	-2.016	4.38E-02	Rejected	-6.302
	Lakota	-2.132	3.30E-02	Rejected	-7.7
	Tabou	-0.408	6.83E-01	Accepted	-2.316
	Adzope	-1.806	7.09E-02	Accepted	-6.716
	Soubré	-1.48	1.39E-01	Accepted	-4.717

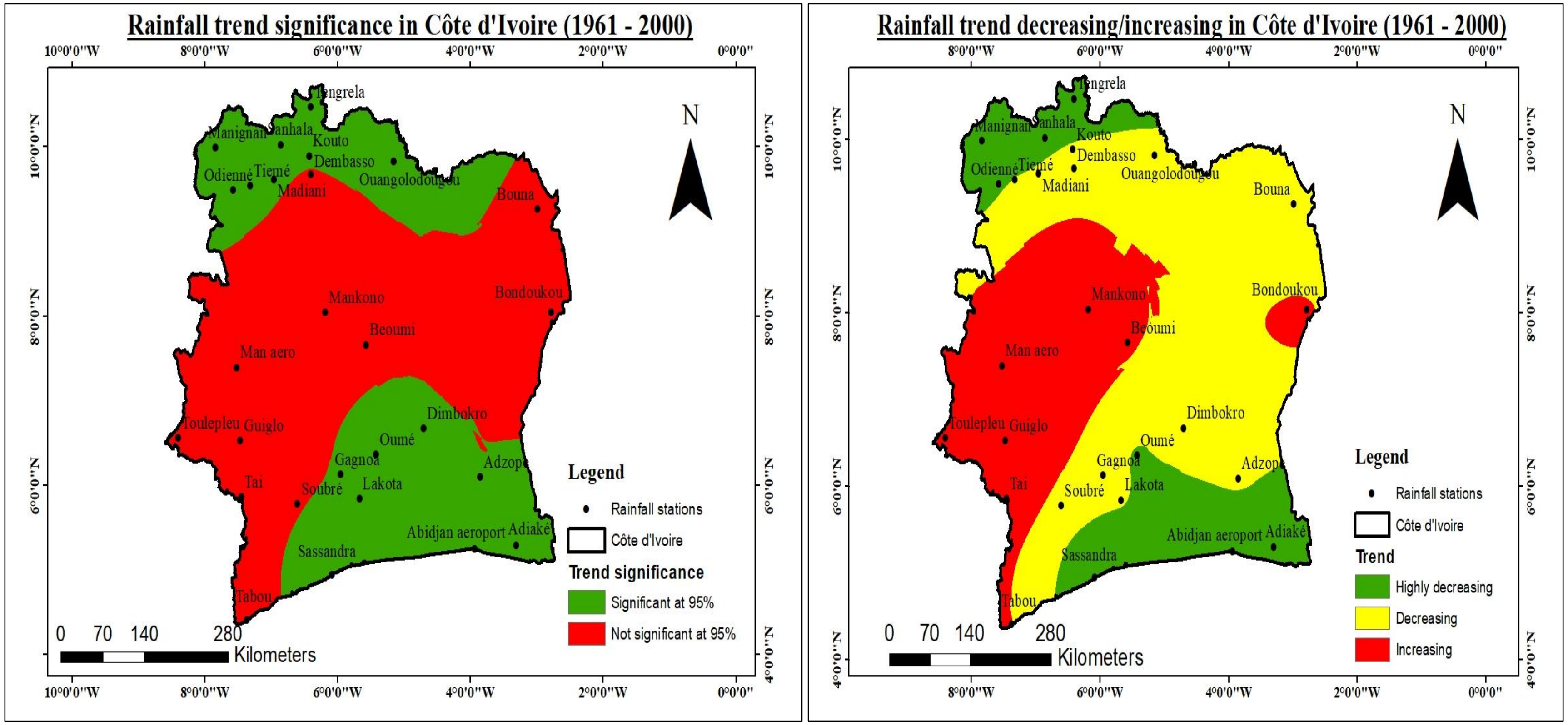


Figure 21: Rainfall trend significance in Côte d’Ivoire

4.3 Break analysis (Pettitt test)

In order to determine the break in the annual time series for the period 1961 to 2000, Pettitt test was performed. The null hypothesis of this test H0 is: there is no break in the annual time series. Indeed, confidence level (**α=0.05**) is used to determine whatever there is a break in the time series or not. The null hypothesis is accepted when the p-value is ≥ 0.05. The result of the table shows no break in all the stations located in the Centre of the country. However, the North part highlights a presence of break in most of the stations except at (Dembasso and Madiani). In the South, we notice that five stations out ten show a break. Indeed, the most common shifting years of the break occurred after 1970. For example, the mean annual rainfall in Abidjan-aéroport station before and after the break of 1982 was **2,011.6** mm and **1,535** mm respectively. In addition, the results obtained by applying Pettitt and Mann Kendall tests are approximately the same. That is means the stations which revelated significant trend show also a presence of break. The result found by Pettitt test is similar to those studies conducted by (Drissa, 2013; Goula et al., 2006; Paturel et al., 1998; Savane et al., 2001) in Côte d'Ivoire and West and Central Africa. We observe that the Northern and Southern part of the country are the most impacted by trend and break on annual rainfall (**Figure 22**).

Table 13: Pettitt test result on annual rainfall at 5% significance level

Climatic zones	Stations Name	P-value	Ho test significance level 5%	Mean annual rainfall before break (mm)	Mean annual rainfall after break (mm)
Sub-tropical	Dembasso	1.71E-01	Accepted	_	_
	Madiani	5.96E-02	Accepted	_	_
	Kouto	5.73E-03	Rejected **(1971)**	1,403.6	1,034.4
	Manignan	2.90E-05	Rejected **(1981)**	1,655.8	1,030.4
	Odienné	3.05E-04	Rejected **(1982)**	1,569.9	1,284.4
	Ouangolodougou	3.15E-02	Rejected **(1975)**	1,139.9	849.4
	Sanhala	8.46E-03	Rejected **(1969)**	2,006.2	1,088.8
	Tengrela	1.98E-03	Rejected **(1977)**	1,285.8	865.7
	Tiemé	5.12E-03	Rejected **(1973)**	1,551.2	1,195.1
Humid tropical	Bouna	2.77E-01	Accepted	_	_
	Beoumi	7.44E-01	Accepted	_	_
	Bondoukou	1.29E+00	Accepted	_	_
	Man aero	4.79E-01	Accepted	_	_
	Mankono	5.84E-01	Accepted	_	_
	Guiglo	1.39E+00	Accepted	_	_
	Toulepleu	7.02E-01	Accepted	_	_
	Tai	6.35E-01	Accepted	_	_
Sub-equatorial	Abidjan aéroport	1.13E-03	Rejected (**198**2)	2,011.6	1,535
	Adiaké	4.77E-04	Rejected (**1982)**	2,037.6	1,584.8
	Sassandra	3.61E-04	Rejected **(1979)**	1,652.4	1,213
	Oumé	5.04E-04	Rejected **(1979)**	1,390.2	1,081.9
	Lakota	1.72E-02	Rejected **(1974)**	1,384	1,122.1
	Tabou	4.68E-01	Accepted	_	_
	Adzope	9.35E-02	Accepted	_	_
	Gagnoa	2.29E-01	Accepted	_	_
	Dimbokro	9.04E-02	Accepted	_	_
	Soubré	1.07E-01	Accepted	_	_

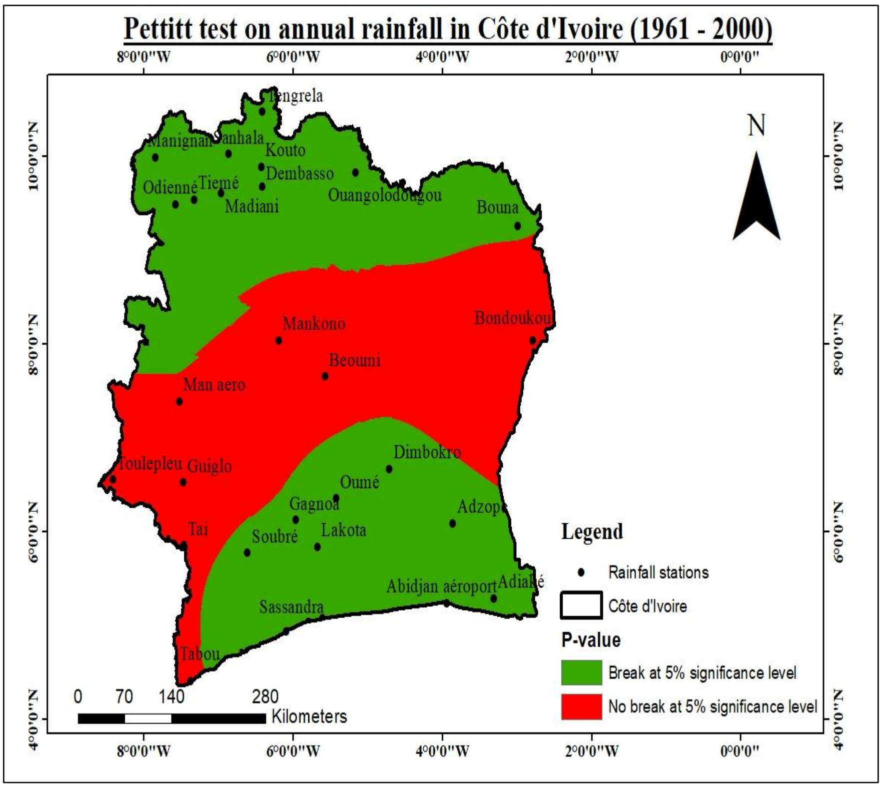


Figure 22: Spatial distribution of break test on annual rainfall in Côte d'Ivoire (1961-2000)

4.4 Annual variability of rainfall in Cote d'Ivoire

To characterize spatial and temporal variability, we use the coefficient of variation. The figures (**Figure 24, Figure 24** and **Figure 25)**, show the mean annual temporal and spatial rainfall distribution in Côte d'Ivoire from 1961-2000. Indeed, the annual variability for all the stations varies from 1**5%** to **63**%. The **figure 25** indicates that the rainfall patterns in Côte d'Ivoire are highly variable especially in the North part. This due to the lowest amount of rains characterized in this region **<1,200mm** (**Figure 24**). The heavy rains that characterize the South eastern and western portion of the country reduce its spatial variability (with CV= **0.19**). The highest the rainfall amount, the lowest CV. We notice also an increasing of rainfall amount from North to South and from East to West. The mountains area located in the west of the country received higher mean amount of rainfall approximately (greater than **1,543.83 mm**). The central region shows a moderate rainfall variability with a coefficient of variation comprise between **0.20 < CV < 0.30**. The North part presented significant rainfall variability and varies considerably from one region to another. Indeed, the understanding of inter-annual rainfall variability is very important for the climatic trend and forecast.

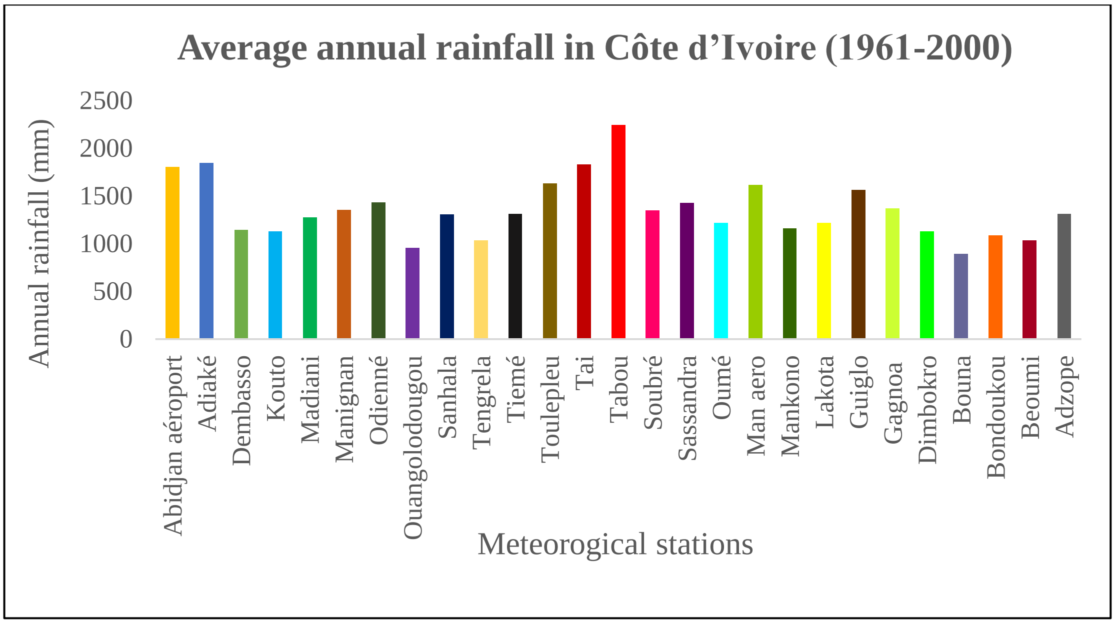
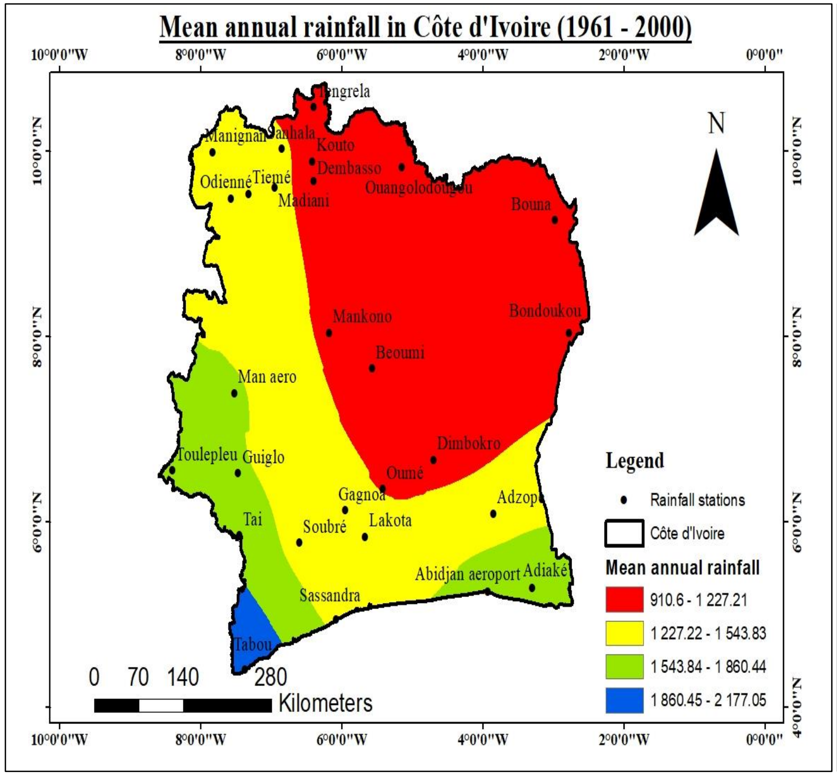


Figure 23: Temporal distribution of average annual rainfall in Côte d'Ivoire (1961-2000)



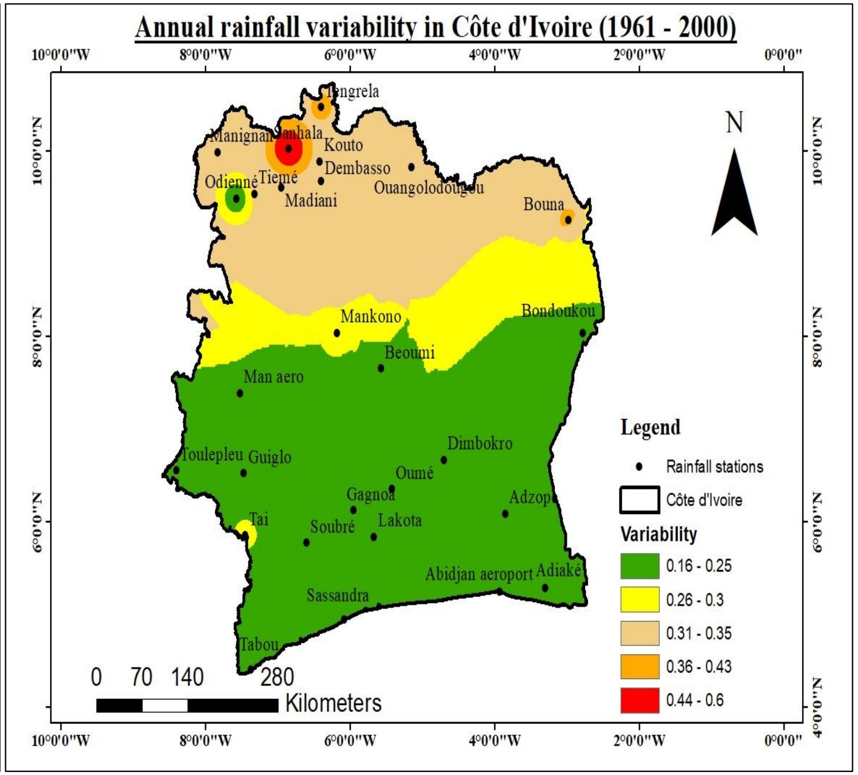


Figure 24: Mean annual rainfall in Côte d’Ivoire

Figure 25: Annual rainfall variability in Côte d’Ivoire

4.5 Rainfall indices calculations

Climates indices are widely used for monitoring extremes events. In this study, temporal distribution of extreme precipitation events was analysed based on the daily precipitation data of 27 meteorological stations in Côte d'Ivoire from 1961to 2000. Twelve indices of precipitation extremes were selected and calculated using RClimDex software as listed in the tables below. The linear regression method was employed to assess trend in extreme precipitation indices, and the Sen's Estimator test was used to determine the slope of the significant trends.

❖ Heavy precipitation day (R10mm)

The result of the heavy precipitation day (R10mm) showed that two out twenty-seven stations present an increasing trend at 5 % significance level. Indeed, the R10mm index is decreasing in all the stations except Mankono and Dimbokro. However, significantly decreasing trend was observed in the North and South regions. The highest decreasing trend in R10mm has been estimated at Manignan (**5.7 days**/decade) and Oumé (**3 days**/decade) respectively. The **Figure 26** shows the spatial distribution of R10mm.

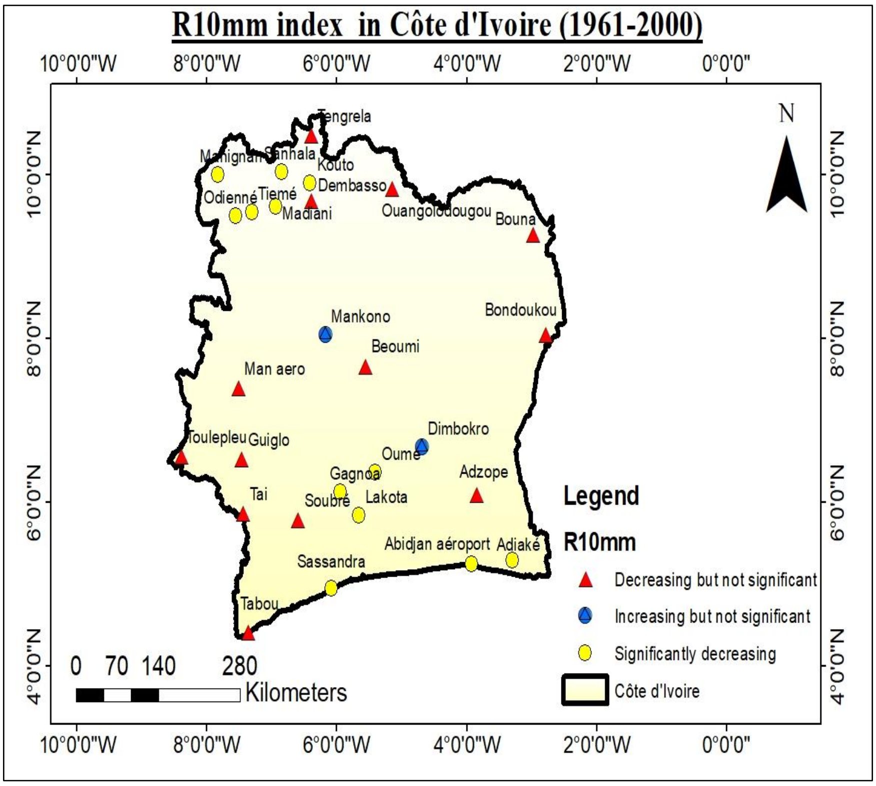


Figure 26: Spatial distribution of R10mm from 1961-2000 in Côte d'Ivoire

❖ Very heavy precipitation index (R20mm)

The result of very heavy precipitation days (R20mm) has been decreasing in most of the stations. Seven stations located in the North western and south eastern part (Abidjan-aéroport, Adiaké, Manignan, Odienné, Dimbokro, Sassandra and Oumé) highlighted a significantly decreasing trend at **5%** confidence level (PV< 0.05). The central and north eastern region showed also a decreasing trend. An increasing trend in the numbers of R20mm was observed in (Tai, Man aero and Bondoukou). Indeed, the maximum decrease in R20mm was estimated at Sassandra (2.69 days/decade) and Manignan (3.52 days/decade) respectively. The maximum increase was observed at Man aero 1.09 days/decade.

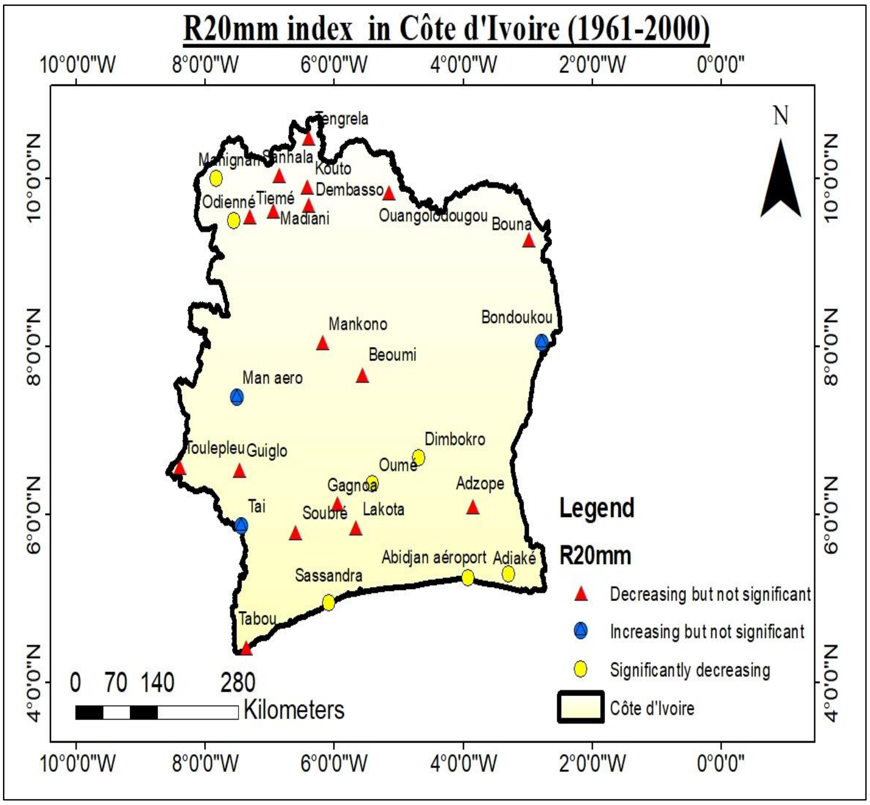


Figure 27: Spatial distribution of R20mm from1961-2000 in Côte d’Ivoire

❖ R40mm and R50mm

The numbers of extremely heavy (**R40mm**) and (**R50mm**) precipitation days have been decreasing in most of the stations in Côte d’Ivoire. The results of both indices revealed a significant decreasing trend at (Adiaké, Manignan, Oumé, Sassandra) stations. Indeed, Tai station indicated a statistically significant increasing (0.118day/year) trend in R50mm index.

Both indices R40mm and R50mm showed that the highest decreasing trend was observed at Sassandra 1.94 and 1.69 days /decade respectively.

The results obtained by R10mm, R20mm, R40mm and R50mm indices showed an overall reduction of rainfall over the period **1961-2000.** However, the stations located in the North western part of Côte d'Ivoire (Odienné, Manignan) and those in the South East (Abidjan aéroport, Adiaké, Oumé, Sassandra) are the most impacted by a decline of heavy and very heavy precipitation days.

❖ R*1day and R*5days

The maximum 1-day (R*1day) have been increasing in most of the stations while R*5days showed a decreasing trend in most of stations. However, out of all the stations three show a significant decreasing trend for R*5days and two stations show also decreasing trend for R*1day. The estimated average decrease is 5 mm/decade for R*1day and 9.1 mm/decade for R*5days. Tai showed the highest increasing trend (11.49 and 15.98 mm/decade) for R1*day and R*5days. Sassandra showed the highest decreasing trend for both indices with 16.13 and 40.89 mm/decade respectively for R*1days and R*5days.

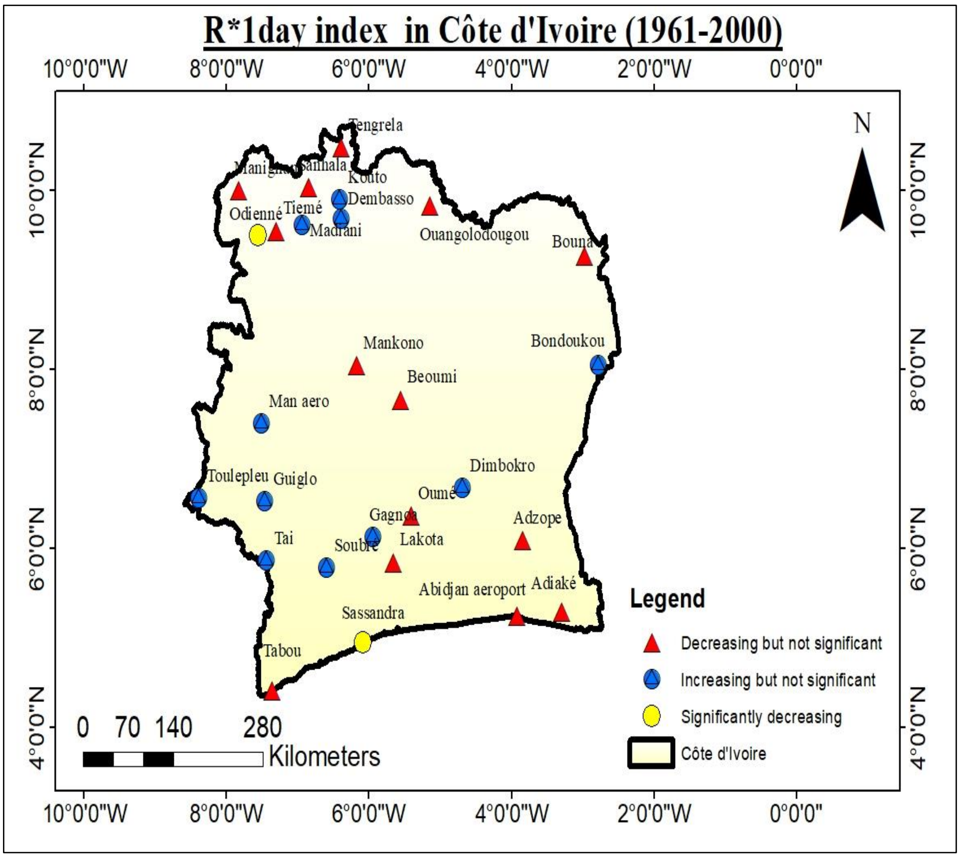


Figure 28: Spatial distribution of R*1day from 1961-2000 in Côte d'Ivoire

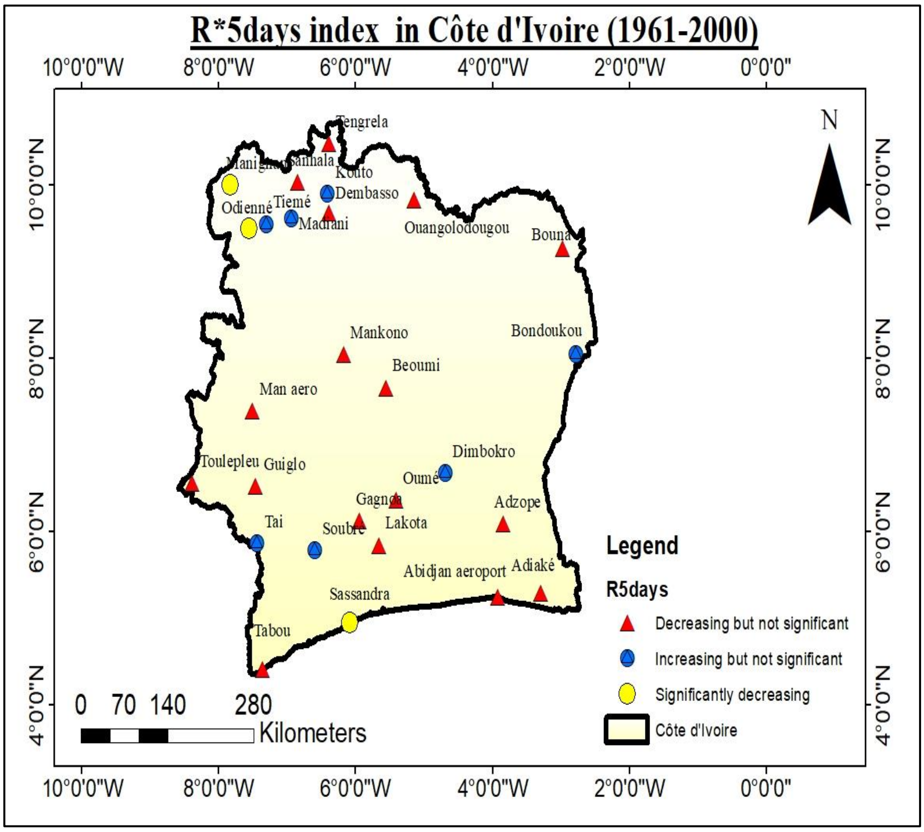


Figure 29: Spatial distribution of R*5days from 1961-2000 in Côte d'Ivoire

❖ R95p and R99p

Very wet days (R95p) and extremely wet days (R99p) are decreasing in most of the stations with an average decrease of 45.2 and 25.5 mm/decade respectively. The maximum decrease of **R95p** was observed in (Sassandra, Odienné and Manignan) with the highest in Sassandra (133mm/decade). The maximum increase was observed at Tai 102.9 mm/decade. The maximum decrease trend of R99p was observed in Sassandra 51.4mm/decrease and the maximum increase was observed in Tai 49.9 mm/decade. The **Figure 30** and the **Figure 31** show the spatial distribution of both indices.

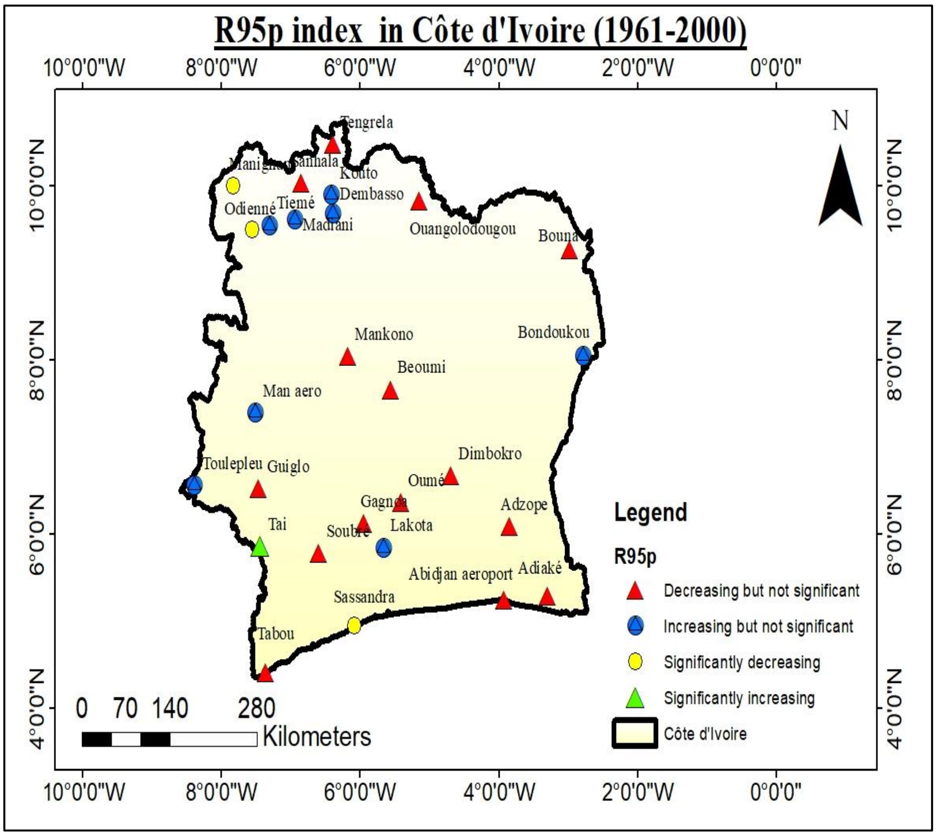


Figure 30: Spatial distribution of R95p from 1961-2000 in Côte d’Ivoire

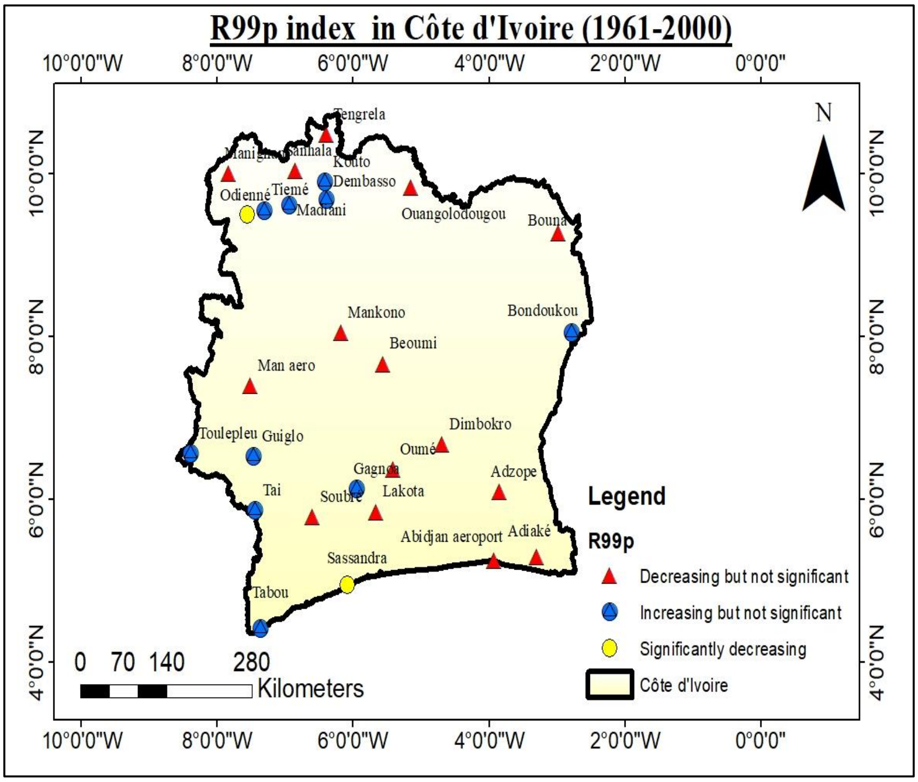


Figure 31: Spatial distribution of R99p from 1961-2000 in Côte d’Ivoire

In view of the results obtained, we highlighted that very wet days (R95p) and extremely wet days (R99p) are the most significant daily water inflows with respect to their thresholds (at 95th and 99th percentiles). Indeed, we observed more rainfall deficit in term of intensity in the both indices and particularly at Sassandra station and an increase of rainfall in Tai. Through the amount of water delivered, they can contribute to natural events such as flooding, soil erosion, etc.

❖ CWD, CDD, SDII, PRCPTOT

Consecutive dry days **(CDD**) are increasing in most of the stations with an average value 3.3 days/decade. The maximum increase has been estimated at Oumé (5.5 days/decade) and Kouto (9 days/decade) and the maximum decrease has been estimated at Guiglo 5.35 days/decade. Consecutive wet days (**CWD**) are decreasing in most of the stations with an average value of 0.43 day/decade. The maximum decrease has been estimated in Manignan 1.4 day/decade.

The simple daily intensity index (**SDII**) is found to be decreasing in most of the stations. The computed average decreasing is 0.07 mm/day per year. The maximum increasing trend was observed in mountainous region at Man aero station and the maximum decreasing trend was observed in Sassandra (0.174 mm/day per year).

Annual total wet-day precipitation **(PRCPTOT**) is decreasing in most part of Côte d'Ivoire with an average rate of 84.5 mm/decade. The maximum decrease rainfall is observed in the North and South portion with the highest decreasing trend noted at Manignan, Sassandra, Oumé, Odienné and Adiaké stations (214.4, 196.2, 123.2, 106.2 and 101 mm/decade) respectively. The figures (**Figure 32**, **Figure 33**, **Figure 34**, **Figure 35**) show the spatial representation of all the indices.

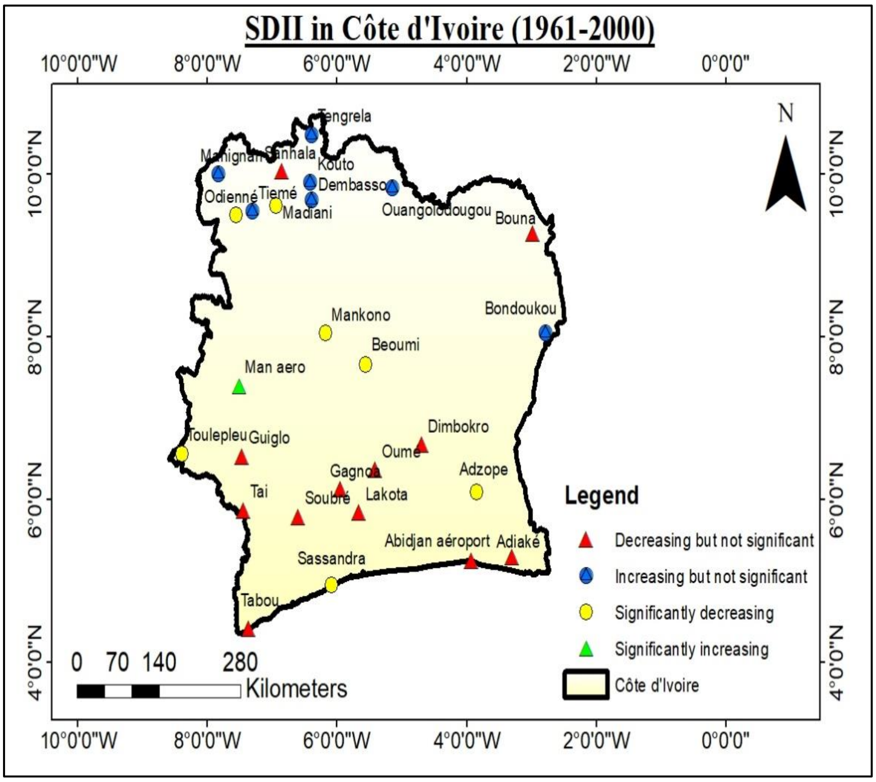


Figure 32: Spatial distribution of SDII from 1961-2000 in Côte d'Ivoire

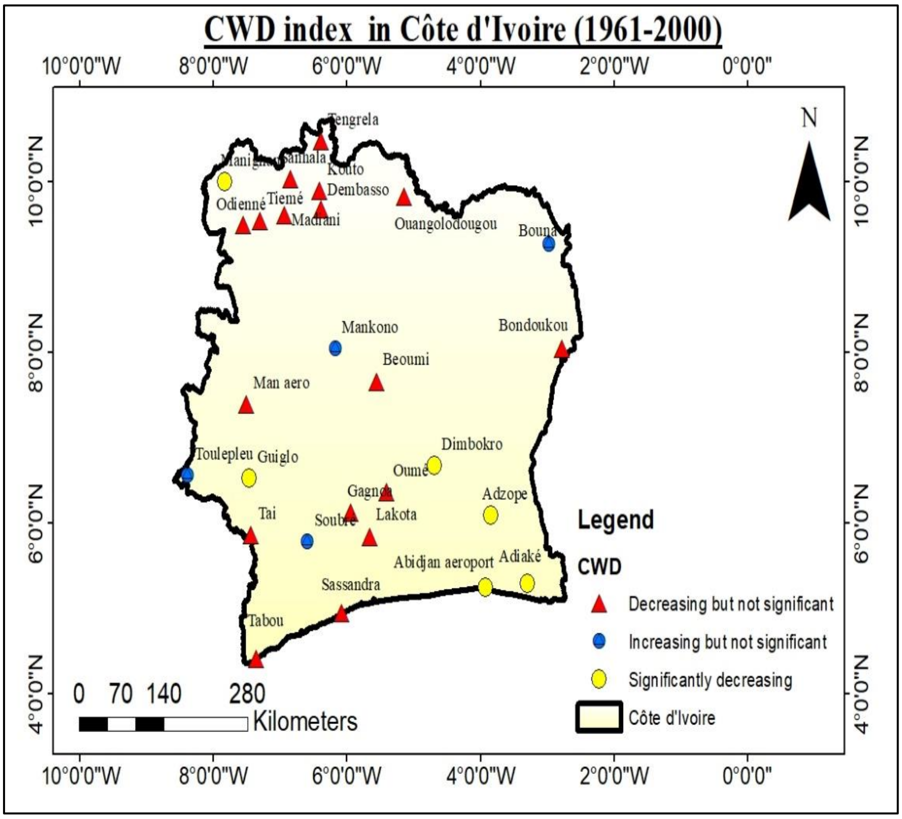


Figure 33: Spatial distribution of CWD from 1961-2000 in Côte d'Ivoire

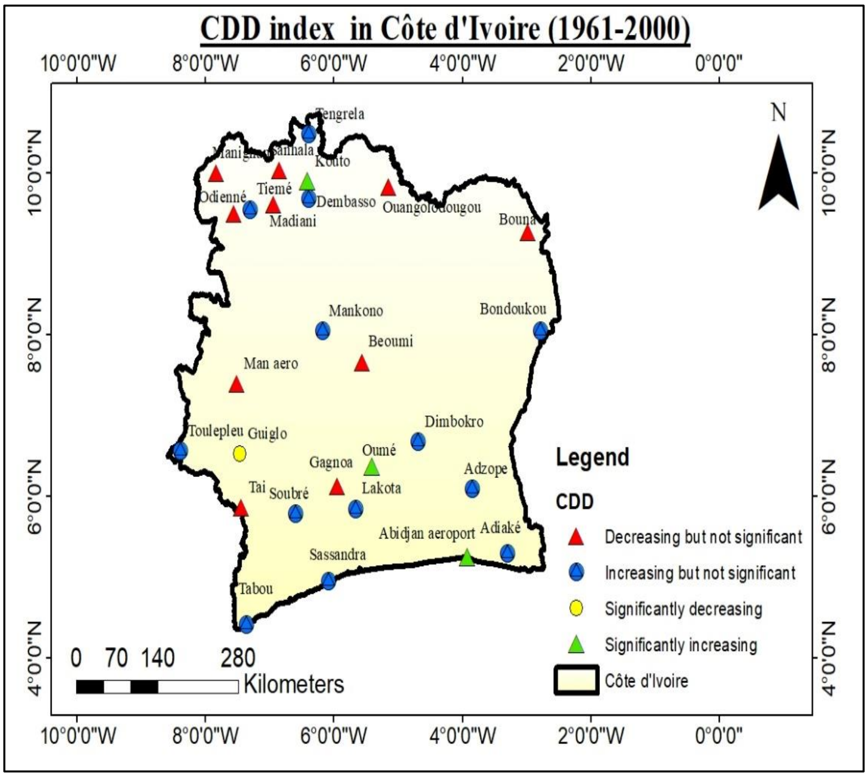


Figure 34: Spatial distribution of CDD from 1961-2000 in Côte d'Ivoire

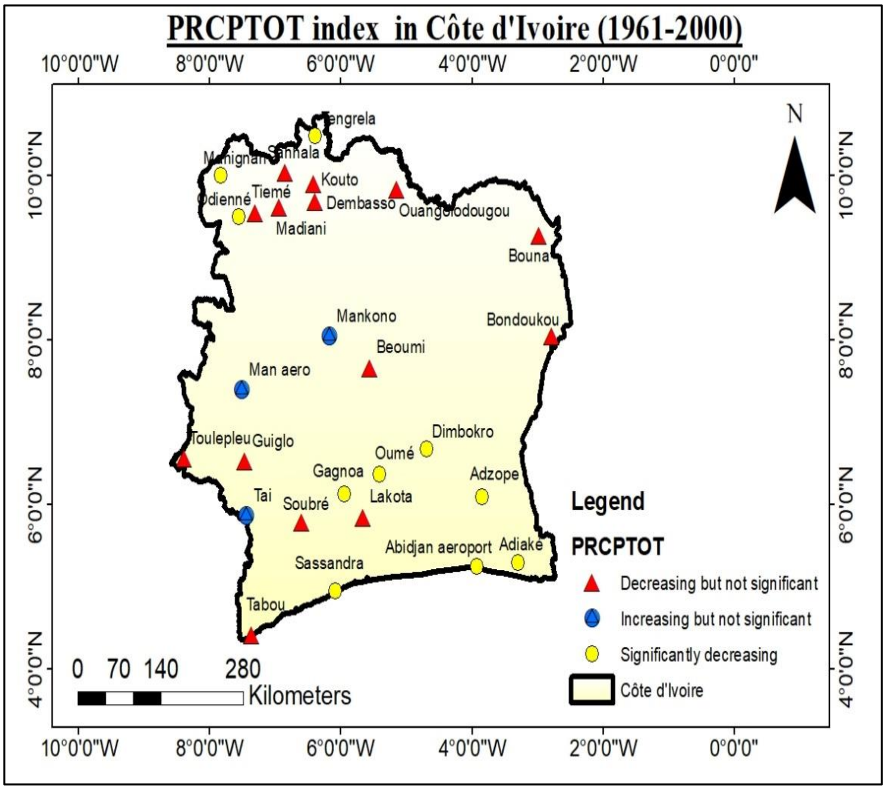


Figure 35: Spatial distribution of PRCPTOT from 1961-2000 in Côte d'Ivoire

The result shows an increase in the number of consecutive dry days (CDD) and a decrease in the number of Consecutive Wet days (CWD) in Côte d'Ivoire during the period 1961-2000. The occurrence of consecutive dry days (CDD) within the rainy season can also have a huge negative impact on agricultural productivity in the region. The number of rainy days (CWD) defines the length of the rainy seasons in a given location. The annual total wet precipitation index (PRCPTOT) recorded during a season has a significant impact on crop yields. Indeed, each crop requires specific quantities of water to grow. However, insufficient quantity leads to decline of production.

The **Table 14** shows the indices for some stations and the result of other indices are summarize in Appendix.

Table 14: Climates indices calculation for daily precipitation from 1961-2000

Indices	**Abidjan aéroport**			**Adiaké**			**Sassandra**			**Oumé**		
Indices	**P-value**	**Slope estimate**	**Significant trend at 95%**	**P-value**	**Slope estimate**	**Significant trend at 95%**	**P-value**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**
R10	0	-0.295	Yes	0	-0.247	Yes	0.001	-0.268	Yes	0.008	-0.298	Yes
R20	0.001	-0.201	Yes	0	-0.192	Yes	0	-0.269	Yes	0.005	-0.183	Yes
R40	0.021	-0.0807	Yes	0.013	-0.08	Yes	0	-0.194	Yes	0.003	-0.103	Yes
R50	0.234	-0.041	No	0.022	-0.056	Yes	0	-0.169	Yes	0.014	-0.05	Yes
R*1day	0.122	-0.656	No	0.505	-0.264	No	0.01	-1.613	Yes	0.422	-0.289	No
R*5day	0.107	-1.378	No	0.293	-0.727	No	0	-4.089	Yes	0.225	-0.721	No
R95p	0.172	-3.609	No	0.062	-3.634	No	0	-13.256	Yes	0.003	-5.258	No
R99p	0.108	-2.786	No	0.272	-1.428	No	0.008	-5.137	Yes	0.421	-0.965	No
SDII	0.568	-0.015	No	0.116	-0.029	No	0	-0.174	Yes	0.285	-0.026	No
PRCPTOT	0.002	-11.994	Yes	0	-10.1	Yes	0	-19.672	Yes	0	-12.316	Yes
CWD	0.042	-0.066	Yes	0.031	-0.048	Yes	0.503	-0.033	No	0.61	-0.011	No
CDD	0.036	0.279	Yes	0.278	0.11	No	0.446	0.125	No	0.034	0.55	Yes

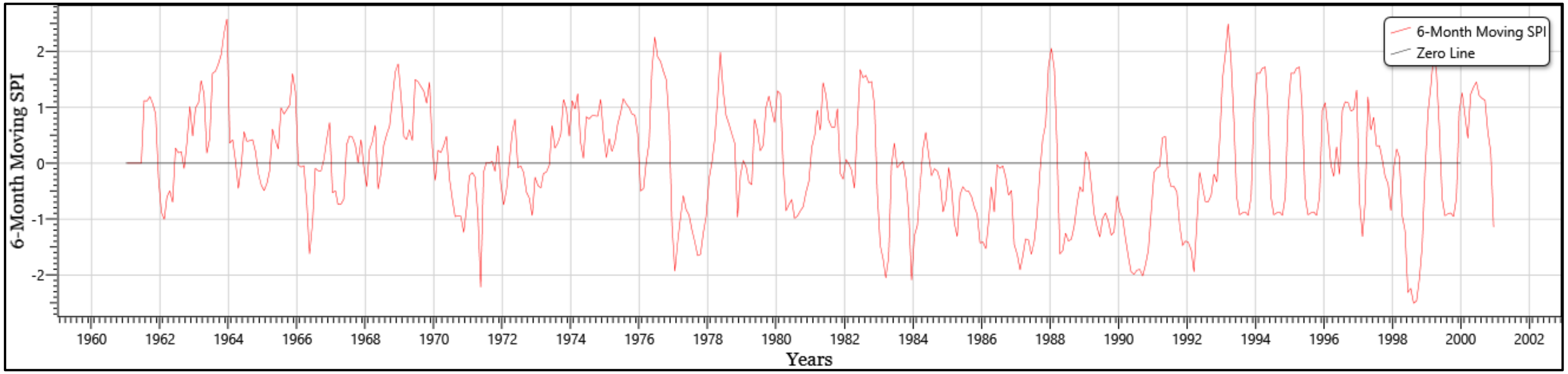
Indices	**Manignan**			**Odienné**			**Tai**			**Adzope**		
Indices	**P-value**	**Slope estimate**	**Significant trend at 95%**	**P-value**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**
R10	0	-0.573	Yes	0.007	-0.267	Yes	0.385	-0.142	No	0.158	-0.175	No
R20	0	-0.352	Yes	0.002	-0.257	Yes	0.808	0.03	No	0.576	-0.05	No
R40	0	-0.177	Yes	0.706	-0.013	No	0.162	0.117	No	0.934	-0.004	No
R50	0.004	-0.111	Yes	0.109	-0.039	No	0.045	0.118	Yes	0.288	-0.036	No
R*1day	0.314	-0.635	No	0.014	-0.812	Yes	0.051	1.149	No	0.064	-0.604	No
R*5day	0	-2.561	Yes	0.036	-1.033	Yes	0.174	1.598	No	0.27	-0.65	No
R95p	0.008	-8.482	Yes	0.016	-4.313	Yes	0.042	10.288	Yes	0.191	-3.108	No
R99p	0.269	-2.435	No	0.012	-3.366	Yes	0.079	4.993	No	0.174	-1.835	No
SDII	0.942	0.003	No	0.028	-0.048	Yes	0.522	-0.029	No	0.007	-0.102	Yes
PRCPTOT	0	-21.437	Yes	0.001	-10.624	Yes	0.271	7.275	No	0.032	-9.279	Yes
CWD	0	-0.142	Yes	0.158	-0.043	No	0.957	-0.002	No	0	-0.092	Yes
CDD	0.134	-0.635	No	0.789	-0.096	No	0.235	-0.28	No	0.074	0.482	No

Based on the results obtained from all indices, we notice a decreasing trend. The R10mm, R95p and PRCPTOT showed the highest significant decreasing trend in most of the stations resulting to rainfall decline in the region. Out of all the indices computed, the R*1day and CDD were the only indices which revealed an increasing rainfall trend. Indeed, these results are similar to those of (New et al., 2006) which in their study of daily extreme events showed that the South and West of Africa are experiencing a decrease in annual total rainfall. (Aguilar et al., 2009) in their analysis of rainfall in Central Africa between 1955 and 2006 came to the same conclusions. Similarly, (Sahani, 2011) demonstrated the decline in most rainfall indices in the city of Butembo (North Kivu/DRC) and (De Longueville et al., 2016) showed that the maximum number of consecutive wet days has decreased while the maximum number of consecutive dry days has increased in all stations in Burkina Faso.

Standardized Precipitation Index (SPI)

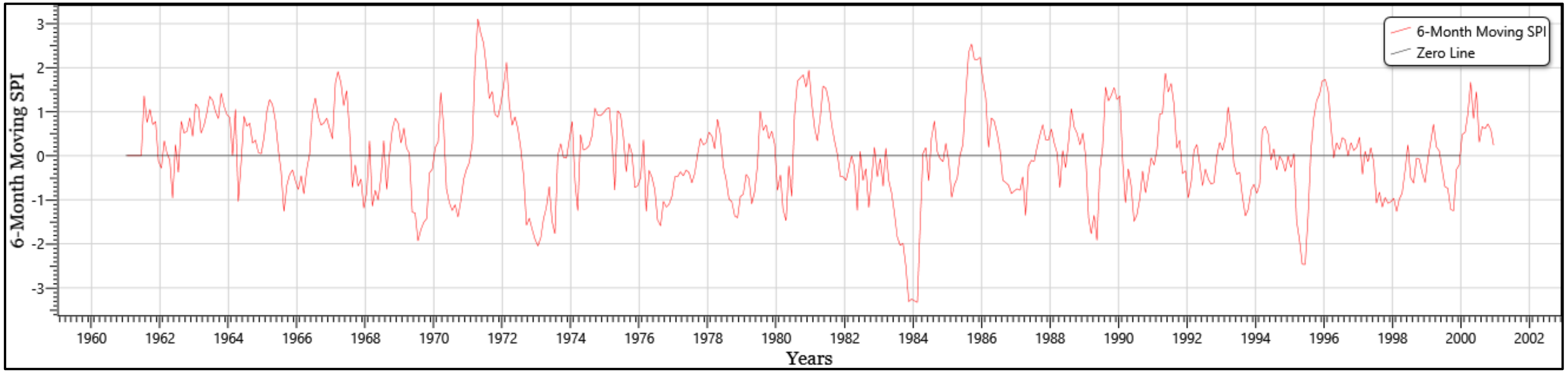
In this study, the Standardized Precipitation Index for 6 and 12 timescales were performed to characterize agricultural, meteorological and hydrological droughts respectively by RDIT (Rainfall-based Drought Indices Tool) software. **Figure 36** (a, b, c, d, e) and **Figure 37** (a, b, c, d) highlight temporal variations of SPI-6 and SPI-12 which indicated different trend in their characteristics in terms of severity and duration.

SPI-6 for Abidjan-aéroport



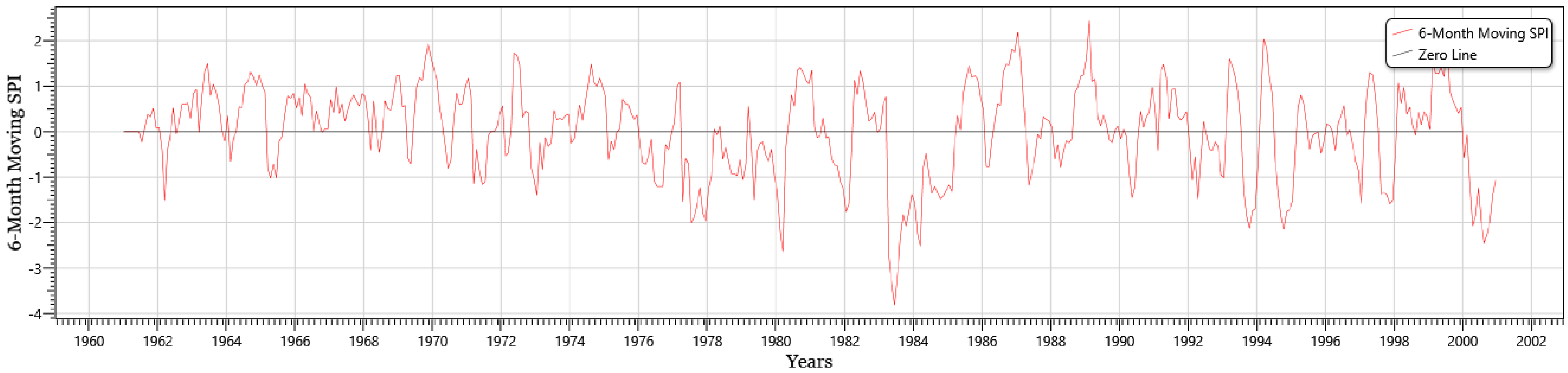
(a)

SPI-6 for Beoumi



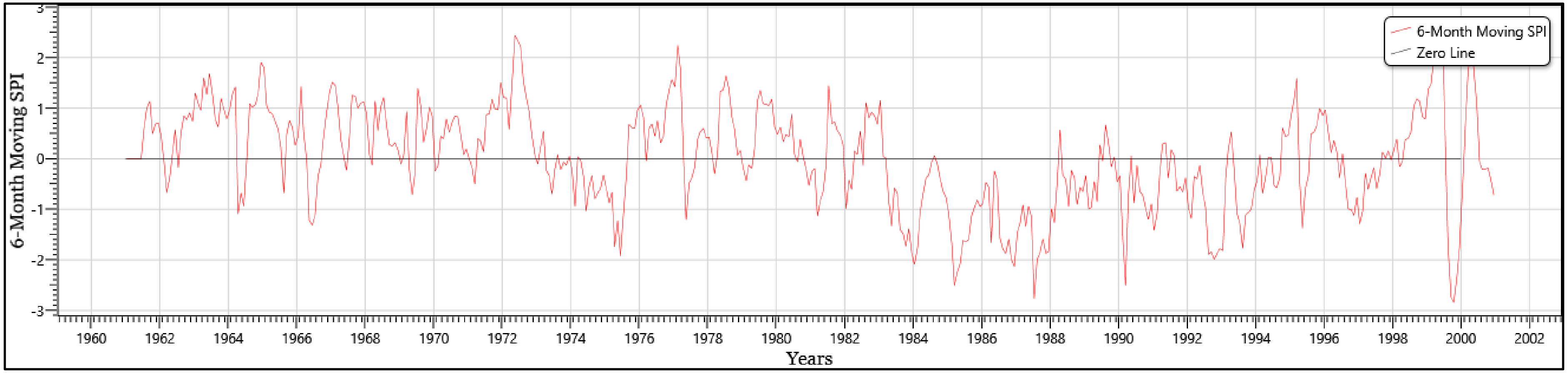
(b)

SPI-6 for Ouangolodougou



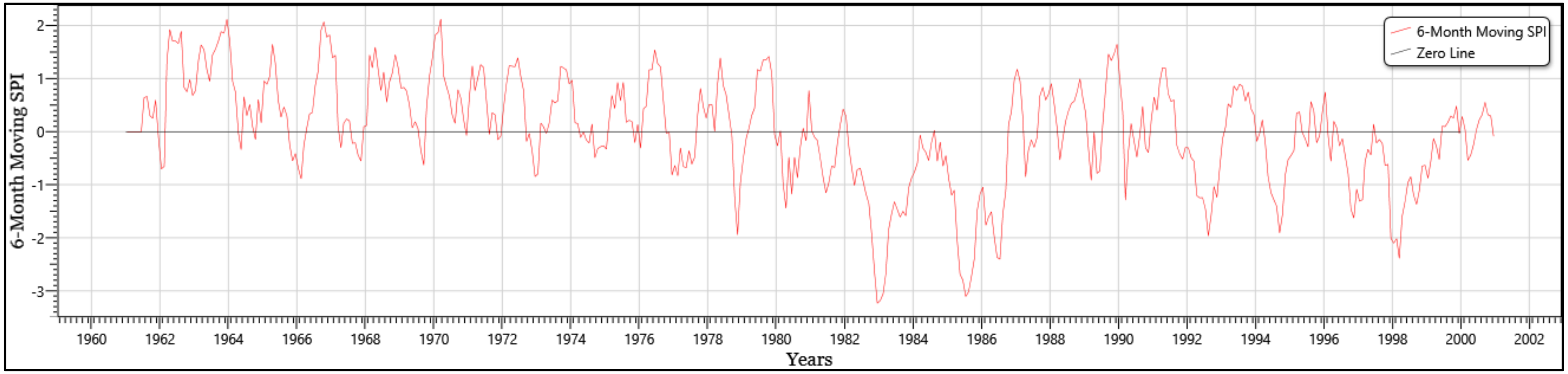
(c)

SPI-6 for Odienné



(d)

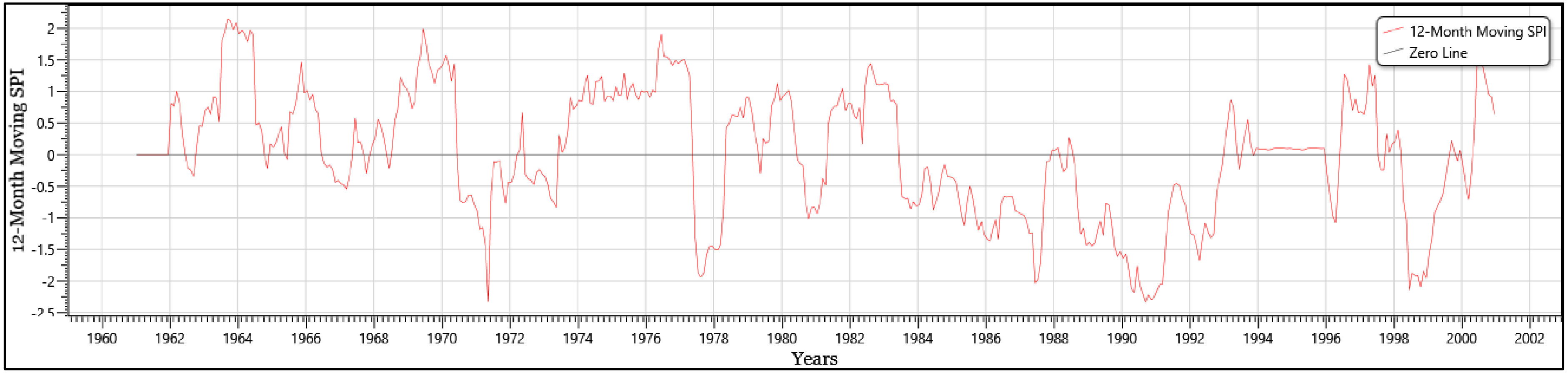
SPI-6 for Oumé



(e)

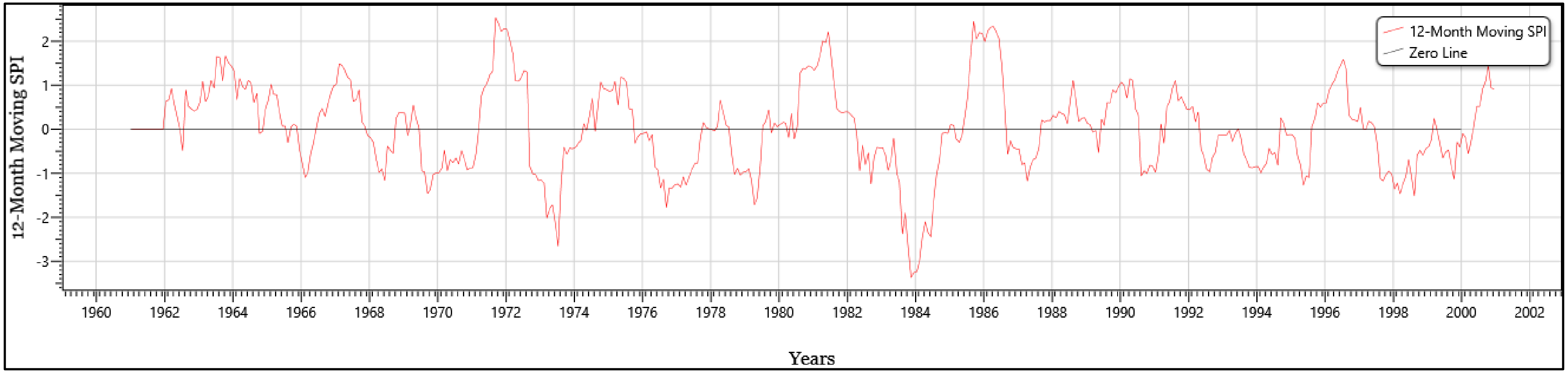
Figure 36: Variation of SPI-6 for some stations in Côte d'Ivoire Abidjan aéroport (a), Beoumi (b), Ouangolodougou(c), Odienné (d), Oumé (e)

SPI-12 for Abidjan-aéroport



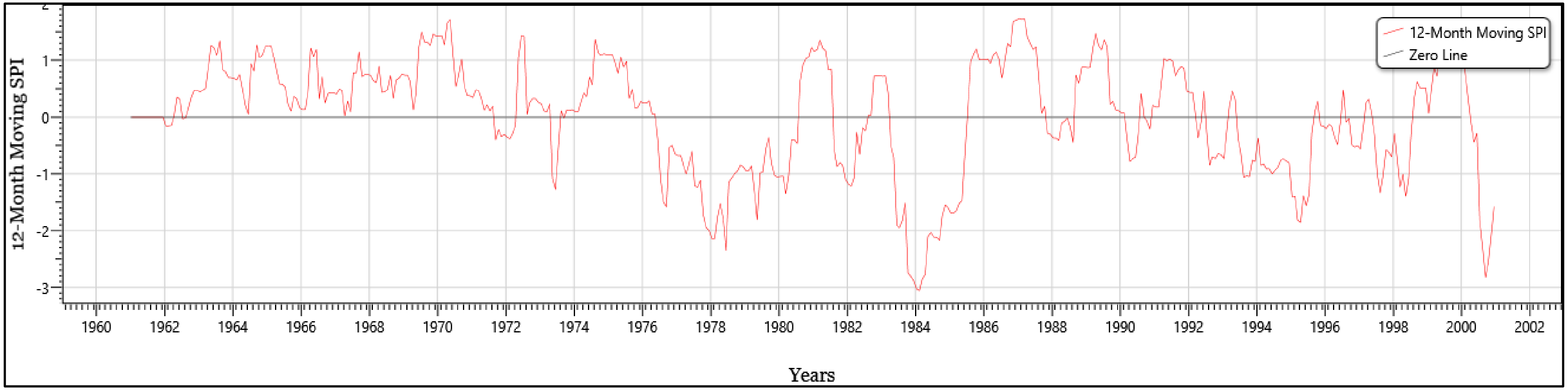
(a)

SPI-12 for Beoumi



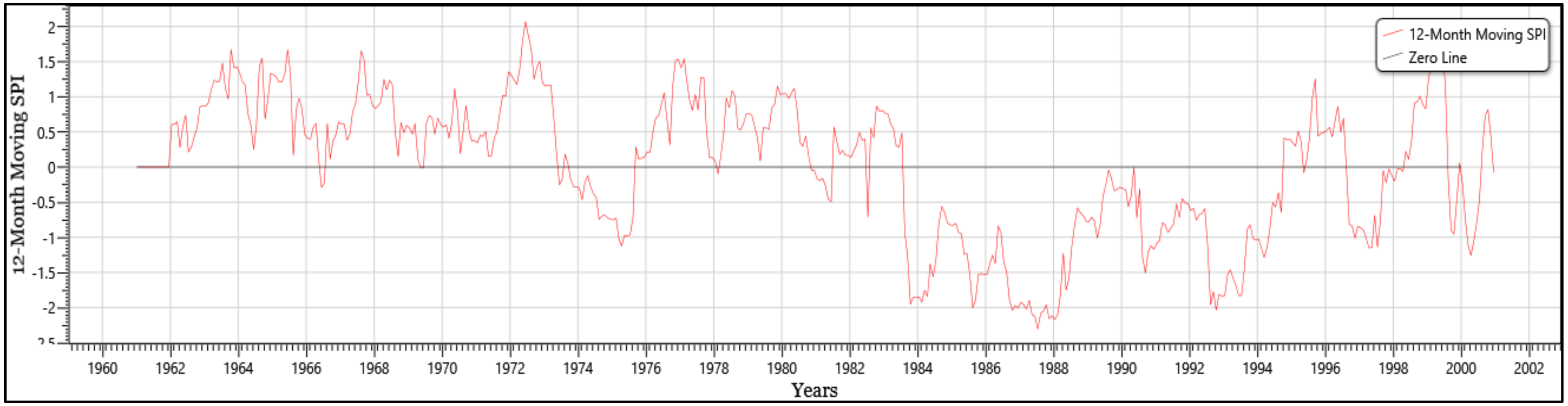
(b)

SPI-12 for Ouangolodougou



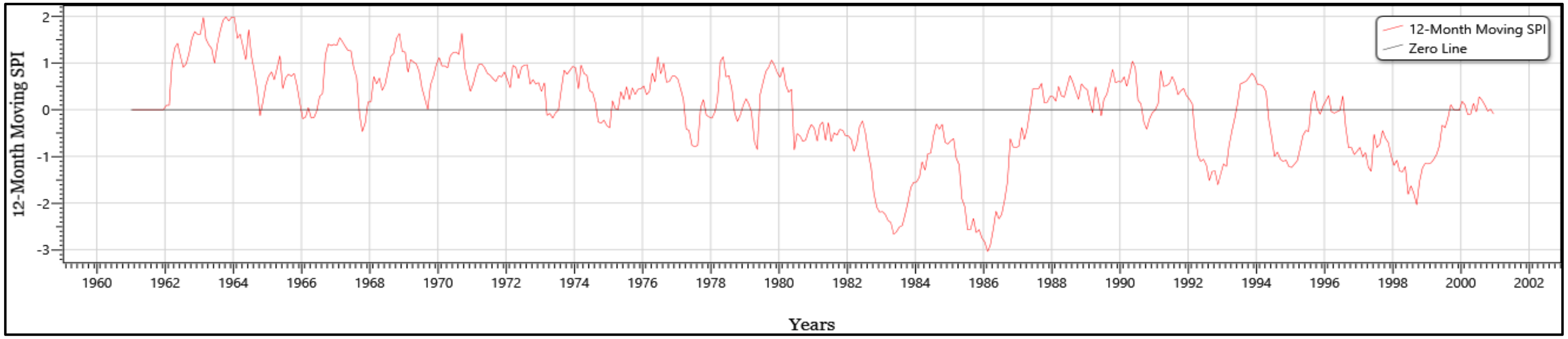
(c)

SPI-12 for Odienné



(d)

SPI-12 for Oumé



(e)

Figure 37: Variation of SPI-12 for some stations in Côte d'Ivoire Abidjan aéroport (a), Beoumi (b), Ouangolodougou (c), Odienné (d), Oumé

In Odienné station, **SPI-6** (agricultural and meteorological droughts) detected extreme droughts in (**1984, 1985, 1986, 1987, 1990 and 1999).** The 1985 drought was more severe than the one of 1987 and 1999 in term of duration. The most extreme drought events started in January to September 1985 with duration of 16 days and severity of **-2.516**. Most of period indicated moderate drought and wetter periods. Indeed, the **SPI-12** (hydrological drought) noted a severe drought with duration of 46 days between the period of July 1986 to July 1988 and the severity was observed in July 1987 **(-2.307**). The period 1992-1993 show another drought with duration of 25 days and severity of **-2.038**.

In Oumé station, **SPI-6** indicated four extreme droughts in 1982, 1983, 1985, 1986, 1997 and 1998. The period between February 1985 to September 1986 was the most severe drought period with duration of 39 days and severity of **-3.107** observed in July 1985. While the drought of 1982 started from August 1982 until November 1983 with 31 days of duration. **SPI-12** showed extreme droughts in 1982, 1983, 1985, 1986 and 1998. The most extreme drought was started on March 1985 to September 1986 with duration of **44** days and severity of **-3.042.** The drought observed on 1983 was the most extreme **(-2.671**) than the one of 1998 with regards to duration and intensity.

In Beoumi staton, **SPI-6** shows four extreme droughts in 1973, 1983 1984 and 1995. The period between June 1983 and March 1984 experienced the most severe drought extended over a period of **25** days with severity of **-3.331**. The drought of 1995 was more severe but with lower duration. **SPI-12** noted three extreme droughts in 1973, 1983 and 1984. The period between June 1983 to August 1984 present the most severe drought in term of duration (35 days) and severity **(-3.374**). We notice that moderately drought is frequent in Beoumi.

In Ouangolodougou station, the result of **SPI-6** shows that severe droughts are more frequent than extreme drought. Severe droughts are shown in (1977, 1978, 1983 and 1984). The drought started on April 1983 to March 1984 was the most extreme drought with duration of 36 days and severity of **-3.817** and **-3.165** observed in June and July respectively. Indeed, SPI -12 displays one extreme drought event in 1984 and one severe drought in 1978. The drought of 1984 started in June 1983 to May 1985 with duration of 50 days and severity of **-3.054**.

In Abidjan aéroport station, **SPI-6** shows four extreme droughts in 1971, 1983, 1990 and 1998. The two severe periods in term of duration and severity were the period from February to November 1990 and the period from May to November 1998. **SPI-12** indicated severe droughts in 1977, 1978, 1989, 1990, 1991 and 1998. The most severe period was started from September 1989 to April 1991 with duration of 38 days and severity of -2.341. The highest moderate drought was showed in 1992.

From these results based on SPI-6 and SPI-12, we notice that agricultural, meteorological and hydrological droughts are frequent in Côte d'Ivoire between the period 1961-2000. Indeed, we realize also that whatever the timescales and climates zones, moderate droughts occur frequently than the other types of droughts since 1980. The most severe and extreme droughts was observed in 1977, 1983, 1984, 1988 and 1998. The drought observed could be due to the spatial and temporal variability of rainfall within the timescales, dry period within the seasonal rainy period and the severe drought that faced most sub-Saharan Africa countries after 1970.

The figures (**Figure 38, Figure 40**, **Figure 40** and **Figure 41**) show the spatial distribution of SPI-6 and SPI-12 for the years 1983, 1984, 1993 and 1998 considered as the most severe period (These maps were done by ArcGIS 10.4 using kriging interpolation method).

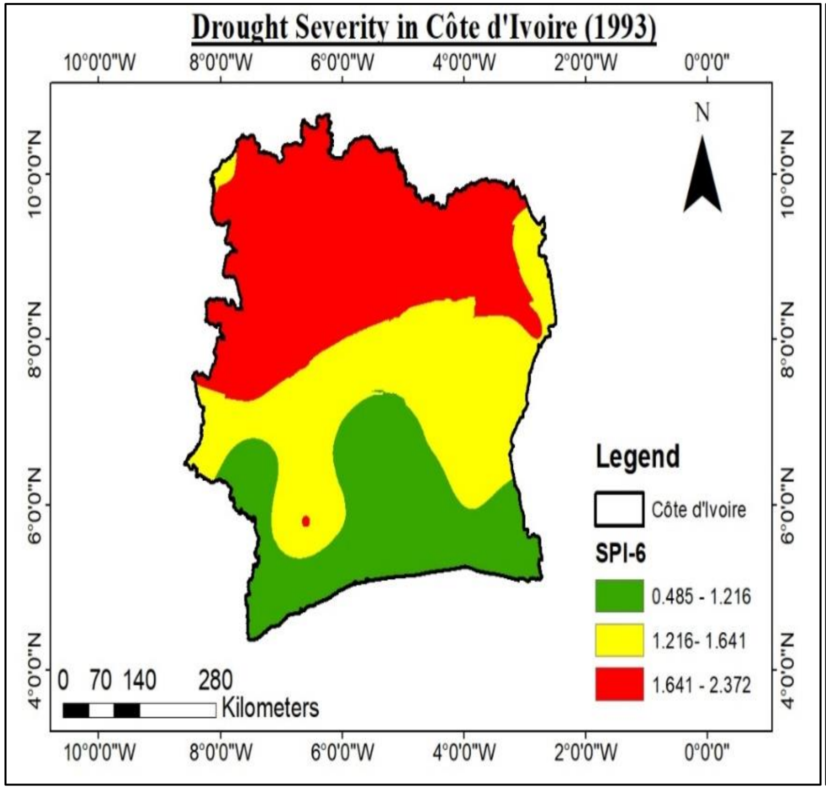


Figure 38: Drought severity of SPI-6 in Côte d'Ivoire (1993**)**

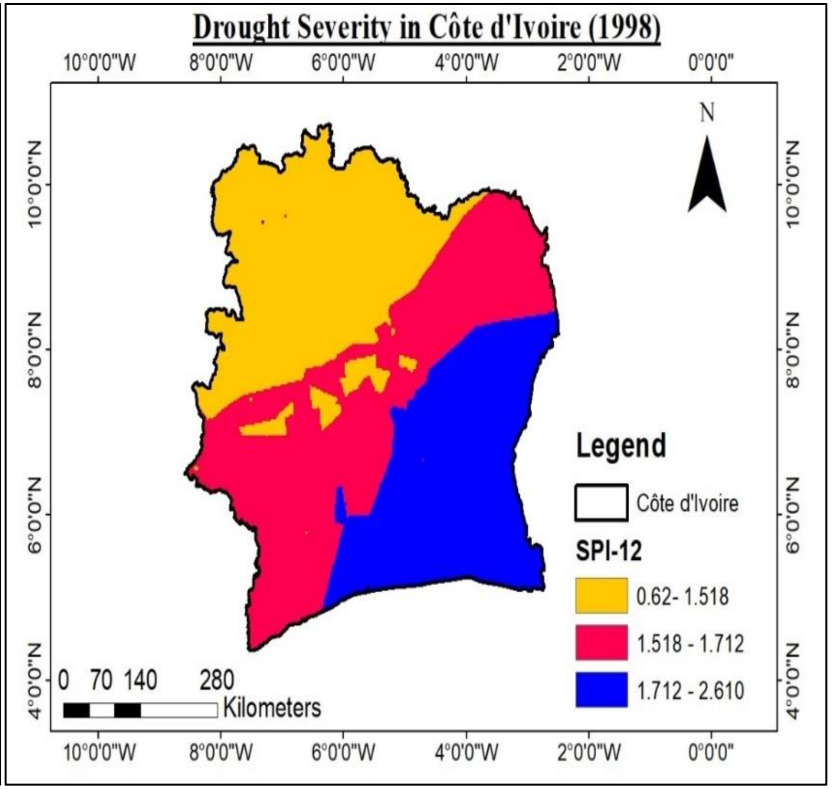
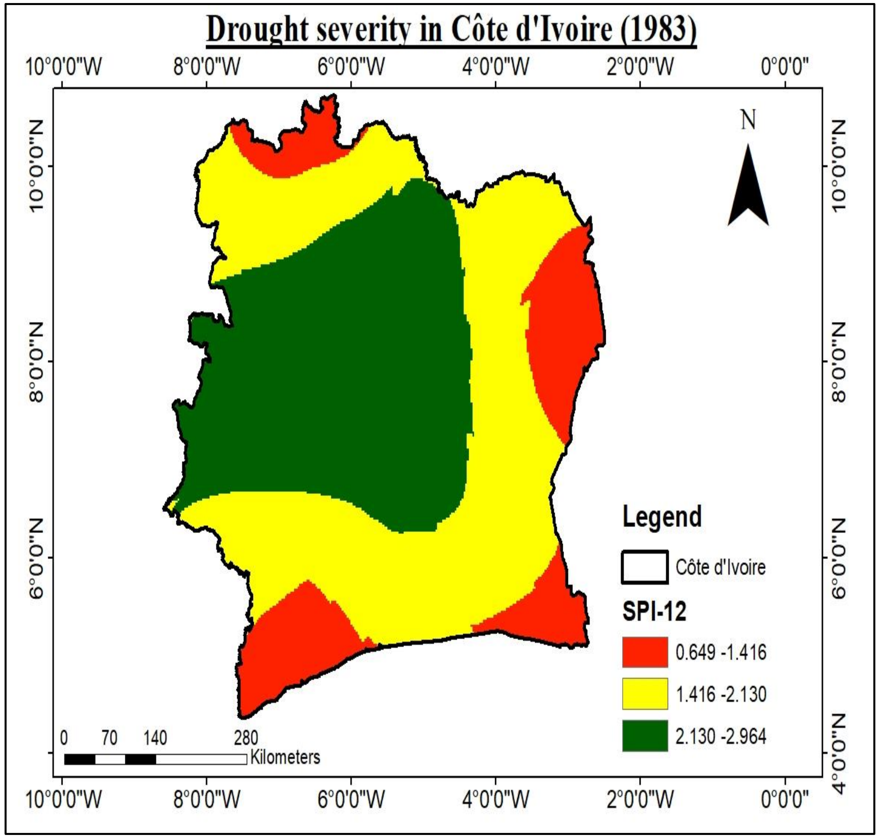


Figure 39: Drought severity of SPI-12 in Côte d'Ivoire (1998)



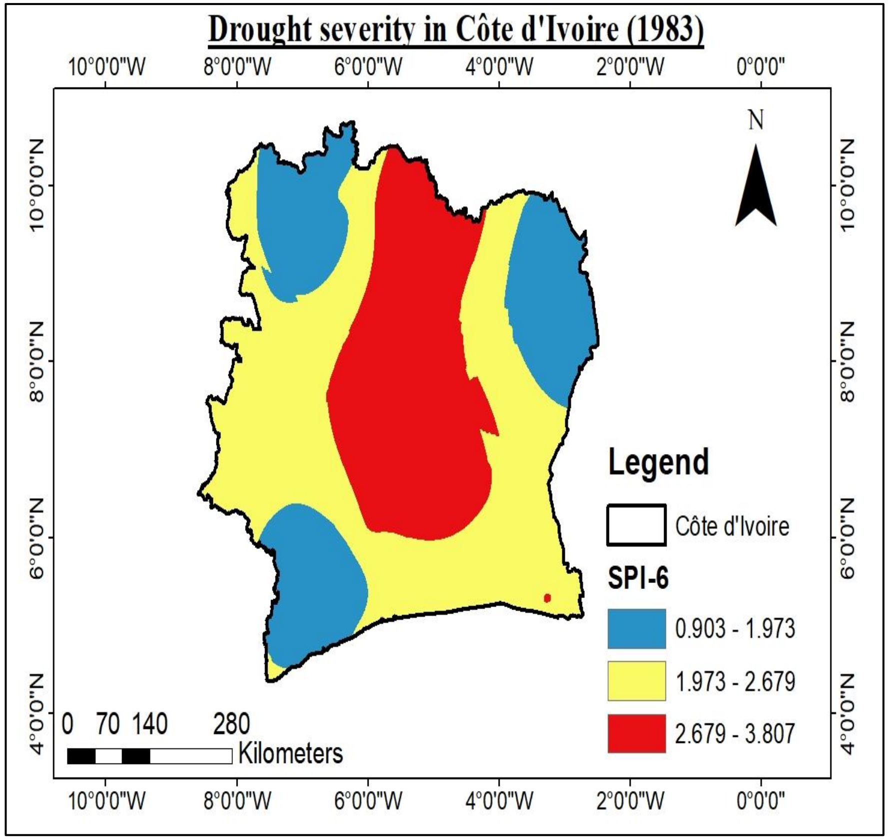
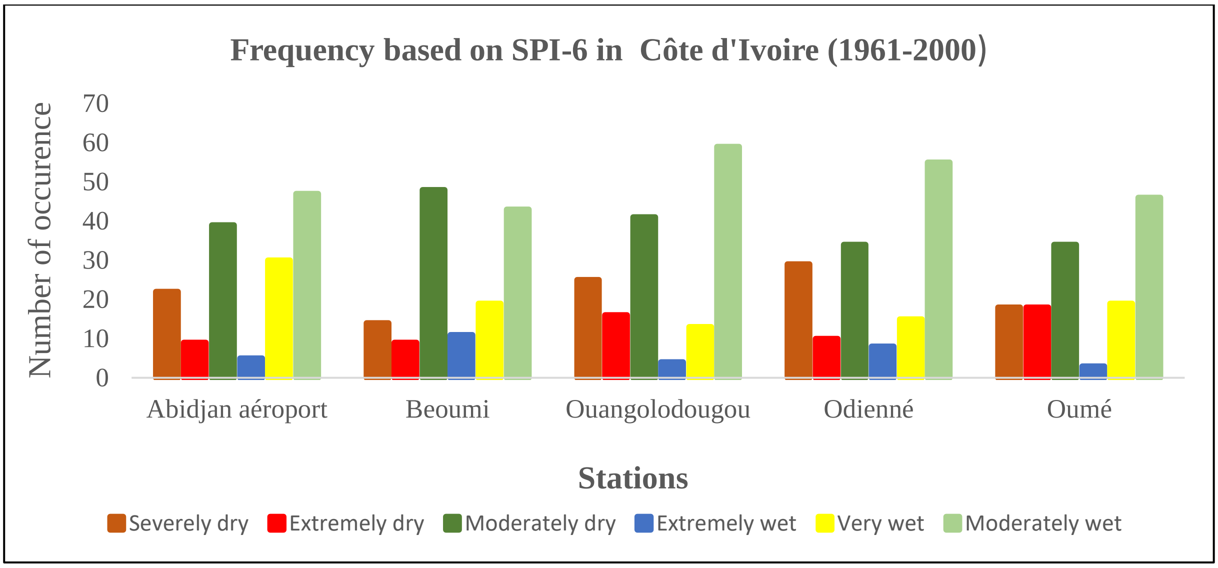


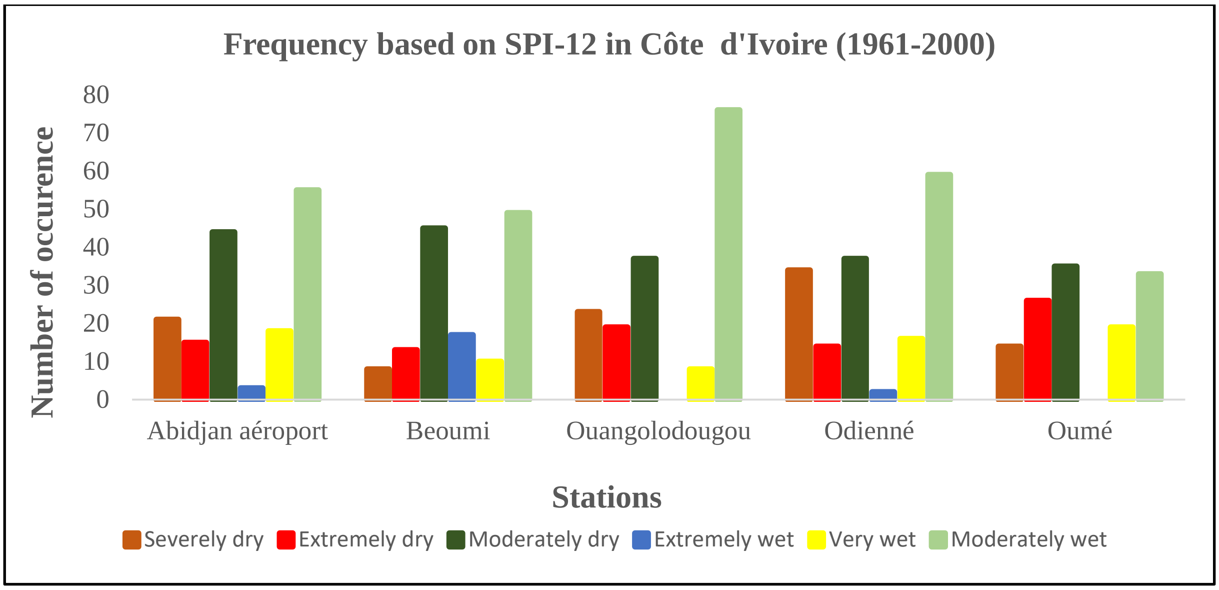
Figure 40: Drought severity of SPI-12 in Côte d’Ivoire (1983)

Figure 41: Drought severity of SPI-6 in Côte d’Ivoire (1983)

The **Figure 42** show drought and flood frequencies from the period 1961-2000 in Côte d'Ivoire based on SPI-6 and SPI-12. The **Figure 42** (a and b) show that Oumé and Ouangolodougou stations experienced the highest number of extreme drought **(26)** and **(19)** while the lowest number was observed in Beoumi **(9)**. However, based on both indices SPI-6 and SPI-12, Odienné indicated high number of severe drought (**29**) and (**24**) respectively. All the stations show huge number of moderate wet and dry period. Ouangolodougou recorded the maximum number of moderately wet period **(76)**. According to **Figure 42** (b), Beoumi station shows the highest number (**17**) of extreme wet conditions. The result observed for all the time scales show that Côte d'Ivoire is prone to droughts and floods conditions between 1961 to 2000. Although, drought occurred more frequently than flood during this period.



(a)



(b)

Figure 42: Drought and flood frequencies for SPI-6 (a) SPI-12 (b) in Côte d'Ivoire

4.6 Modeling Approach

4.6.1 Calibration and Validation of Hydrological model

5-years Sliding calibration test

The objective is to know how X1 (Maximum capacity of soil reservoir), X2 (exchange function) parameters and the Nash-Sutcliffe criterion (NSE) are evolved for all stations and which period is the most suitable for calibration model. The **Figure 43** to the **Figure 47** shows the result of this test.

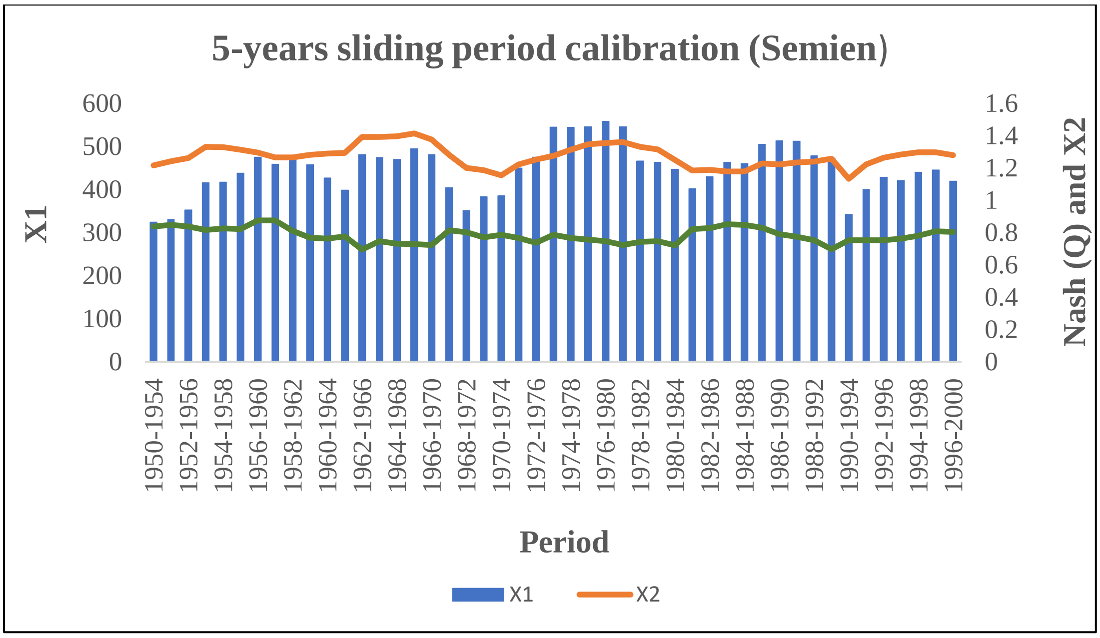


Figure 43: 5-years sliding calibration (Semien)

From the observation of **Figure 43**, we notice that the Nash criterion Nash (Q) varies from 69.44 to 87.64; X1 from 324.56-558.44 and X2 from 1.13 to 1.41 in Semien. The maximum (**87.64 %**) Nash (Q) was observed in **1956-1960.** This period is the suitable for calibration due to its high performance. However, the minimum (**69.44%**) Nash (Q) was noted in 1962-1966. Indeed, the result highlighted the Nash (Q) is varies from all period but range from good to very good values with no trend. The parameter (X1) shows variability with an alteration of higher and lower values since 1973. It seems that the X1 present an increasing trend while X2 shows a decreasing trend. The result shows that when X1 and X2 parameters are increasing the Nash criterion decreasing. The 5-years sliding calibration period show a good performance over all the period 1950-2000. Indeed, the average Nash (Q) from the period 1960 to 2000 is **74.71 %**. It could be due to the good adequation between the model and the rainfall/runoff process.

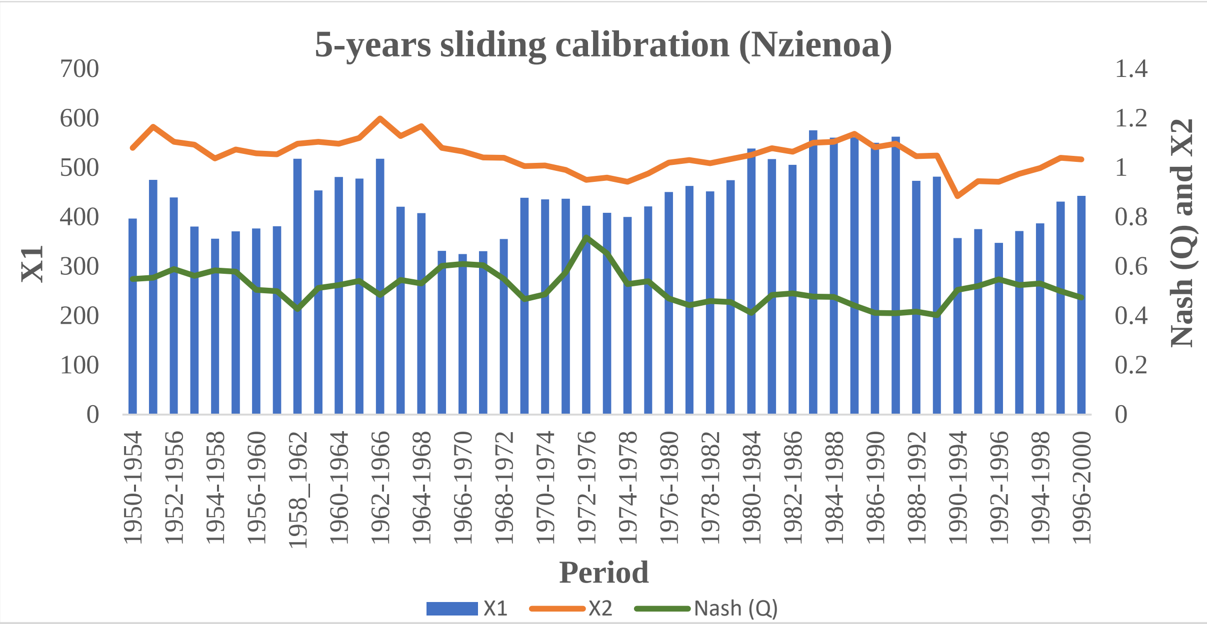


Figure 44: 5-years sliding calibration (Nzienoa)

The Nash criterion Nash (Q) ranged from **40.17** to **71.67%.** The period 1972-1976 shows the highest value (71.67%), i.e. the best performing period. The minimum Nash (Q) was observed in 1989-1993. We notice a downward trend in the Nash (Q) evolution. Two most decreasing period which show lower Nash (Q) criterion was observed in 1980-1993 and 1962-1966. The X1 parameter varies from 0.88 to 1.19 and presents an upward trend while the X2 shows a decreasing trend over all period (1950-2000). The average Nash (Q) from the period 1960-

2000 is given by **48.06 %**. We conclude that the model is not efficient namely after the period 1980. That is could be due to the high not available data in this period.

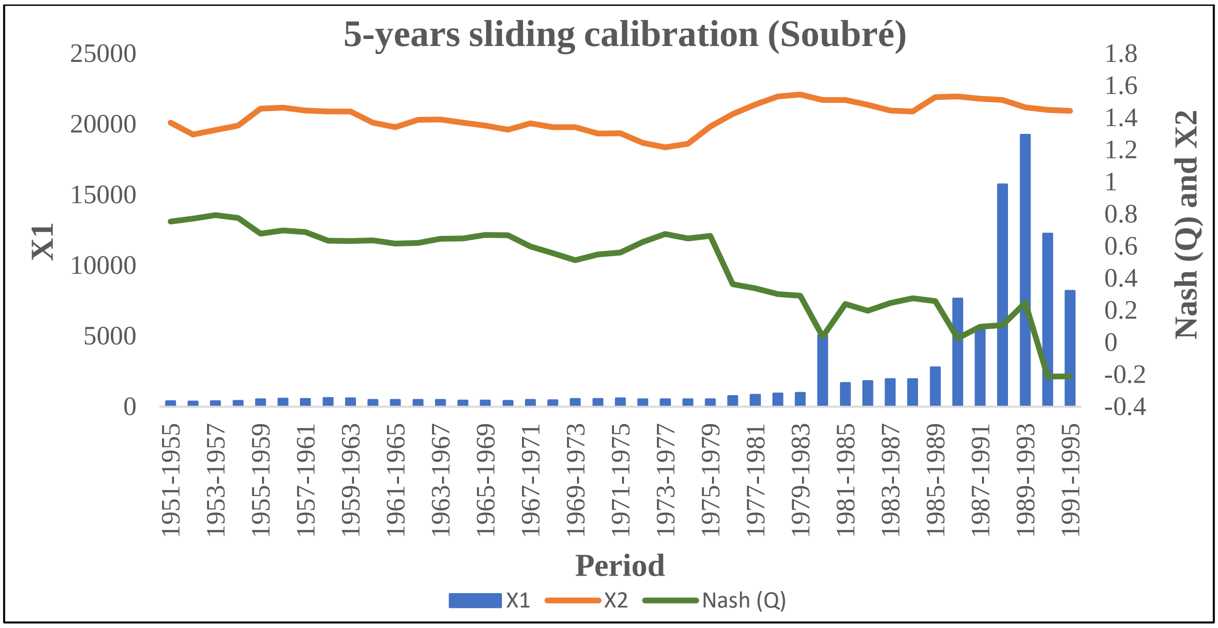


Figure 45: 5-years sliding calibration (Soubré)

In Soubré station, the period 1953-1957 indicated the higher criterion (**79.27%)**. The minimum Nash (Q) was observed in 1991-1995 (-21.23%). Only the period from 1951-1958 present a greater criterion (>70%). The Nash (Q) is significantly decreasing since 1980 to 1995 (with an average value of **16.18%**). The average Nash (Q) is equal to **42.9** from the period 1960 to 2000. The Nash (Q) shows a significant decreasing trend. The X1 range from **358.77** to **19,228.77**. We notice a significant increasing trend in the evolution of X1. The X2 range from (**1.214-1.545**) and did not show any trend. The 5-years sliding calibration is not efficient for the period after 1980. This lower performance, can be explain by the high percentage of missing data, the size of the basin and the socio-economic impact of (hydroelectric dams, agricultural dams, etc.) in the precipitation pattern since 1980. According to (Santé et al., 2019), this basin is mainly marked by strong anthropogenic pressures.

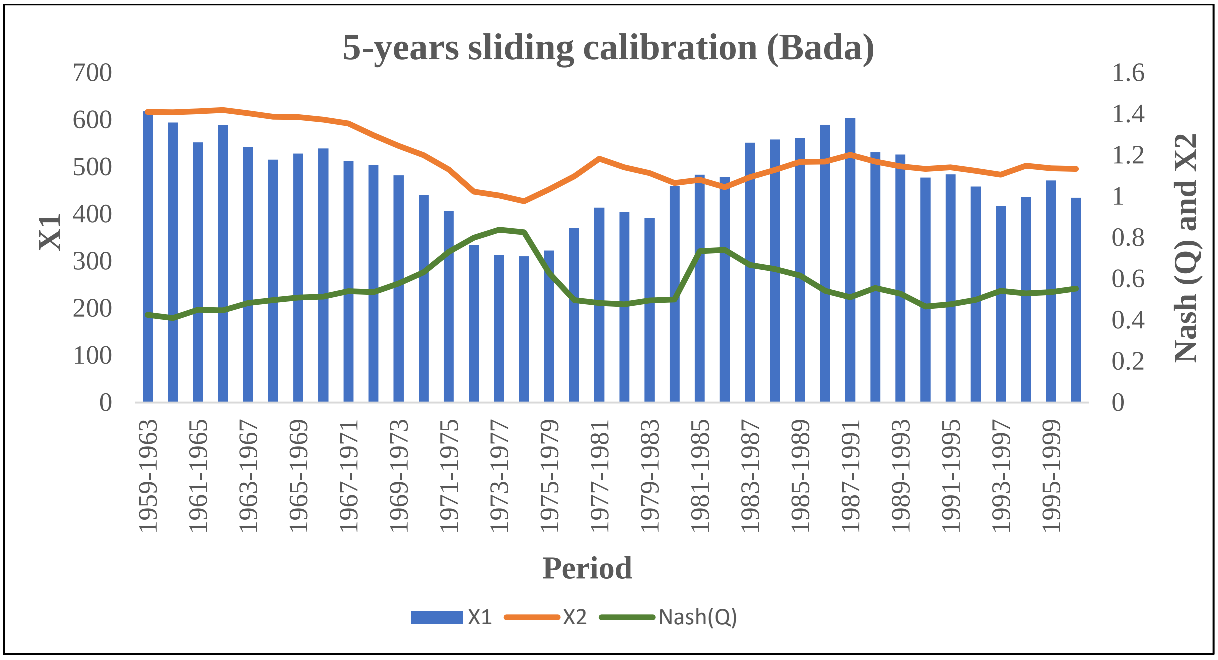


Figure 46: 5-years sliding calibration (Bada)

The Nash criterion Nash (Q) in Bada station varies from 40.98 to 83.9 %. The period 1973-1977 show the highest value of Nash (Q) that is mean the best performing period. The minimum (40.98%) Nash (Q) was observed in 1960-1964. Indeed, the Nash criterion is highly decreasing between 1959 to 1973 then increasing from 1974 to 1979 and quietly decreasing until 1984. The Nash criterion shows no trend in its evolution. The X2 range from **0.97 to 1.41** and X1 from **310.38 to 618.32**. We notice a decreasing trend the X2 distribution while X1 shows an alteration of the values in its evolution with no trend associated**.** Bada behaved differently from Nzienoa. The 5-years sliding calibration is not give a good performance overall the period (1959-1999). The average Nash (Q) from the period 1960-2000 is **51.46 %**. Indeed, this could be explained by the fact that missing data and the drought period occur after 1980 have an impact on the result.

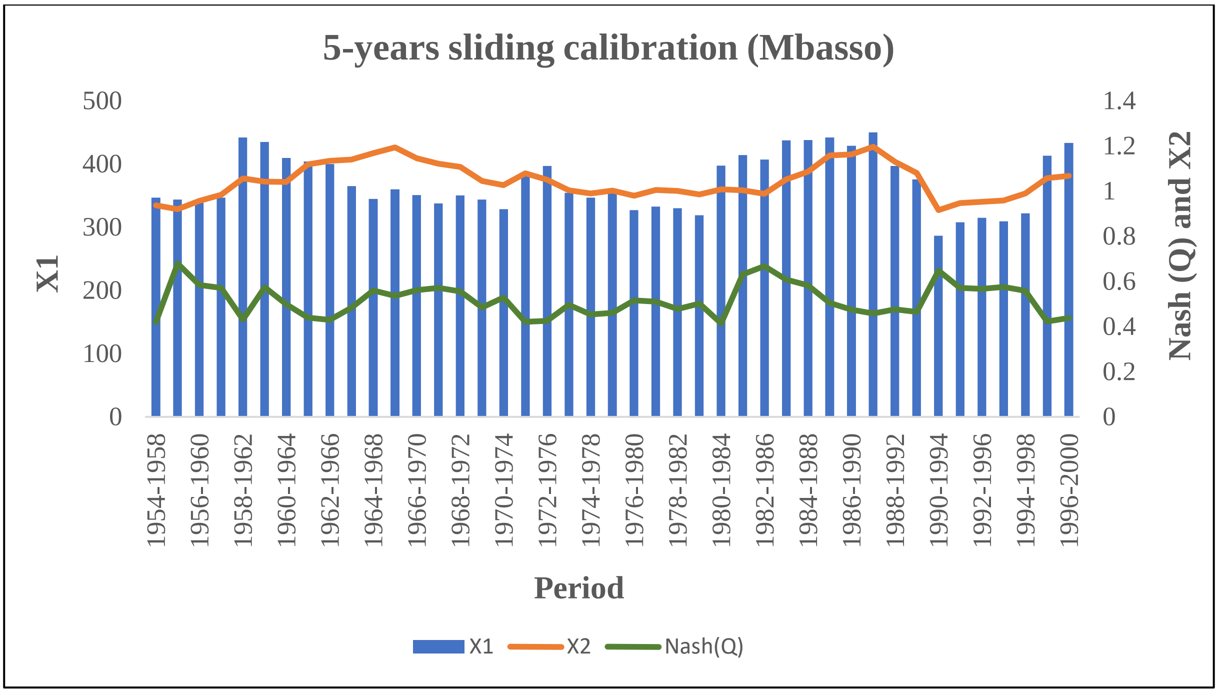


Figure 47: 5-years sliding calibration (Mbasso)

The Mbasso station indicated a Nash criterion range from **41.38-67.9%**. The lowest value of Nash (Q) is observed in 1980-1984 and the highest in 1955-1959. Indeed, there is no trend on the evolution of Nash criterion. The X1 varies from **286.70 to 450.51** while the X2 range between **0.91 to 1.19**. The both parameters are moderately variable with no trend. The higher X1 value, the lower Nash criterion. The average Nash (Q) is equal to 49.81 % from the period 1960-2000.

From the observation of the 5-years sliding calibration period, the model performs well in Semien and less good in Soubré. The Nash (Q) criterion ranges from 42.9% to 74.71 %. The X1 parameter shows no trend while X2 present a trend in most of the stations. The not available data (NA) have an impact on the calibration period.

The **Figure 48** and the **Figure 49** show the best and poor performing periods for calibration at Semien.

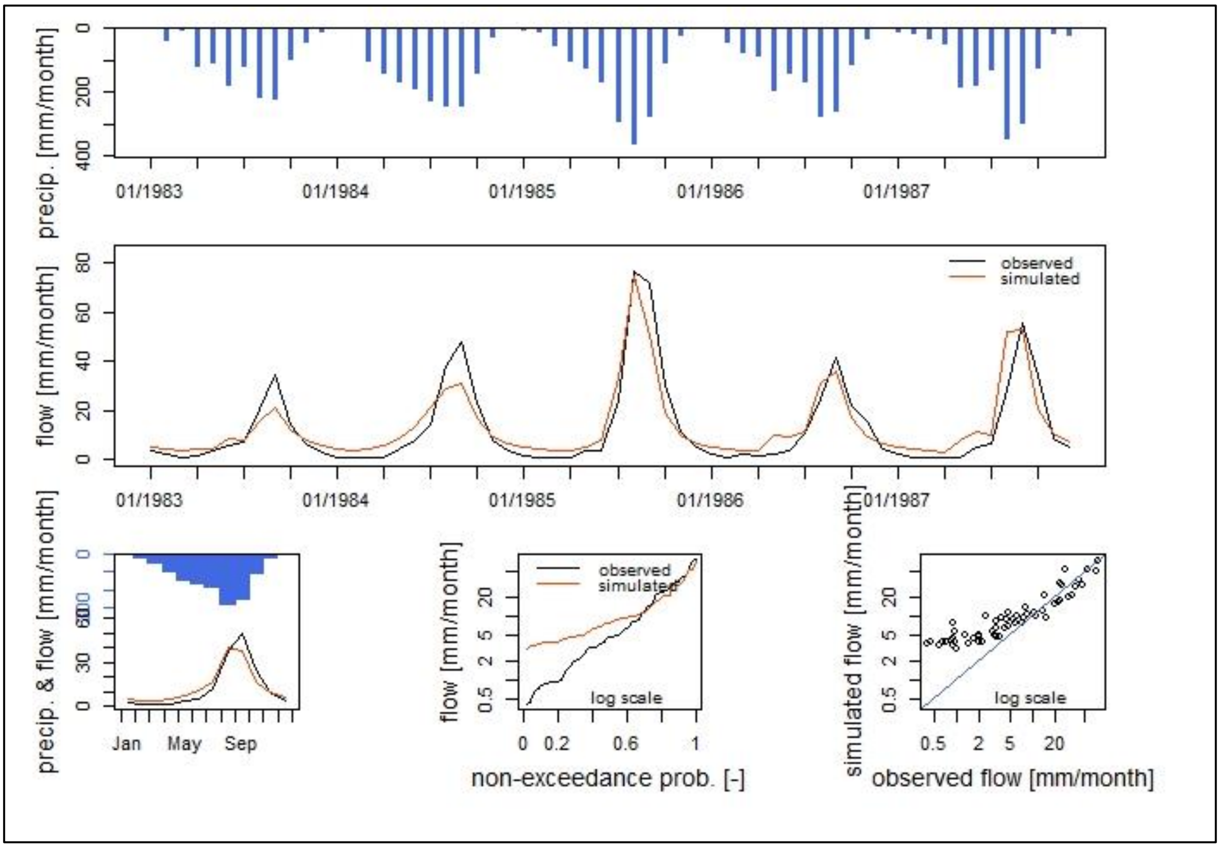


Figure 48: Best performing period at Semien (1983-1987)

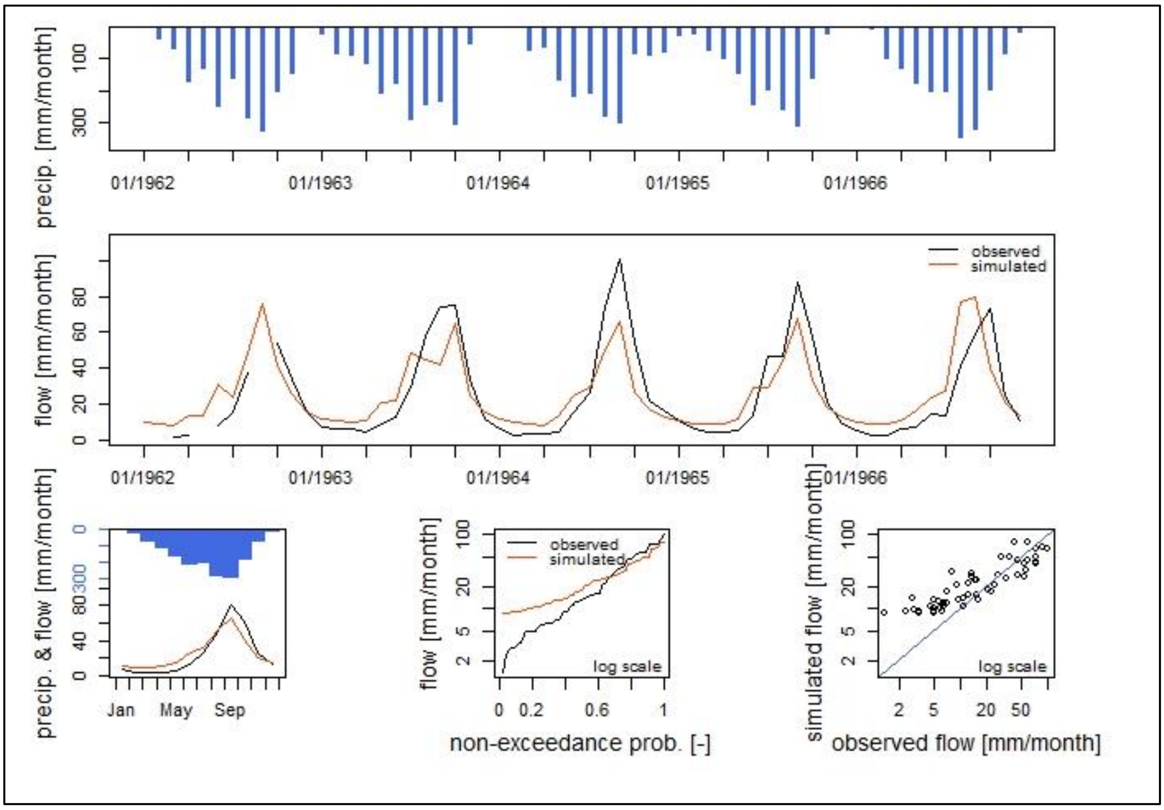


Figure 49: Poor performing period at Semien (1962-1966)

Split sample-test

The result of Split sample-test for all the stations is given by the **Table 15** to **Table 19**.

Table 15: Semien split sample-test

Calibration Semien before 1970				Validation Semien before 1970			
Calibration before 1970				1952-1956	1957-1961	1962-1966	1967-1970
Period	Nash (Q)	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1952-1956	83.83	352.96761	1.261247		62.35	**58.06**	76.31
1957-1961	87.56	459.07439	1.266286	67.17		66.25	73.14
1962-1966	69.44	481.05968	1.391824	75.46	**84.24**		77.79
Semien after 1970				**Semien validation after 1970**			
Semien				1972-1976	1977-1981	1982-1986	1992-1996
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	475.68424	1.252519	73.78		71.18	**82.35**	72.15
1977-1981	545.82934	1.361062	72.36	72.18		79.15	71.39
1982-1986	430.08285	1.188956	82.86	73.1	**69.12**		72.86
1987-1991	512.29866	1.233942	77.41	71.47	69.22	79.49	66.19

Table 16: Nzienoa split sample-test

Calibration Nzienoa before 1970				Validation Nzienoa before 1970			
Before 1970				1952-1956	1957-1961	1962-1966	1967-1970
Period	Nash (Q)	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1952-1956	58.87	439.07459	1.104054		48.81	46.72	54
1957-1961	49.94	380.96019	1.053755	56.93		**42.18**	**58**
1962-1966	48.38	518.02352	1.198719	55.92	46		51.97
Nzienoa after 1970				**Nzienoa validation after 1970**			
Nzienoa				1972-1976	1977-1981	1982-1986	1992-1996
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	422.67227	0.9500839	71.67		**42.18**	46.46	45.68
1977-1981	462.88438	1.030834	44.26	**69.26**		48.53	49.64
1982-1986	505.70604	1.064341	49	67.78	43.93		47.8
1987-1991	562.09685	1.095781	41.02	64.69	42.67	48.55	45.01

Table 17: Soubré split sample-test

Calibration **Soubré** before 1970				Validation **Soubré** before 1970			
Calibration before 1970				1952-1956	1957-1961	1962-1966	1967-1970
Period	Nash (Q)	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	
1952-1956	77.06	358.77751	1.294459		**46.6**	52.64	67.1
1957-1961	68.81	543.24714	1.444934	63.99		60.48	62.43
1962-1966	61.86	468.48477	1.387673	**70.26**	66.85		66.42
Soubré after 1970				**Soubré** validation after 1970			
Soubré				1972-1976	1977-1981	1982-1986	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1972-1976	522.5354	1.243039	62.53		24.73	**-0.5323**	
1977-1981	818.70553	1.482232	33.7	**49**		-16.42	
1982-1986	1793.7295	1.479943	19.62	33.3	20.82		
1987-1991	5651.8386	1.517343	9.79	16.39	6.44	12.03	

Table 18: Bada split sample-test

Calibration Bada before 1970				**Validation Bada before 1970**			
Bada before 1970				1959-1963	1964-1968		
Period	Nash (Q)	X1	X2	Nash (Q)	Nash (Q)		
1959-1963	42.59	618.32235	1.410521		**47.41**		
1964-1968	49.77	515.42139	1.38659	39.09			
Bada Calibration after 1970				**Bada validation after 1970**			
Bada				1972-1976	1977-1981	1982-1986	1992-1996
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	334.7142	1.024109	80.04		46.7	**28.36**	38.14
1977-1981	413.90757	1.183654	48.34	**75.68**		34.06	40.16
1982-1986	478.03133	1.045341	74.05	61.83	33.7		44.76
1987-1991	604.29574	1.20157	51.15	60.5	35.45	69.15	45.85

Table 19: Mbasso split sample-test

Calibration Mbasso before 1970				Validation **Mbasso** before 1970			
Calibration before 1970				1954-1958	1959-1963	1964-1968	
Period	Nash (Q)	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	
1954-1958	42.02	347.2344	0.9375		**52.63**	36.86	
1959-1963	57.43	434.9782	1.042082	36.61		31.96	
1964-1968	56.08	344.77362	1.168021	-168.16	**-54.05**		
Calibration Mbasso after 1970				**Mbasso** validation after 1970			
Mbasso				1972-1976	1977-1981	1982-1986	1992-1996
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	397.09937	1.051423	42.54		47.79	**60.04**	53.05
1977-1981	332.75372	1.005679	51.04	37.96		41.31	56.02

1982-1986	407.49923	0.9884946	66.84	38.8	39.83		46.09
1987-1991	450.51618	1.197704	45.8	33.67	43.26	**27.19**	42.15

The result of the split sample (Calibration and validation at the same period with same climate characteristics) show that, among all the basins, Semien is the one which give a better Nash criterion values on both calibration and validation. The average Nash (Q) on the same wet period of calibration and validation is **80.28%** and **68.92%** respectively. The average Nash (Q) on the dry period is **76.60** % and **74.51%** respectively in calibration and validation. The others station (Nzienoa and Bada) shows satisfactory result. However, we notice a negative Nash criterion in validation at Soubré and Mbasso **Nash (Q) = -0.53 %** and **-54.05%** during dry and wet period respectively.

Differential split-sample test

Differential Split-Sample Tests are used to assess the hydrological modelling robustness of the GR2M conceptual lumped model for all the basins and to test the spatial and temporal transposability of the parameters from wet to dry period and inversely. The tables 20 to 24 show the results of X1, X2 and Nash (Q) on both calibration and validation.

Table 20: Differential split sample test Semien (Semien)

Semien Calibration before 1970				**Semien validation after 1970**			
Semien Calage before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1952-1956	352.96761	1.261247	83.83	30.86	30.31	50.24	**6.72**
1957-1961	459.07439	1.266286	87.56	72.91	70.37	**82.07**	70.92
1962-1966	481.05968	1.391824	69.44	63.68	65.42	72.88	54.93
After 1970				**Semien validation before 1970**			
Semien				1952-1956	1957-1961	1962-1966	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1972-1976	475.68424	1.252519	73.78	61.41	86.87	63.29	
1977-1981	545.82934	1.361062	72.36	61.16	85.68	64.14	
1982-1986	430.08285	1.188956	82.86	64.05	**87.07**	63.66	
1987-1991	512.29866	1.233942	77.41	**49.76**	82.74	55.82	

Table 21: Differential split sample test (Bada)

Bada Calibration before 1970				Bada validation after 1970			
Calage before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1959-1963	618.32235	1.410521	42.59	47.72	42.77	15.91	24.09
1964-1968	515.42139	1.38659	49.77	**50.19**	43.96	**-5.2**	0.68
Calibration after 1970				**Bada validation before 1970**			
Bada				1959-1963	1964-1968		
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)		
1972-1976	334.7142	1.024109	80.04	**25.09**	37.96		
1977-1981	413.90757	1.183654	48.34	35	**45.34**		
1982-1986	478.03133	1.045341	74.05	25.55	25.53		
1987-1991	604.29574	1.20157	51.15	30.71	30.7		

Table 22: Differential split sample test (Nzienoa)

Nzienoa Calibration before 1970				Nzienoa validation after 1970			
Nzienoa				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1952-1956	439.07459	1.104054	58.87	37.24	30.14	**39.1**	25.34
1957-1961	380.96019	1.053755	49.94	19.48	21.28	30.12	**12.2**
1962-1966	518.02352	1.198719	48.38	14.04	17.35	33.59	22.09
Nzienoa after 1970				**Nzienoa validation before 1970**			
Calibration				1952-1956	1957-1961	1962-1966	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1972-1976	422.67227	0.9500839	71.67	41.1	37.67	**32.5**	
1977-1981	462.88438	1.030834	44.26	**48.85**	41.36	38.52	
1982-1986	505.70604	1.064341	49	47.34	39.74	37.52	
1987-1991	562.09685	1.095781	41.02	44.13	37.13	34.92	

Table 23: Differential split sample test (Mbasso)

Mbasso Calibration before 1970				Mbasso validation after 1970			
Mbasso before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1954-1958	347.2344	0.9375	42.02	40.32	45.31	63.33	36.42
1959-1963	434.9782	1.042082	57.43	40.33	41.66	**65.98**	36.4
1964-1968	344.77362	1.168021	56.08	0.8	29.63	**-55.49**	29.01
Mbasso after 1970				**Mbasso validation before 1970**			
Mbasso				1954-1958	1959-1963	1964-1968	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1972-1976	397.09937	1.051423	42.54	29.57	52.67	40.81	
1977-1981	332.75372	1.005679	51.04	23.57	30.68	48.4	
1982-1986	407.49923	0.9884946	66.84	39.89	**56.97**	29.9	

1987-1991	450.51618	1.197704	45.8	**-76.07**	33.5	47.8

Table 24: Differential split sample test (Soubré)

Soubré Calibration before 1970				**Soubré validation after 1970**			
Soubré before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1952-1956	358.77751	1.294459	77.06	-36.98	-44.55	-377.56	**-2771.39**
1957-1961	543.24714	1.444934	68.81	**35.3**	19.04	-126.82	-1131.32
1962-1966	468.48477	1.387673	61.86	25.77	6.7	-181.36	-1501
Soubré after 1970				**Soubré validation before 1970**			
Soubré				1952-1956	1957-1961	1962-1966	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1972-1976	522.5354	1.243039	62.53	41.85	**60.51**	47.49	
1977-1981	818.70553	1.482232	33.7	37.12	55.7	44.26	
1982-1986	1793.7295	1.479943	19.62	2.19	23.45	15.07	
1987-1991	5651.8386	1.517343	9.79	**-13.12**	4.15	-1.87	

From the results obtained on all the basins (Semien, Mbasso, Bada, Soubré and Nzienoa), we notice that the model performs differently in calibration and validation on the periods having different climate characteristics. The calibration on the period before 1970 and the validation after 1970 in the basins resulted a lower performance (with more often negative Nash criterion as values equal to **-36.98%** in Soubré and **-5.2%** in Bada). However, the calibration on dry period (after 1970) and the validation on wet period (before 1970) show a good performance. This is highlighted by the result of calibration on 1982-1986 and validation 1957-1961 in Semien which a Nash (Q) are **82.06%** and **87.07%** respectively. Therefore, it is important to calibrate the model on the dry period and to validate on the wet period. Indeed, among all the studied basins, Semien shows a good Nash (Q) criterion values than the others. This is showing the robustness of the model in this basin.

Proxy basin-test

The **Table 25** and **Table 26** summarize the results obtained from proxy basin-test

Table 25: Semien-Soubré proxy basin-test

Calibration on Semien before 1970				Validation on Soubré before 1970			
Semien before 1970				1951-1955	1956-1960	1961-1965	1966-1969
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1951-1955	330.16437	1.242416	84.84	**74.35**	**41.76**	43.74	61.88
1956-1960	475.3074	1.295486	87.64	51.88	67.28	59.55	59.78
1961-1965	398.66057	1.29227	77.58	69.68	62.54	59.45	66.31
1966-1969	518.32618	1.42013	71.46	59.26	69.58	60.74	63.18
Semien after 1970				Validation on Soubré after 1970			
Calibration after 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	475.68424	1.252519	73.78	59.1	21.39	-88.98	**-880.6**
1977-1981	545.82934	1.361062	72.36	55.33	26.72	-74.91	-792.16
1982-1986	430.08285	1.188956	82.86	56.92	15.48	-111.86	-102.99
1987-1991	512.29866	1.233942	77.41	**62.52**	24.04	-57.02	-643.76

Table 26: Mbasso-Bada proxy basin test

Calibration on Mbasso before 1970				Validation on Bada before 1970			
Mbasso before 1970				1959-1963	1964-1968		
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)		
1954-1958	347.2344	0.9375	42.02	26.18	31.28		
1959-1963	434.9782	1.042082	57.43	29.59	31.23		
1964-1968	344.77362	1.168021	56.08	**14.75**	**39.31**		
Mbasso				**Bada**			
Calibration on Mbasso after 1970				Validation on Bada after 1970			
After 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	397.09937	1.051423	42.54	75.71	44.68	61.68	33.93
1977-1981	332.75372	1.005679	51.04	**79.97**	46.46	33.19	**2.12**
1982-1986	407.49923	0.9884946	66.84	68.07	38.16	71.23	41.61
1987-1991	450.51618	1.197704	45.8	74.14	47.57	48.67	30.21

The result highlighted a satisfactory Nash (Q) from the calibration on Semien before 1970 and validation on Soubré before 1970 with an average Nash (Q) = 60.69 %. Indeed, when we calibrated in Mbasso on the wet period and then validated on Bada on the same period, the result gives poor criterion with an average Nash (Q) = 49.84 %. We notice that when two basins are located in the same geographic area and having similar climate conditions the transposability and transferability of the parameters (X1 and X2) give better result. Indeed, as both period (wet and dry) for the basins studied (Semien-Soubré, Mbasso-Bada) show poor Nash (Q) criterion thus the parameters transferability cannot be applied on these periods.

Proxy- basin differential split-sample test

The choice based on this combination (Semien-Soubré) and (Mbasso-Bada) are: Semien-Soubré is downstream-upstream basins while Mbasso-Bada is neighboring basins.

The result of the proxy-basin differential split-sample test is given in the **Table 27** and **Table 28**.

Table 27: Semien-Soubré proxy basin differential split test

Calibration on Semien before 1970				Validation on Soubré after 1970			
Calibration before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1951-1955	330.16437	1.242416	84.84	-55.75	-60.85	-433	**-3125.47**
1956-1960	475.3074	1.295486	87.64	**53.31**	19.64	-108.4	-1020.76
1961-1965	398.66057	1.29227	77.58	14.56	-9.17	-240.88	-1899.45
1966-1969	518.32618	1.42013	71.46	35.62	16.87	-136.21	-1198.88
Semien				**Soubré**			
Calibration on Semien after 1970				Validation on Soubré before 1970			
After 1970				1951-1955	1956-1960	1961-1965	1966-1969
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	475.68424	1.252519	73.78	44.77	65.05	56.71	55.86
1977-1981	545.82934	1.361062	72.36	45.54	**66.89**	57.32	56.76
1982-1986	430.08285	1.188956	82.86	47.42	63.98	56.96	56.61
1987-1991	512.29866	1.233942	77.41	**31.26**	60.2	50.09	48.15

Table 28: Mbasso-Bada proxy basin differential split test

Calibration on Mbasso before 1970				Validation on Bada after1970			
Mbasso before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1954-1958	347.2344	0.9375	42.02	**74.34**	42.29	60.01	27.32
1959-1963	434.9782	1.042082	57.43	68.94	39.33	71.72	44.27
1964-1968	344.77362	1.168021	56.08	69.17	41.79	-34.78	**-54.72**
Calibration on Mbasso after 1970				Validation on Bada before 1970			
After 1970				1959-1963	1964-1968		
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)		
1972-1976	397.09937	1.051423	42.54	31.97	36.87		
1977-1981	332.75372	1.005679	51.04	**25.32**	37.12		
1982-1986	407.49923	0.9884946	66.84	27.02	28.72		
1987-1991	450.51618	1.197704	45.8	37.95	**44.69**		

Calibration and validation were performed in different stations having different morphologic and climate characteristics. Indeed, calibration was done in Semien and Mbasso before 1970 then validated in Soubré and Bada after 1970 respectively. The same process was repeated by inversing the rule.

The result shows generally poor Nash criterion in the stations Semien-Soubré and Mbasso-Bada. The calibration before 1970 on Semien and the validation after 1970 on Soubré give negative Nash criterion while the calibration after 1970 in Semien and the validation before 1970 on Soubré show a satisfactory result with an average **Nash(Q) = 53.97%**. Indeed, the calibration on Mbasso after 1970 then the validation on Bada before 1970 gives an average **Nash (Q) =33.70 %.** From this observation, both periods for all the basins give a bad Nash criterion does mean the transferability of the parameters upstream/downstream stations and neighboring stations cannot be applied in these basins.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study has aimed at analysing spatial and temporal rainfall variability in Côte d'Ivoire during the period 1961-2000. The analysis of the rainfall indices evolution and hydrological modelling highlighted important observations. The use of the standardized Precipitation Index (SPI) has made it possible to characterize drought conditions in the country. The SPI revealed that Cote d'Ivoire has experienced more of moderate and severe droughts (agricultural and meteorological drought) and extreme hydrological droughts. These dry events reached their peak in **1983**, **1984**, 1**985**, **1987** and **1988**. Among the twenty-seven studied stations, the North and Southeast seems to be the most affected by droughts. Mann Kendall and Pettitt test showed significant decreasing trends and break in the annual rainfall of most North and South regions while the Central western (mountainous areas) revealed an increasing trend but not significant.

Therefore, the study further showed that the annual total precipitation (PRCPTOT) and very wet days (R95p) decreasing significantly with an average of (**84.5** and **45.2** mm/decade). All the rainfall indices computed by RclimDex revealed that the South and North portion have been impacted by a huge decreasing of rainfall.

The use of the rainfall-runoff model at monthly scale GR2M at the five stations allowed to determine the best set of parameters (X1 and X2) for the 5-years sliding calibration method and Klemes test. The study noted that in order to get a high performance on both calibration and validation, it is important to calibrate the model on the dry period (after 1970) and then validated on the wet period (before 1970). Indeed, Semien station showed a better Nash (Q) criterion value than all the other stations. In addition, this study will contribute to tackle farmer's vulnerability to rainfall hazards and enable decision-makers to develop new water resource management strategies. This work allows us to understanding well the hydrological modeling, the R software and the others materials used.

5.2 RECOMMENDATIONS

Based on the findings from this study, it is recommended that

- In the future, to conduct the rainfall impact on hydrological modelling studies further in recent periods.
- To simulate the water resources of the studied basins on the horizon 2050-2100, in order to see its availability in the face of increasing demand for water resources in the future.
- These kinds of studies must be continued because the historical study is very important for climate change investigation.
- **Environmental Information System on Water Resources and their Modeling** (S*ysteme d'Information Environmentale sur les Ressources en Eau et leur Modélisation* (SIEREM) must complete their long-term stream flow, temperature and rainfall data for better calculation of rainfall climates indices and Standardized Precipitation Index (SPI) based on climate change monitoring and drought index. Rainfall and stream flow data must be collected and updated in the SIEREM database.

References

Aguilar, E., Barry, A. A., Brunet, M., Ekang, L., Fernandes, A., Massoukina, M., Mbah, J., Mhanda, A., do Nascimento, D. J., Peterson, T. C., Umba, O. T., Tomou, M., & Zhang, X. (2009). Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955-2006. *Journal of Geophysical Research Atmospheres*, *114*(2). https://doi.org/10.1029/2008JD011010

Amir, M. S. I. I., Khan, M. M. K., Rasul, M. G., Sharma, R. H., & Akram, F. (2013). Automatic Multi-Objective Calibration of a Rainfall Runoff Model for the Fitzroy Basin, Queensland, Australia. *International Journal of Environmental Science and Development*, *4*(3), 311–315. https://doi.org/10.7763/ijesd.2013.v4.361

Azizzadeh, M. R., & Javan, K. (2018). Temporal and spatial distribution of extreme precipitation indices over the lake Urmia Basin, Iran. *Environmental Resources Research*, *6*(1), 25. http://www.ipcc.ch/

Babatolu, J. S., Akinnubi, R. T., Folagimi, A. T., & Bukola, O. O. (2014). Variability and Trends of Daily Heavy Rainfall Events over Niger River Basin Development Authority Area in Nigeria. *American Journal of Climate Change*, *03*(01), 1–7. https://doi.org/10.4236/ajcc.2014.31001

Bedoum, A., Bouka Biona, C., Alladoum, M., Adoum, I., & Baohoutou, L. (2013). Variabilités climatiques et ruptures dans les séries des précipitations en République du Tchad. *Rev.Ivoir.Scci.Technol*, *21–22*, 187–208. http://www.revist.ci

Bedoum, A., Bouka Biona, C., Jean Pierre, B., Adoum, I., Mbiake, R., & Baohoutou, L. (2017). Évolution des indices des extrêmes climatiques en République du Tchad de 1960 à 2008. *Atmosphere - Ocean*, *55*(1), 42–56. https://doi.org/10.1080/07055900.2016.1268995

Belarbi, H., Touaibia, B., Boumechra, N., Amiar, S., & Baghli, N. (2017). Drought and modification of the rainfall−runoff relation: case of Wadi Sebdou basin (western Algeria). *Hydrological Sciences Journal*, *62*(1), 124–136. https://doi.org/10.1080/02626667.2015.1112394

Belaroui, & Haouchine. (2017). Modélisation Hydrologique du bassin versant d ' oued El Harrach amont à l ' aide des modèles globaux (pluie-débit). *Ressources En Eau & Changement Climatique (Eau-Societé-Climat), October*, 0–6. https://doi.org/https://www.researchgate.net/publication/321213420 Modélisation

Bodian, A. (2014). Caractéristique de la variabilité temporelle récente des précipitations annuelles au Sénégal (Afrique de l'Ouest). *Physico-Géo*, *8*.

Bra, R. K. M., Kone, B., Soro, D. P., Raymond, T. A., N'krumah, S., Soro, N., Ndione, J. A., Sy, I., & Ceccato, P. (2018). Impact of climate variability on the transmission risk of malaria in northern Cote d ’ Ivoire. *PLOS ONE*, 1–15. https://doi.org/https://doi.org/10.1371/journal.pone.0182304

D. N. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, & T. L. Veith. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *TranAmerican Society of Agricultural and Biological Engineers*, *50*(3), 885–900. https://doi.org/10.13031/2013.23153

De Longueville, F., Hountondji, Y. C., Kindo, I., Gemenne, F., & Ozer, P. (2016). Long-term analysis of rainfall and temperature data in Burkina Faso (1950–2013). *International Journal of Climatology*, *36*(13), 4393–4405. https://doi.org/10.1002/joc.4640

De Sherbinin, A., Chai-Onn, T., Jaiteh, M., Mara, V., Pistolesi, L., Schnarr, E., & Trzaska, S. (2015). Data integration for climate vulnerability mapping in West Africa. *ISPRS International Journal of Geo-Information*, *4*(4), 2561–2582. https://doi.org/10.3390/ijgi4042561

Dekoula, C. S., Kouame, B., N’Goran, K. E., Ehounou, J.-N., Yao, G. F., Kassin, K. E., Kouakou, J. B., N’Guessan, A. E. B., & Soro, N. (2019). Variabilité des descripteurs pluviométriques intrasaisonniers à impact agricole dans le bassin cotonnier de Côte d’Ivoire : cas des zones de Boundiali, Korhogo et Ouangolodougou. *Journal of Applied Biosciences*, *130*(1), 13199–13212. https://doi.org/10.4314/jab.v130i1.7

Drissa, S. T. (2013). Climate Variability Impact on Groundwater Resources in the Highest Bandama Watershed at Tortiya (Northern Côte D′Ivoire). *American Journal of Environmental Protection*, *2*(4), 103. https://doi.org/10.11648/j.ajep.20130204.11

Drouiche, A., Nezzal, F., & Djema, M. (2019). Variabilité interannuelle des précipitations dans la plaine de la Mitidja en Algérie du NordInterannual variability of precipitation in the Mitidja plain in Northern Algeria. *Revue Des Sciences de l’eau*, *32*(2), 165–177. https://doi.org/10.7202/1065205ar

Eldin, M. (1971). Le climat en Cote d’Ivoire. *ORSTOM*, *107*(2), 78–108.

Elhagrsy, R. M., Gado, T. A., & Rashwan, I. M. H. (2018). Climate change effects on annual rainfall characteristics in Egypt. *International Water Technology*, *June*, 372–382. https://www.researchgate.net/publication/324246771

Fankhauser, S., Leemans, R., Lin, E., Ogallo, L., Pittoc, B., & Rosenzweig, C. (2001). Vulnerability to climate change and reasons for concern: A synthesis. *In Climate Change 2001:Impacts, Adapdation and Vulnerability*, 913–967.

Faria Filho, D. E., Dias, A. N., Veloso, A. L. C., Bueno, C. F. D., Couto, F. A. P., Matos Junior, J. B., Barreto, K. Z. O., Rodrigues, P. A., & Carneiro, W. A. (2010). Classification of coefficients of variation in experiments with commercial layers. *Revista*

Brasileira de Ciencia Avicola, *12*(4), 255–257. https://doi.org/10.1590/S1516-635X2010000400006

Ficchí, M. A. (2017). An adaptive hydrological model for multiple time-steps : Diagnostics and improvements based on fluxes consistency. *Thesis, University Pierre et Marie Curie-Paris VI, Ecole Doctorale 398 Géosciences, Ressources Naturelles et Environnement*, 281. https://webgr.irstea.fr/wp-content/uploads/2017/09/2017-Thesis_final_Andrea_Ficchi_Irstea_2017.pdf

Forsythe, K. W., Schatz, B., Swales, S. J., Ferrato, L. J., & Atkinson, D. M. (2012). Visualization of lake mead surface area changes from 1972 to 2009. *ISPRS International Journal of Geo-Information*, *1*(2), 108–119. https://doi.org/10.3390/ijgi1020108

Goula, B. T. A., Savane, I., Konan, B., Fadika, V., & Kouadio, G. B. (2006). Impact de la variabilité climatique sur les ressources hydriques des bassins de N'Zo et N'Zi en Côte d'Ivoire (Afrique tropicale humide). *VertigO*, *7*(Volume 7 Numéro 1), 1–12. https://doi.org/10.4000/vertigo.2038

Goula, B. T. A., Soro, E. G., Kouassi, W., & Srohourou, B. (2012). Tendances et ruptures au niveau des pluies journalières extrêmes en Côte d'Ivoire (Afrique de l'Ouest). *Hydrological Sciences Journal*, *57*(6), 1067–1080. https://doi.org/10.1080/02626667.2012.692880

Goula Bi, T. ., Soro, G. ., Dao, A., Kouassi, F. ., & Srohourou, B. (2010). Frequency Analysis and New Cartography of Extremes Daily Rainfall Events in Cote d'Ivoire. *Journal of Applied Sciences*, *10*(16), 1684–1694.

Hallouz, F., Meddi, M., Mahe, G., Karahacane, H., & Ali Rahmani, S. E. (2019). Trend in precipitation and evolution of discharge in a climate change context: Wadi mina watershed in Algeria. *Revue Des Sciences de l'Eau*, *32*(2), 83–114. https://doi.org/10.7202/1065202ar

Hassan, R., & Nhemachena, C. (2008). Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. *Centre for Environmental Economics and Policy in Afica (CEEPA)*, *2*(1), 83–104. https://www.researchgate.net/publication/46534644

Hayes, M., Svoboda, M., Wall, N., & Widhalm, M. (2011). The lincoln declaration on drought indices: Universal meteorological drought index recommended. *Bulletin of the American Meteorological Society*, *92*(4), 485–488.

Houghton, J. ., Dring, Y., Griggs, D. ., Noguer, M., Linden van der, P. ., Dai, X., & Maskell, K. (2001). Climate Change. *Contribution of Working Group I to the Third Assessment Report of IPCC, January*.

Hountondji, Y., De Longueville, F., & Ozer, P. (2000). Trends in extreme rainfall events in

Benin (West Africa), 1960-2000. *1st International Conference on Energy, Environment And Climate Changes*, 1–7.

IPCC. (2012). Glossary of Terms, in : Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. *Cambridge University*, 555–556.

IPCC. (2013). Climate Change: The Physical Science Basis. *Fifth Assessment Report of the Intergovermental Panel on Climate Change*.

Jaiswal, R. K., Lohani, A. K., & Tiwari, H. L. (2015). Statistical Analysis for Change Detection and Trend Assessment in Climatological Parameters. *Environmental Processes*, *2*(4), 729–749. https://doi.org/10.1007/s40710-015-0105-3

Jongman, B., Wagemaker, J., Revilla Romero, B., & Coughlan De Perez, E. (2015). Early flood detection for rapid humanitarian response: Harnessing near real-time satellite and twitter signals. *ISPRS International Journal of Geo-Information*, *4*(4), 2246–2266. https://doi.org/10.3390/ijgi4042246

Jourda, J. P., Kouame, K. J., Saley, M. B., Eba, L. E., Anani, A. T., & Biemi, J. (2015). Détermination des zones potentiellement favorables à l'implantation de forages manuels à partir d'analyse multicritère et d'un SIG: Cas de la Côte d'Ivoire. *Revue Des Sciences de l'Eau*, *28*(2), 119–137. https://doi.org/10.7202/1032294ar

Kabore, P. N., Ouedraogo, A., Sanon, M., Yaka, P., & Some, L. (2017). Caractérisation de la variabilité climatique dans la région du Centre-Nord du Burkina Faso entre 1961 et 2015. *Climatologie*, *Volume 14*, 82–92. https://doi.org/10.4267/climatologie.1268

Kabouya, M. (1990). *Modelisation Pluie-Débit aux pas de temps mensuel et annuel en Algerie Septentrionale*. Université Paris Sud.

Karabulut, M. (2015). Drought analysis in Antakya-Kahramanmaraş Graben, Turkey. *Journal of Arid Land*, *7*(6), 741–754. https://doi.org/10.1007/s40333-015-0011-6

Khomsi, K., Mahe, G., Tramblay, Y., Sinan, M., & Snoussi, M. (2015). Trends in rainfall and temperature extremes in Morocco. *Natural Hazards and Earth System Sciences Discussions*, *3*(2), 1175–1201. https://doi.org/10.5194/nhessd-3-1175-2015

KlemeŠ, V. (1986). Operational testing of hydrological simulation models. *Hydrological Sciences Journal*, *31*(1), 13–24. https://doi.org/10.1080/02626668609491024

Knoben, W. J. M., Freer, J. E., & Woods, R. A. (2019). Technical note: Inherent benchmark or not? Comparing Nash-Sutcliffe and Kling-Gupta efficiency scores. *Hydrology and Earth System Sciences*, *23*(10), 4323–4331. https://doi.org/10.5194/hess-23-4323-2019

Kouadio, K. Y., Aman, A., Ochou, A. D., Ali, K. E., & Assamoi, P. A. (2011). Rainfall Variability Patterns in West Africa : Case of Cote d ' Ivoire and Ghana. *Journal of Environmental Science and Engineering*, *5*, 1229–1238.

Kouakou, K. E., Goula Bi, T. A., & Issiaka, S. (2007). Impacts de la Variabilité Climatique sur les Resources en Eau de Surface en Zone Tropicale Humide: Cas du bassin versant Transfrontalier de la Comé (Cote d'Ivoire-Burkina Faso). *European Journal of Scientific Research*, *16*(1), 31–43.

Lawan, K. G., BAcci, M., & Mouhaimini, M. (2014). Caracterisation Climatique De La Region De Tillaberi. *ANADIA NIger*, 1–34.

Li, X., He, B., Quan, X., Liao, Z., & Bai, X. (2015). Use of the standardized precipitation evapotranspiration index (SPEI) to characterize the drying trend in Southwest China from 1982-2012. *Remote Sensing*, *7*(8), 10917–10937. https://doi.org/10.3390/rs70810917

Lyon, S. W., King, K., Polpanich, O. uma, & Lacombe, G. (2017). Assessing hydrologic changes across the Lower Mekong Basin. *Journal of Hydrology: Regional Studies*, *12*, 303–314. https://doi.org/10.1016/j.ejrh.2017.06.007

Mahé, G., L'Hote, Y., Olivry, J. claude, & Wotling, G. (2001). Trends and discontinuities in regional rainfall of West and Central Africa: 1951–1989. *Hydrological Sciences Journal*, *46*(2), 211–226. https://doi.org/10.1080/02626660109492817

Mallakpour, I., & Villarini, G. (2016). A simulation study to examine the sensitivity of the Pettitt test to detect abrupt changes in mean. *Hydrological Sciences Journal*, *61*(2), 245–254. https://doi.org/10.1080/02626667.2015.1008482

Mathevet, T., Michel, C., Andréassian, V., & Perrin, C. (2006). A bounded version of the Nash-Sutcliffe criterion for better model assessment on large sets of basins. *IAHS-AISH Publication*, *307*, 211–219.

Mckee, T. B., Doesken, N. J., & Kleist, J. (1993). The Relationship of Drought Frequency and Duration to Time Scales. *Eighth Conference on Applied Climatology, California, Jannuary*.

McPhillips, L. E., Chang, H., Chester, M. V., Depietri, Y., Friedman, E., Grimm, N. B., Kominoski, J. S., McPhearson, T., Méndez-Lázaro, P., Rosi, E. J., & Shafiei Shiva, J. (2018). Defining Extreme Events: A Cross-Disciplinary Review. *Earth's Future*, *6*(3), 441–455. https://doi.org/10.1002/2017EF000686

MRC. (2013). Glossary of Terms and Definitions on Climate Change and Adaptation. *Climate Change and Adaptation Initiative*, 1–23.

New, M., Hewitson, B., Stephenson, D. B., Tsiga, A., Kruger, A., Manhique, A., Gomez, B., Coelho, C. A. S., Masisi, D. N., Kululanga, E., Mbambalala, E., Adesina, F., Saleh, H., Kanyanga, J., Adosi, J., Bulane, L., Fortunata, L., Mdoka, M. L., & Lajoie, R. (2006). Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research Atmospheres*, *111*(14). https://doi.org/10.1029/2005JD006289

Niasse, M., Afouda, A., & Amani, A. (2004). Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification. *UICN Union Mondiale Pour La Nature*.

Nicholson, S. E., Some, B., & Kone, B. (2000). An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Nino and the 1998 La Nina years. *Journal of Climate*, *13*(14), 2628–2640. https://doi.org/10.1175/1520-0442(2000)013<2628:AAORRC>2.0.CO;2

Noufé, D., Mahé, G., Kamagaté, B., E, S., Goula Bi Tié, A., & Savané, I. (2015). Climate change impact on agricultural production: the case of Comoé River basin in Côte d'Ivoire. *Hydrological Sciences Journal*, *60*(11), 1–26. https://doi.org/10.1080/02626667.2015.1032293

Nyatuame, M., & Agodzo, S. (2017). Analysis of Extreme Rainfall Events (Drought and Flood) over Tordzie Watershed in the Volta Region of Ghana. *Journal of Geoscience and Environment Protection*, *05*(09), 275–295. https://doi.org/10.4236/gep.2017.59019

Ologunorisa, T. E., & Tersoo, T. (2006). The changing rainfall pattern and its implication for flood frequency in Makurdi, Northern Nigeria. *Journal of Applied Sciences and Environmental Management*, *10*(3), 97–102. https://doi.org/10.4314/jasem.v10i3.17327

Paturel, J. E., Servat, E., Delattre, M. O., & Lubes-niel, H. (1998). Analyse de séries pluviométriques de longue durée en Afrique de l'Ouest et Centrale non sahélienne dans un contexte de variabilité climatique. *Hydrological Sciences Journal*, *43*(6), 937–946. https://doi.org/10.1080/02626669809492188

PNCC. (2015). Programme National Changement Climatique (PNCC). *Ministere de l'Environnement, de La Salubrite Urbaine et Du Developpement Durable*, 1–79.

Ross, I., & Robert, G. (1996). R: A language for data analysis and graphics. In *Journal of Computational and Graphical Statistics* (Vol. 5, Issue 3, pp. 299–314).

Sahani, M. (2011). Le contexte urbain et climatique des risques hydrologiques de la ville de Butembo (Nord-Kivu/RDC). *Université de Liège, Faculté Des Sciences, Thèse de Doctorat En Sciences*.

Salehnia, N., Alizadeh, A., Sanaeinejad, H., Bannayan, M., Zarrin, A., & Hoogenboom, G. (2017). Estimation of meteorological drought indices based on AgMERRA precipitation data and station-observed precipitation data. *Journal of Arid Land*, *9*(6), 797–809. https://doi.org/10.1007/s40333-017-0070-y

Santé, N., N'Go, Y. A., Soro, G. E., Meledje, N. H., & Bi, T. A. G. (2019). Characterization of meteorological droughts occurrences in Côte d'Ivoire: Case of the Sassandra Watershed. *Climate*, *7*(4). https://doi.org/10.3390/cli7040060

Savane, I., Coulibaly, M. K., & Gioan, P. (2001). Variabilité Climatique et ressources en eaux souterraines dans la région semi-montagneuse de Man. *Centre de Recherche En Écologie*, *12*(4), 231–237.

Servat, E., Paturel, J., Kouame, B., Travaglio, M., Ouedraogo, M., Boyer, J.-F., Masson, J.-M., & Marieu, B. (1998). Identification, caractérisation et conséquences d 'une variabilité hydrologique en Afrique de l 'ouest et centrale. *Water Resources Variability in Africa during the XXth Century (Proceedings of the Abidjan 98 Conference Held at Abidjan, Cote d'Ivoire, November 1998)*, *252*, 323–337.

Soro, G. E, Bi, T. A. G., Kouame, Y. M., & Yao, A. B. (2017). Climate change and its impacts on water resources in the Bandama basin, Côte D'ivoire. *Hydrology*, *4*(1), 1–13. https://doi.org/10.3390/hydrology4010018

Soro, G.E, Goula, B. T. ., Kouassi, F. ., & Srohourou, B. (2010). Evolution des intensites maximales annuelles des pluies horaires en Côte d'Ivoire. *Agronomie Africaine*, *22*(1), 33–44. https://doi.org/10.4314/aga.v22i1.62314

Soro, G E, A, G., GLD, A., Srohorou, B., & Savane, I. (2014). Caracterisation des sequences de sécheresse méteorologique a diverses échelles de temps en climat de type soudanais : cas de l'extrême Nord - Ouest de la Cote d'Ivoire. *LARHYSS Journal*, *18*(1112–3680), 107–124.

Soro, Gneneyougo Emile, Noufé, D., Bi, T. A. G., & Shorohou, B. (2016). Trend analysis for extreme rainfall at sub-daily and daily timescales in Côte d'Ivoire. *Climate*, *4*(3), 1–15. https://doi.org/10.3390/cli4030037

Stephenson, D. B. (2008). Definition, diagnosis, and origin of extreme weather and climate events. *Climate Extremes and Society*, *9780521870*, 11–23. https://doi.org/10.1017/CBO9780511535840.003

Traore, V. B., Sambou, S., Tamba, S., Fall, S., Diaw, A. T., & Cisse, M. T. (2014). Calibrating the Rainfall-Runoff Model GR4J and GR2M on the Koulountou River Basin, a Tributary of the Gambia River. *American Journal of Environmental Protection*, *3*(1), 36. https://doi.org/10.11648/j.ajep.20140301.15

UNDP. (2019). Evaluation du Paysage des situations d'urgence complexe et des catastrophes naturelles. *Plateforme Humnitaire*, 1–57.

UNICEF. (2009). Republique de la Cote D'Ivoire: Etude de Faisabilite des Forages Manuels Identification des Zones Potentiellement Favorables. *The United Nations Children's Fund, UNICEF*, *October*, *1*, 1–73. www.unicef.org

WMO. (2015). Guidelines on the Defintion and Monitoring of Extreme Weather and Climate Events. *Extreme Weather and Climate Events*, *December 2015*, 1–62.

WMO. (2018). *Guidelines on the Defintion and Monitoring of Extreme Weather and Climate Events*. *January*, 1–43.

World Bank. (2019). *Situation economique en Côte d'Ivoire*. *Juillet*, 1–64.

Yuan, X., Jian, J., & Jiang, G. (2016). Spatiotemporal variation of precipitation regime in China from 1961 to 2014 from the standardized precipitation index. *ISPRS International Journal of Geo-Information*, *5*(11), 2–18. https://doi.org/10.3390/ijgi5110194

Zhang, X., Feng, Y., & Chan, R. (2018). Introduction to RClimDex. *Climate Research Division Environment Canada*, 1–26.

APPENDIX

APPENDIX 1: Descriptive statistics of rainfall from two databases

Station code	Station Name	Coordinates (DD)		Source	Begin date	End date	NA number	% NA	Total observation	Time series (years)	Max (mm)	Min (mm)	Mean	SD
		Latitude	Longitude											
090090PJ	**Abidjan aeroport**	5.25	-3.933	Other database	1936	2005	1133	4.43%	25568	69	700	0	5.371	16.52
1090000100C				SIEREM	1936	2000	1506	6.34%	23742	64	311.6	0	5.314	16.26
090091PJ	**Adiaké**	5.3	-3.3	Other database	1944	2005	679	3.00%	22646	61	280	0	5.273	14.74
1090001300C				SIEREM	1944	2000	153	0.73%	20820	56	280	0	5.241	14.79
090006PJ	**Dembosso**	9.68333	-6.4	Other database	1961	1990	0	0.00%	10957	29	145.8	0	3.403	9.38
1090008800C				SIEREM	1961	2000	1157	7.92%	14610	39	145.8	0	3.405	10
090004PJ	**Kouto**	9.9	-6.41666667	Other database	1961	1990	0	0.00%	10957	29	115.4	0	3.423	9.5
1090012700C				SIEREM	1961	2000	1210	8.28%	14610	39	154.2	0	3.381	10
090009PJ	**Madiani**	9.61667	-6.95	Other database	1961	1990	0	0.00%	10957	29	106.9	0	3.696	9.83
1090013900C				SIEREM	1961	2000	940	6.43%	14610	39	121.8	0	3.739	10.1
090002PJ	**Manignan**	10	-7.83333333	Other database	1960	1990	0	0.00%	11323	30	283.6	0	4.151	11.74
1090014500C				SIEREM	1950	2000	607	3.26%	18628	50	283.6	0	3.811	11.4

090007PJ	**Odienne**	9.5	-7.56666667	Other database	1921	2002	35	0.12%	29950	81	181	0	4.18	11.17
1090016000C				SIEREM	1921	2000	821	2.81%	29220	79	181	0	4.196	10.97
090005PJ	**Ouangolodougou**	9.83333	-5.15	Other database	1950	1990	0	0.00%	14975	40	142.8	0	3.156	9.63
1090016300C				SIEREM	1950	2000	1157	6.21%	18628	50	142.8	0	3.095	9.75
090003PJ	**Sinhala**	10.0333	-6.85	Other database	1961	1990	0	0.00%	10957	29	159.5	0	3.432	9.11
1090017900C				SIEREM	1961	1996	1062	8.08%	13149	35	350.6	0	3.892	12.7
090001PJ	**Tengrela**	10.4833	-6.4	Other database	1950	1990	6	0.04%	14975	40	175.1	0	3.34	9.87
1090019300C				SIEREM	1953	2000	2612	14.90%	17532	47	175.1	0	3.391	10.24
090008PJ	**Tieme**	9.55	-7.31666667	Other database	1961	1990	0	0.00%	10957	29	190.6	0	3.845	10.14
1090020100C				SIEREM	1961	1999	1033	7.25%	14244	38	190.6	0	3.878	10.39

Script for conversion daily to annual rainfall time series for some stations

```
setwd("C:/Users/HALIMA/Desktop/Reference all stations/csv daily stations")
tabou<-read.csv2("Tabou.csv", dec = ".")
soubre<-read.csv2("Soubre.csv", dec = ".")
sassandra<-read.csv2("Sassandra.csv", dec = ".")
oume<-read.csv2("Oumé.csv", dec = ".")
abidjan<-read.csv2("aeroport.csv", dec = ".")
adiake<-read.csv2("adiake.csv", dec = ".")

abidjanannual<-aggregate(Value~Years, abidjan, sum)
abidjancumul<-write.csv(x=abidjanannual, file = "annual data_abidjan.csv",
row.names = TRUE)

adiakeannual<-aggregate(Value~Years, adiake, sum)
adiakecumul<-write.csv(x=adiakeannual, file = "annual data_adiake.csv", ro
w.names = TRUE)

sassandraannual<-aggregate(Rain~Year, sassandra, sum)
sassandracumul<-write.csv(x=sassandraannual, file = "annual data_sassandra
.csv", row.names = TRUE)

soubreannual<-aggregate(Rain~Year, soubre, sum)
soubrecumul<-write.csv(x=soubreannual, file = "annual data_soubre.csv", ro
w.names = TRUE)
```

Script for conversion monthly stream flow data to annual stream flow data

```
setwd("C:/Users/HALIMA/Desktop/modelisation doc/Affadine/Bassins versants
model work/CSV bassins")
Nzienoa<-read.csv2("Nzienoa.csv", dec = ".")
semien<-read.csv2("Semien.csv", dec = ".")
mbasso<-read.csv2("Mbasso.csv", dec = ".")
bada<-read.csv2("Bada.csv", dec = ".")
soubre<-read.csv2("Soubré.csv", dec = ".")

badaannual<-aggregate(Q_mm~Year, bada, sum)
badacumul<-write.csv(x=badaannual, file = "annual data_bada.csv", row.name
s = TRUE)

soubreannual<-aggregate(Q_mm~Year, soubre, sum)
soubrecumul<-write.csv(x=soubreannual, file = "annual data_soubre.csv", ro
w.names = TRUE)

mbassoannual<-aggregate(Q_mm~Year, mbasso, sum)
mbassocumul<-write.csv(x=mbassoannual, file = "annual data_mbasso.csv", ro
w.names = TRUE)

semienannual<-aggregate(Q_mm~Year, semien, sum)
semiencumul<-write.csv(x=semienannual, file = "annual data_semien.csv", ro
w.names = TRUE)
```

```
Nzienoaannual<-aggregate(Q_mm~Year, Nzienoa, sum)
Nzienoacumul<-write.csv(x=Nzienoaannual, file = "annual data_nzienoa.csv",
row.names = TRUE)
```

Script for annual descriptive analysis for rainfall time series

```
setwd("C:/Users/HALIMA/Desktop/Reference all stations/CSV daily stations")
abidjan<-read.csv2("aeroport.csv",dec = ".")
abidjan<-abidjan[9133:23742, 1:4]
adiake<-read.csv2("adiake.csv", dec = ".")
adiake<-adiake[6211:20820, 1:4]
odienne<-read.csv2("Odienne.csv", dec = ".")
odienne<-odienne[14611:29220,1:4]

summary(odienne)

##      Years          Month             Day            Value        
##  Min.   :1961   Min.   : 1.000   Min.   : 1.00   Min.   :  0.000  
##  1st Qu.:1971   1st Qu.: 4.000   1st Qu.: 8.00   1st Qu.:  0.000  
##  Median :1980   Median : 7.000   Median :16.00   Median :  0.000  
##  Mean   :1981   Mean   : 6.523   Mean   :15.73   Mean   :  3.929  
##  3rd Qu.:1991   3rd Qu.:10.000   3rd Qu.:23.00   3rd Qu.:  1.950  
##  Max.   :2000   Max.   :12.000   Max.   :31.00   Max.   :127.100  
##                                                  NA's   :395

sd(odienne$Value, na.rm = TRUE)

## [1] 10.14361

odiennetable<-table(odienne$Value, useNA = "always", deparse.level = 2)
odienneproptable<-prop.table(odiennetable)*100

summary(adiake)

##      Years          Month             Day            Value        
##  Min.   :1961   Min.   : 1.000   Min.   : 1.00   Min.   :  0.000  
##  1st Qu.:1971   1st Qu.: 4.000   1st Qu.: 8.00   1st Qu.:  0.000  
##  Median :1980   Median : 7.000   Median :16.00   Median :  0.000  
##  Mean   :1981   Mean   : 6.523   Mean   :15.73   Mean   :  5.048  
##  3rd Qu.:1991   3rd Qu.:10.000   3rd Qu.:23.00   3rd Qu.:  2.400  
##  Max.   :2000   Max.   :12.000   Max.   :31.00   Max.   :277.500  
##                                                  NA's   :1

sd(adiake$Value, na.rm = TRUE)

## [1] 14.49646

adiaketable<-table(adiake$Value, useNA = "always", deparse.level = 2)
adiakeproptable<-prop.table(adiaketable)*100

summary(abidjan)

##      Years          Month             Day            Value        
##  Min.   :1961   Min.   : 1.000   Min.   : 1.00   Min.   :  0.000  
##  1st Qu.:1971   1st Qu.: 4.000   1st Qu.: 8.00   1st Qu.:  0.000  
##  Median :1980   Median : 7.000   Median :16.00   Median :  0.000  
##  Mean   :1981   Mean   : 6.523   Mean   :15.73   Mean   :  5.042  
```

```
## 3rd Qu.:1991   3rd Qu.:10.000   3rd Qu.:23.00   3rd Qu.:  1.300
## Max.   :2000   Max.   :12.000   Max.   :31.00   Max.   :311.600
##                                                 NA's   :1460
```

```
abidjantable<-table(abidjan$Value, useNA ="always", deparse.level = 2)
abidjanproptable<-prop.table(abidjantable)*100
sd(abidjan$Value, na.rm = TRUE)
```

```
## [1] 15.8505
```

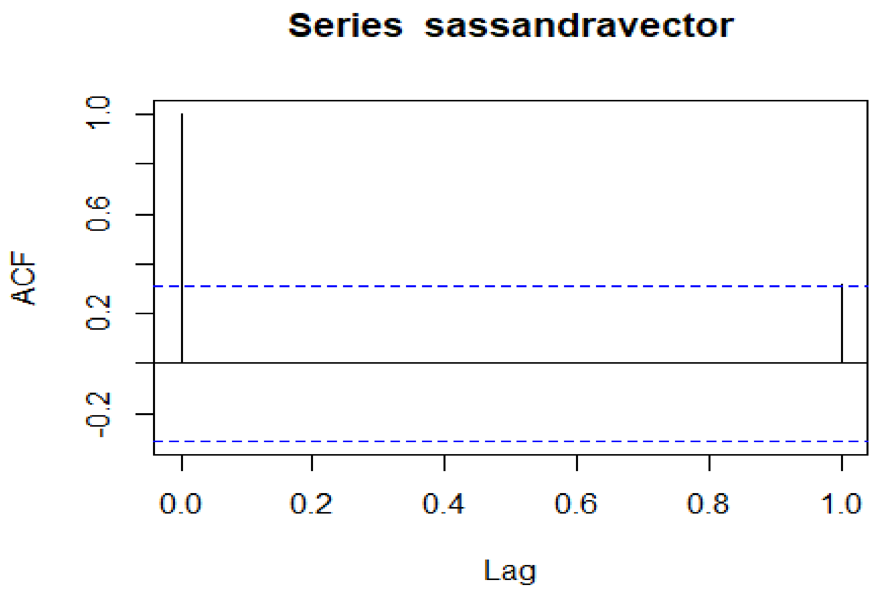
Descriptive statistic script for stream flow data

```
setwd("C:/Users/HALIMA/Desktop/modelisation doc/Periode glissants")
soubre<-read.csv2("soubre.csv", dec = ".")
soubre<-soubre[13:636,1:4]
Nzienoa<-read.csv2("Nzienoa.csv", dec = ".")
Nzienoa<-Nzienoa[13:636,1:4]
semien<-read.csv2("Semien.csv", dec = ".")
semien<-semien[13:636,1:4]
mbasso<-read.csv2("Mbasso.csv", dec = ".")
mbasso<-mbasso[13:636,1:4]
bada<-read.csv2("Bada.csv", dec = ".")
bada<-bada[13:636,1:4]

tablesemien<-table(semien$Q_mm, useNA = "always", deparse.level = TRUE)
semienproptable<-prop.table(tablesemien)*100
sd(semien$Q_mm, na.rm = TRUE)

tablenzienoa<-table(Nzienoa$Q_mm, useNA = "always", deparse.level = TRUE)
nzienoaproptable<-prop.table(tablenzienoa)*100
sd(Nzienoa$Q_mm, na.rm = TRUE)
```

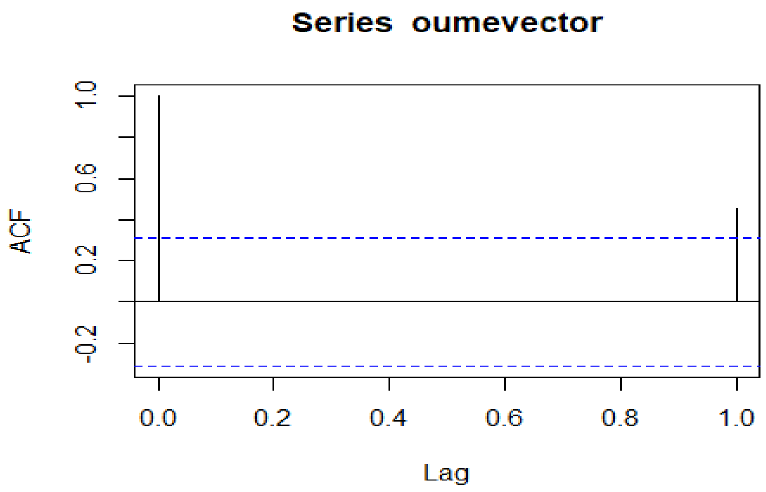
APPENDIX 2: Statistical analysis

Mann Kendall test script for annual time series

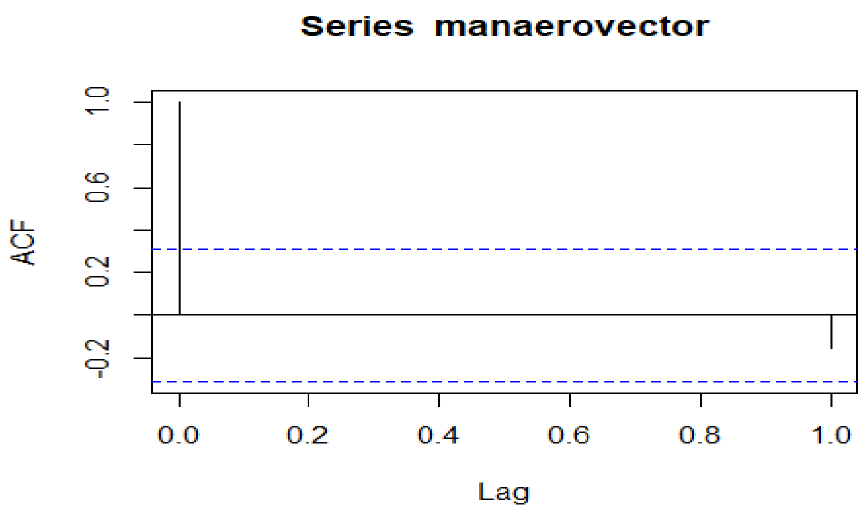
```
setwd("C:/Users/HALIMA/Desktop/Reference all stations/CSV annual data")
sassandra<-read.csv2("Sassandra.csv", dec = ".")
oume<-read.csv2("Oumé.csv", dec = ".")
manaero<-read.csv2("Man aero.csv", dec = ".")
library(modifiedmk)

sassandravector<-sassandra$Rain
sassandraacf<-acf(sassandravector, lag.max = 1)
```




```
mkttest(sassandravector)

##       Z-Value    Sen's slope              S         Var(S)        P-value
## -4.299232e+00 -1.942132e+01 -3.700000e+02  7.366667e+03  1.713912e-05
##           Tau
## -4.743590e-01

oumevector<-oume$Rain
oumeacf<-acf(oumevector, lag.max = 1)
```




```
mkttest(oumevector)

##         Z-Value    Sen's slope              S         Var(S)        P-value
## -3.693378e+00 -1.196418e+01 -3.180000e+02  7.366667e+03  2.212947e-04
##            Tau
## -4.076923e-01

manaerovector<-manaero$Rain
manaeroacf<-acf(manaerovector, lag.max = 1)
```




```
mkttest(manaerovector)

##       Z-Value Sen’s slope        S        Var(S)      P-value
## 5.359840e-01 2.800000e+00 4.700000e+01 7.365667e+03 5.919696e-01

Tau

6.025641e-02
```

Pettitt test Script for annual time series

```
setwd("C:/Users/HALIMA/Desktop/Reference all stations/CSV annual data")
beoumi<-read.csv2("Beoumi.csv", dec = ".")
tengrela<-read.csv2("tengrelasierem.csv", dec = ".")
odienne<-read.csv2("Odiennesierem.csv", dec = ".")
odienne<-odienne[1:40,1:2]
adiake<-read.csv2("Adiakesierem.csv", dec = ".")
adiake<-adiake[1:40,1:2]
abidjan<-read.csv2("abidjansierem.csv", dec = ".")
library(trend)
```

```
pettitt.test(abidjan$Value)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  abidjan$Value
## U* = 286, p-value = 0.001127
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                               22
```

```
pettitt.test(adiake$Value)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  adiake$Value
## U* = 302, p-value = 0.0004767
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                               22
```

```
pettitt.test(odienne$Value)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  odienne$Value
## U* = 310, p-value = 0.0003046
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                               22
```

```
pettitt.test(tengrela$Value)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  tengrela$Value
## U* = 275, p-value = 0.001982
```

```
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                              17
```

```r
pettitt.test(beoumi$Rain)
```

```
##
##  Pettitt's test for single change-point detection
##
## data:  beoumi$Rain
## U* = 104, p-value = 0.7437
## alternative hypothesis: two.sided
## sample estimates:
## probable change point at time K
##                               8
```

APPENDIX 3: Rainfall indices calculations

Indices	Dembasso			Kouto			Madiani			Ouangolodougou		
Indices	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**
R10	0.156	-0.167	No	0.003	-0.291	Yes	0.009	-0.263	Yes	0.218	-0.154	No
R20	0.616	-0.04	No	0.25	-0.09	No	0.053	-0.171	No	0.574	-0.042	No
R40	0.171	0.073	No	0.556	0.025	No	0.989	0.001	No	0.221	-0.049	No
R50	0.099	0.074	No	0.362	0.029	No	0.521	-0.022	No	0.434	-0.021	No
R*1day	0.667	0.186	No	0.277	0.381	No	0.437	0.222	No	0.241	-0.433	No
R*5day	0.694	-0.243	No	0.918	0.055	No	0.946	0.038	No	0.028	-1.338	Yes
R95p	0.14	4.435	No	0.302	2.152	No	0.903	0.284	No	0.43	-1.329	No
R99p	0.251	1.808	No	0.505	0.92	No	0.637	0.659	No	0.686	-0.546	No
SDII	0.996	0	No	0.351	0.029	No	0.03	-0.091	Yes	0.391	0.033	No
PRCPTOT	0.706	-1.317	No	0.132	-4.457	No	0.308	-3.198	No	0.073	-5.968	No
CWD	0.757	-0.01	No	0.076	-0.066	No	0.983	-0.001	No	0.251	-0.035	No
CDD	0.68	0.199	No	0.023	0.927	Yes	0.771	-0.132	No	0.307	-0.545	No

Indices	Sanhala			Tengrela			Tiemé			Bouna		
Indices	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**
R10	0.039	-0.367	Yes	0.183	-0.122	No	0.032	-0.217	Yes	0.151	-0.24	No
R20	0.125	-0.24	No	0.275	-0.092	No	0.179	-0.11	No	0.153	-0.147	No
R40	0.871	-0.023	No	0.061	-0.108	No	0.833	-0.01	No	0.403	-0.037	No
R50	0.554	-0.08	No	0.109	-0.046	No	0.52	0.018	No	0.452	-0.023	No
R*1day	0.526	-0.755	No	0.598	-0.221	No	0.863	-0.083	No	0.746	-0.145	No
R*5day	0.482	-2.246	No	0.906	-0.077	No	0.786	0.172	No	0.869	-0.108	No
R95p	0.436	-14.564	No	0.102	-3.818	No	0.877	0.403	No	0.598	-1.14	No
R99p	0.366	-13.712	No	0.175	-2.375	No	0.774	0.474	No	0.801	-0.319	No
SDII	0.452	-0.142	No	0.106	0.08	No	0.86	0.006	No	0.48	-0.031	No
PRCPTOT	0.234	-21.002	No	0.03	-8.728	Yes	0.086	-4.695	No	0.249	-5.342	No
CWD	0.417	-0.036	No	0.127	-0.072	No	0.387	-0.027	No	0.703	0.007	No
CDD	0.986	-0.021	No	0.385	0.419	No	0.95	0.023	No	0.834	-0.103	No

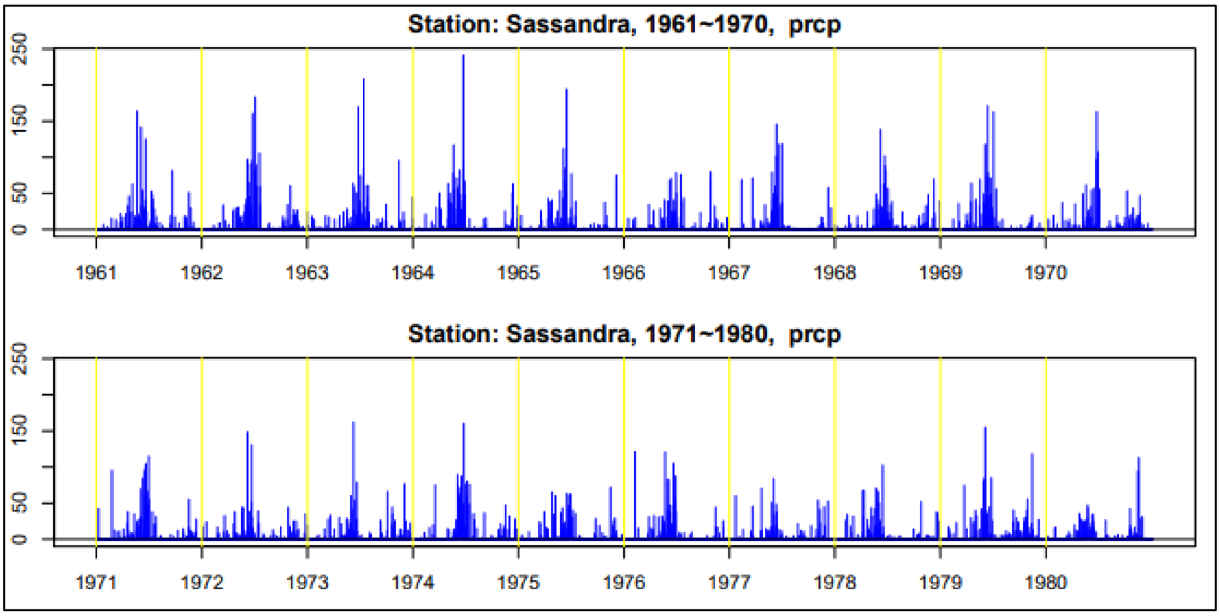
Indices	Mankono			Bondoukou			Beoumi			Dimbokro		
Indices	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**
R10	0.677	0.044	No	0.521	-0.069	No	0.288	-0.086	No	0.099	0.169	No
R20	0.415	-0.058	No	0.836	0.016	No	0.585	-0.036	No	0.033	-0.119	Yes
R40	0.309	-0.044	No	0.731	-0.01	No	0.236	-0.036	No	0.29	-0.027	No
R50	0.366	-0.03	No	0.959	-0.001	No	0.219	-0.031	No	0.243	-0.025	No
R*1day	0.894	-0.053	No	0.807	0.063	No	0.533	-0.25	No	0.964	0.012	No
R*5day	0.603	-0.322	No	0.364	0.325	No	0.07	-0.959	No	0.833	0.098	No
R95p	0.405	-1.953	No	0.944	0.117	No	0.259	-2.075	No	0.185	-1.941	No
R99p	0.129	-1.935	No	0.804	0.283	No	0.098	-2.153	No	0.775	-0.299	No
SDII	0.001	-0.161	Yes	0.493	0.015	No	0.01	-0.112	Yes	0.727	-0.007	No
PRCPTOT	0.485	2.249	No	0.362	-2.716	No	0.479	-1.995	No	0.018	-6.618	Yes

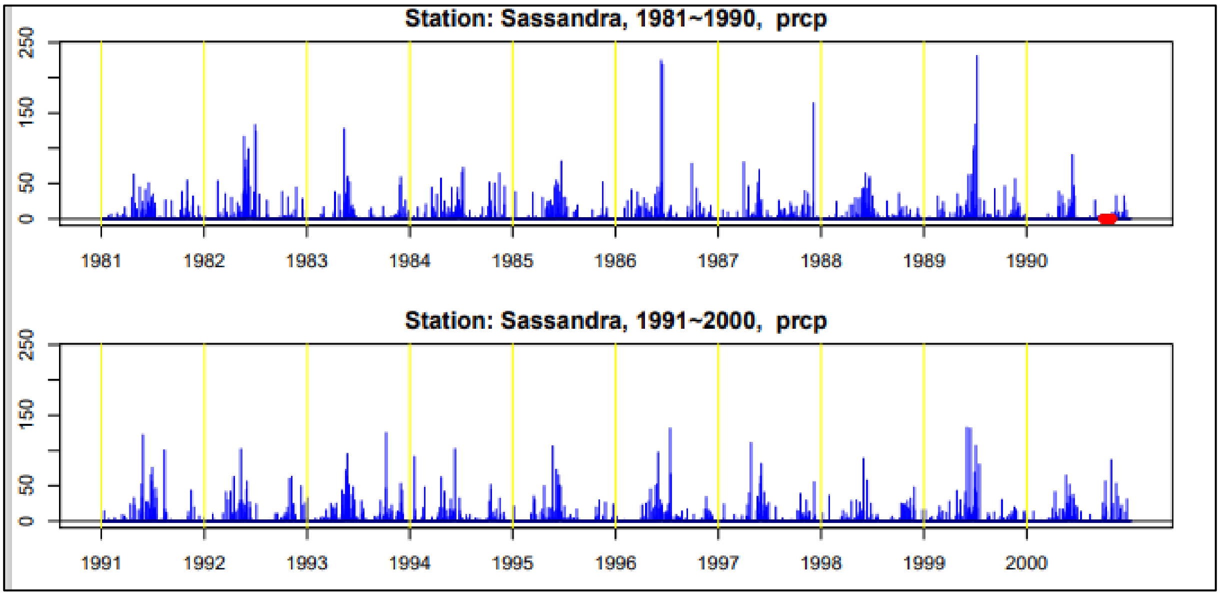
CWD	0.075	0.06	No	0.208	-0.023	No	0.456	-0.014	No	0.026	-0.044	Yes
CDD	0.106	0.794	No	0.313	0.32	No	0.774	-0.089	No	0.564	0.17	No

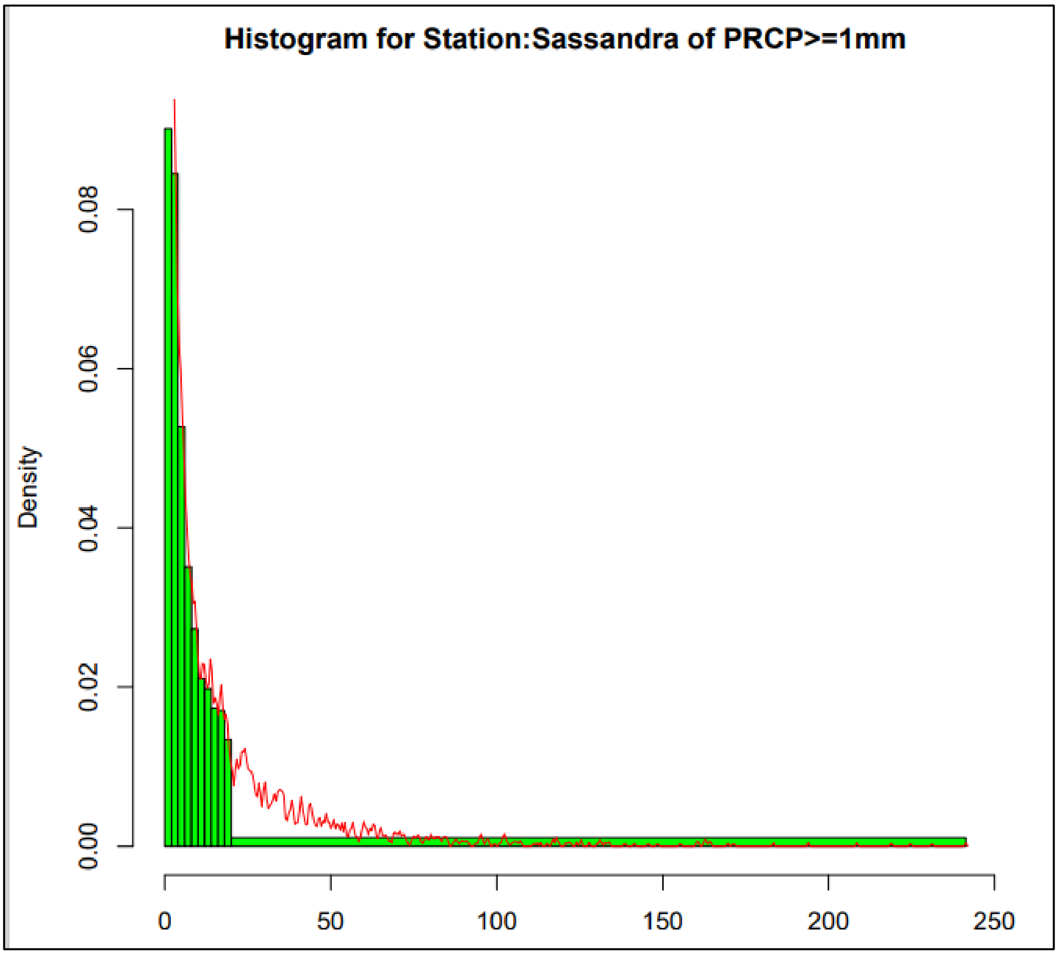
Indices	**Man aero**			**Guiglo**			**Gagnoa**			**Lakota**		
Indices	**Pvalue**	**slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**
R10	0.943	-0.008	No	0.152	-0.211	No	0.018	-0.262	Yes	0.008	-0.381	Yes
R20	0.142	0.109	No	0.401	-0.074	No	0.093	-0.097	No	0.121	-0.123	No
R40	0.212	0.056	No	0.967	0.002	No	0.43	-0.025	No	0.564	0.02	No
R50	0.456	0.028	No	0.369	-0.031	No	0.719	-0.009	No	0.633	-0.01	No
R*1day	0.48	0.211	No	0.568	0.213	No	0.506	0.186	No	0.358	-0.221	No
R*5day	0.358	-0.494	No	0.464	-0.43	No	0.374	-0.343	No	0.488	-0.246	No
R95p	0.412	2.299	No	0.36	-2.203	No	0.568	-1.11	No	0.694	0.72	No
R99p	0.787	-0.414	No	0.898	0.202	No	0.891	0.176	No	0.022	-1.723	Yes
SDII	0.04	0.05	Yes	0.438	-0.021	No	0.638	-0.008	No	0.058	-0.059	No
PRCPTOT	0.639	1.636	No	0.335	-3.545	No	0.017	-7.01	Yes	0.082	-5.408	No
CWD	0.727	-0.015	No	0.049	-0.083	Yes	0.74	-0.009	No	0.086	-0.041	No
CDD	0.828	-0.066	No	0.032	-0.535	Yes	0.959	-0.013	No	0.743	0.073	No

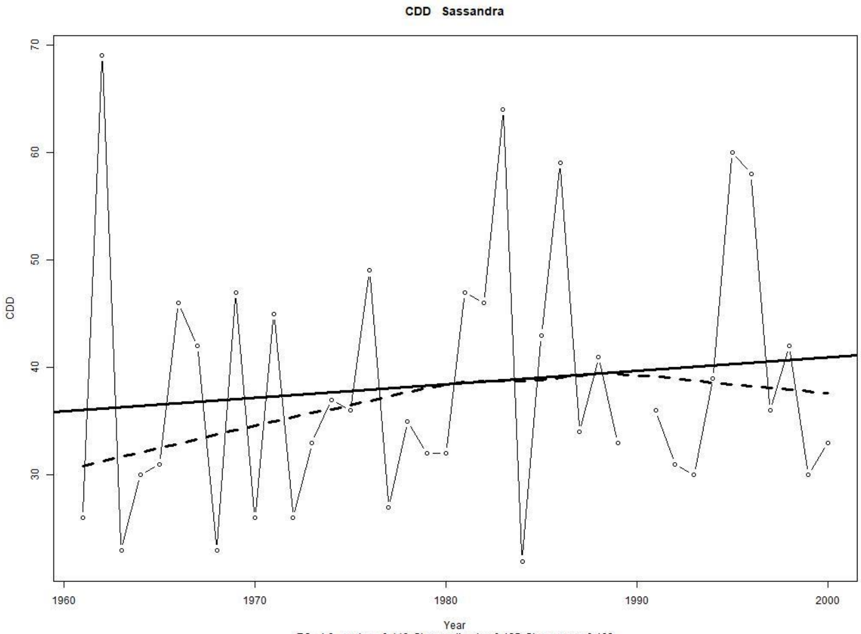
Indices	**Soubré**			**Tabou**			**Toulepleu**		
Indices	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**Slope estimate**	**Significant trend at 95%**	**Pvalue**	**slope estimate**	**Significant trend at 95%**
R10	0.378	-0.105	No	0.563	-0.08	No	0.264	-0.177	No
R20	0.061	-0.15	No	0.381	-0.092	No	0.124	-0.206	No
R40	0.732	-0.014	No	0.597	-0.033	No	0.434	-0.048	No
R50	0.761	0.007	No	0.568	-0.026	No	0.697	0.016	No
R*1day	0.756	0.151	No	0.74	-0.253	No	0.781	0.123	No
R*5day	0.688	0.23	No	0.394	-1.097	No	0.147	-0.895	No
R95p	0.975	-0.058	No	0.56	-2.39	No	0.876	0.446	No
R99p	0.875	-0.255	No	0.748	0.918	No	0.84	0.281	No
SDII	0.147	-0.116	No	0.333	-0.033	No	0.006	-0.13	Yes
PRCPTOT	0.234	-4.351	No	0.533	-3.713	No	0.518	-3.344	No
CWD	0.5	0.025	No	0.541	-0.039	No	0.702	0.024	No
CDD	0.286	0.312	No	0.908	0.018	No	0.99	0.004	No

Distribution of the rainfall time series in Sassandra station

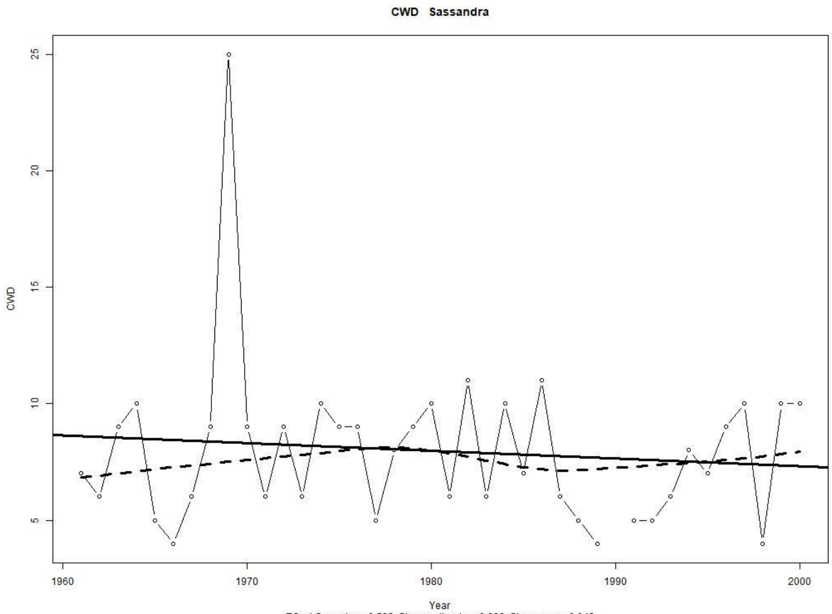




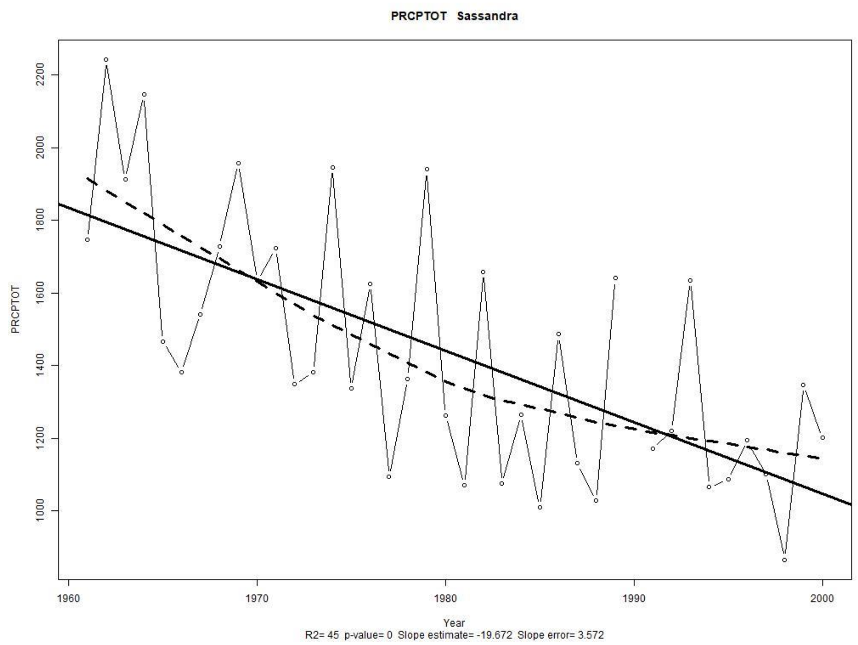

Histogram for Station:Sassandra of PRCP>=1mm
Density
0.00
0.02
0.04
0.06
0.08
0
50
100
150
200
250

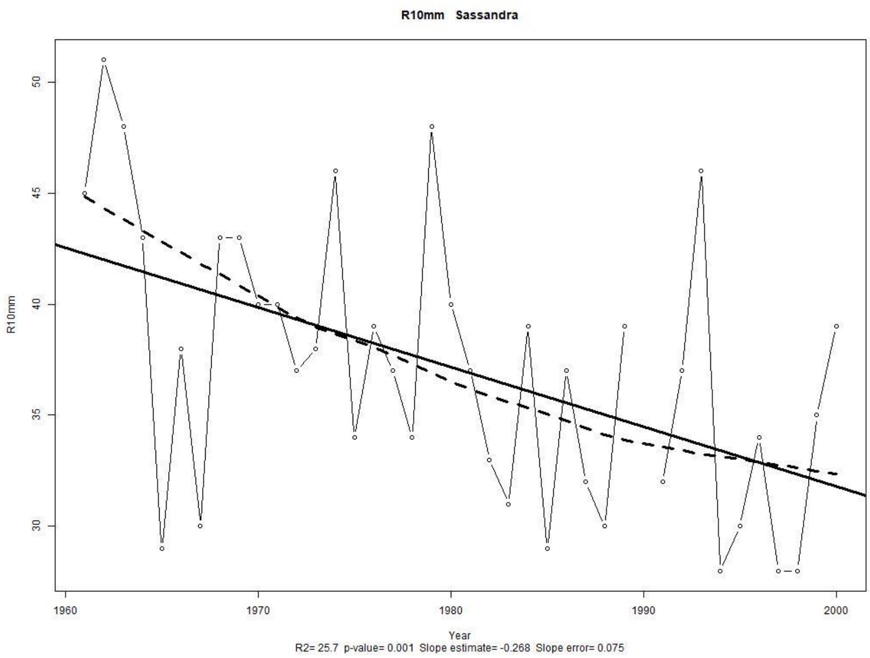


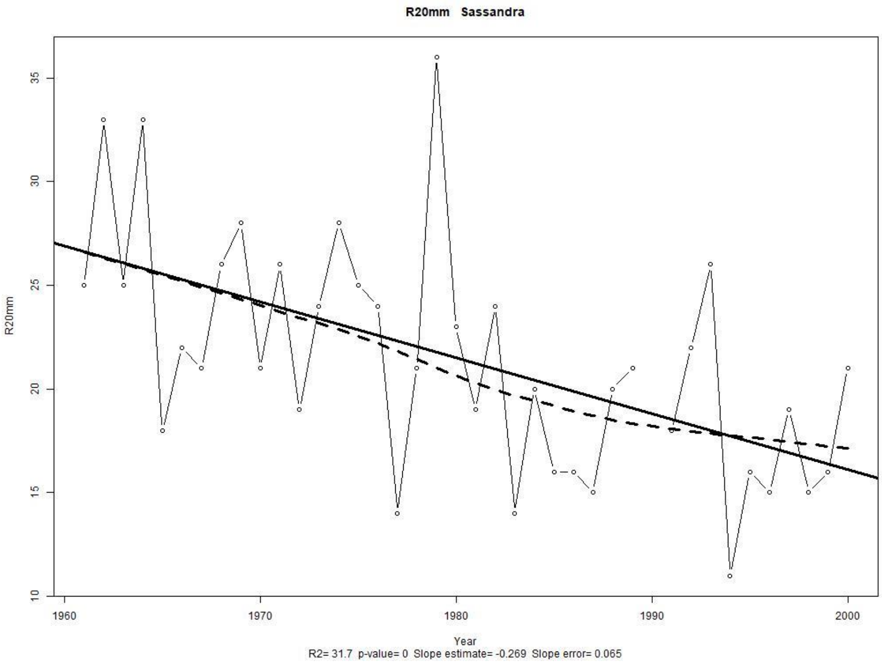
R2= 1.6 p-value= 0.446 Slope estimate= 0.125 Slope error= 0.163

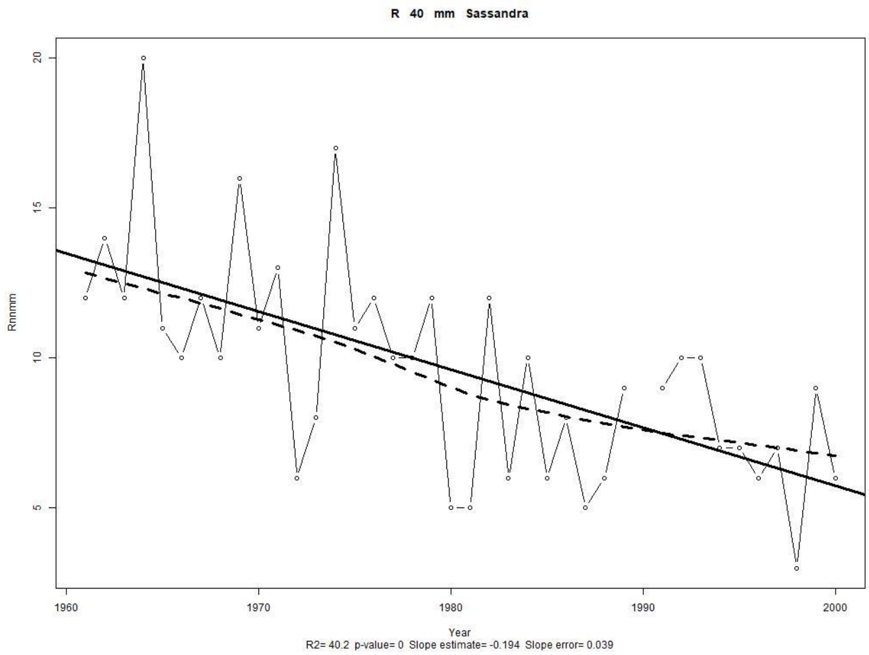


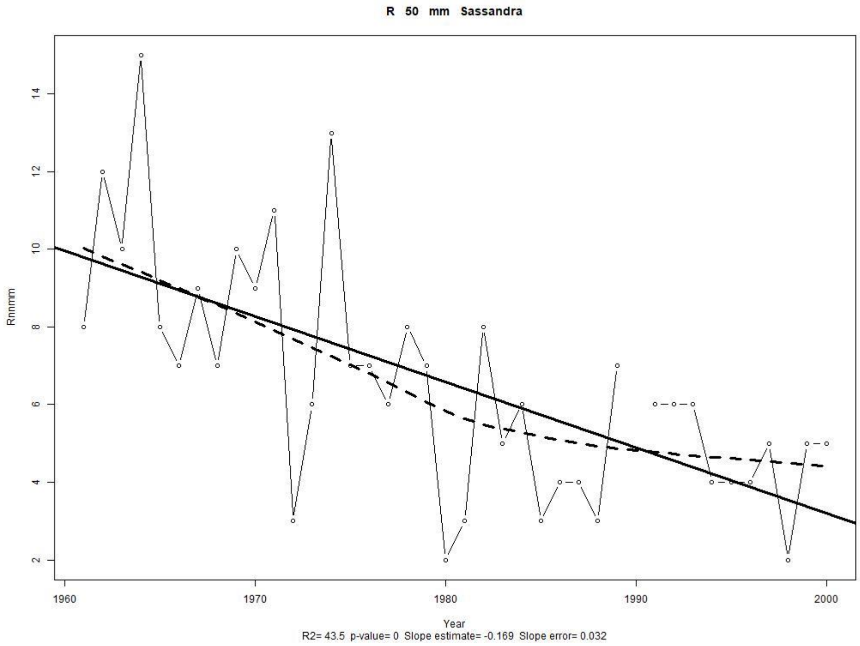
R2= 1.2 p-value= 0.503 Slope estimate= -0.033 Slope error= 0.049

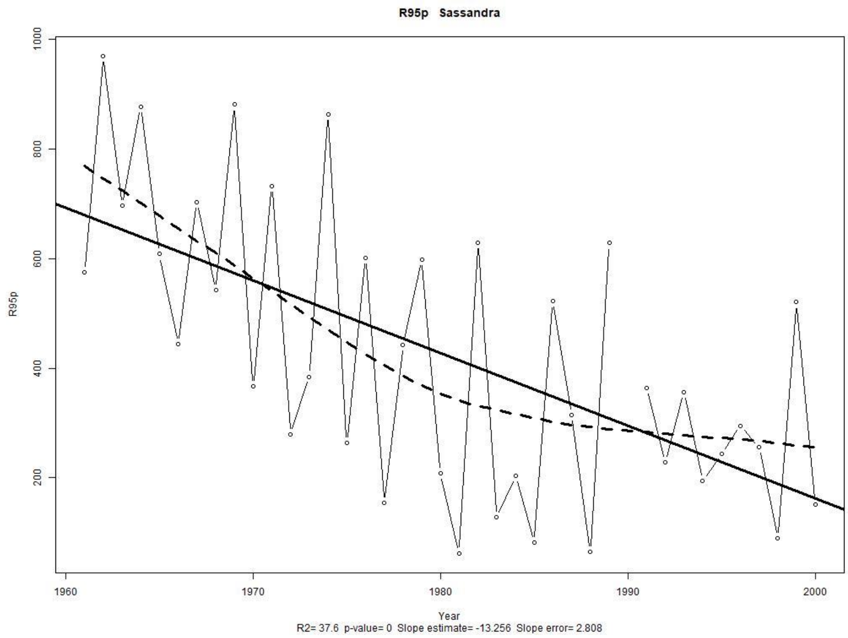

PRCPTOT Sassandra
PRCPTOT
Year
R2= 45 p-value= 0 Slope estimate= -19.672 Slope error= 3.572

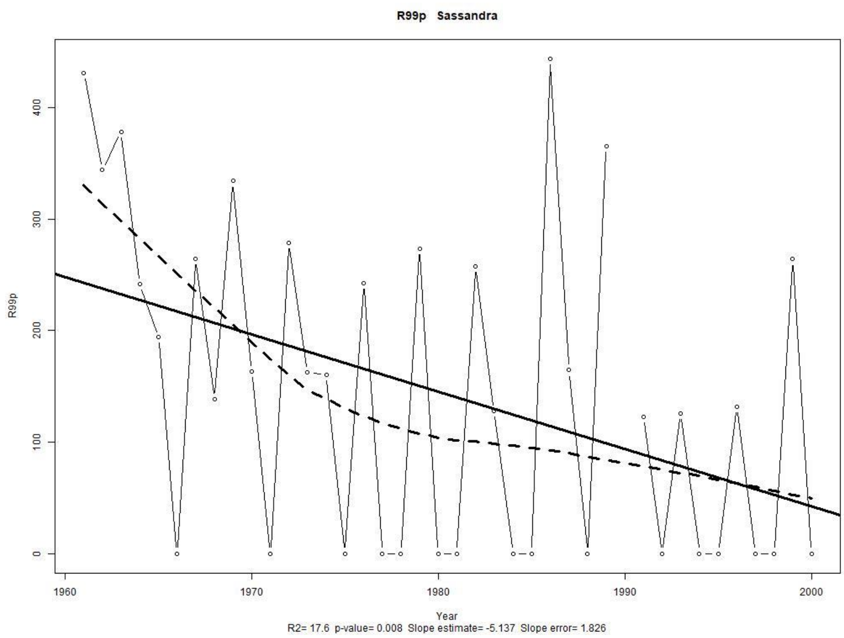

R10mm Sassandra
R10mm
Year
R2= 25.7 p-value= 0.001 Slope estimate= -0.268 Slope error= 0.075

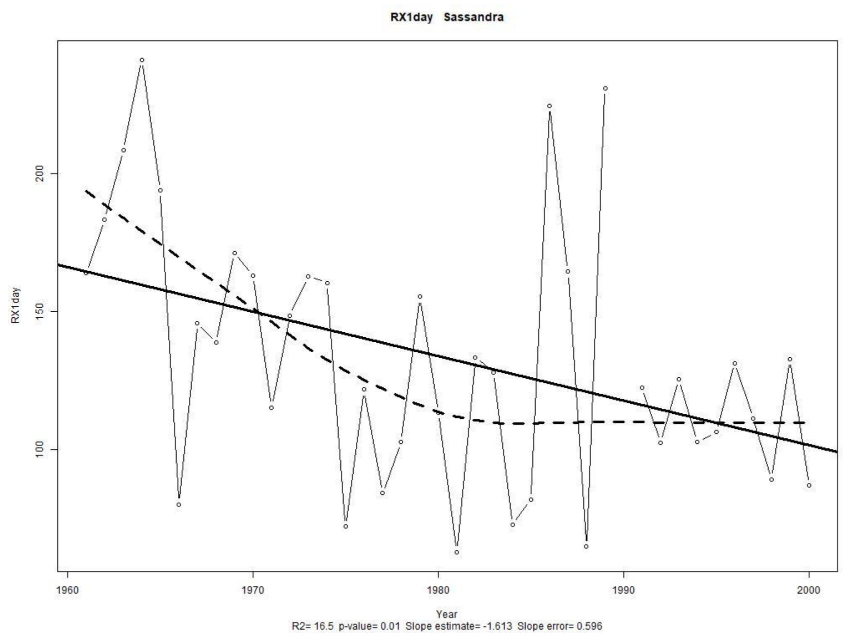

R20mm Sassandra
R20mm
Year
R2= 31.7 p-value= 0 Slope estimate= -0.269 Slope error= 0.065

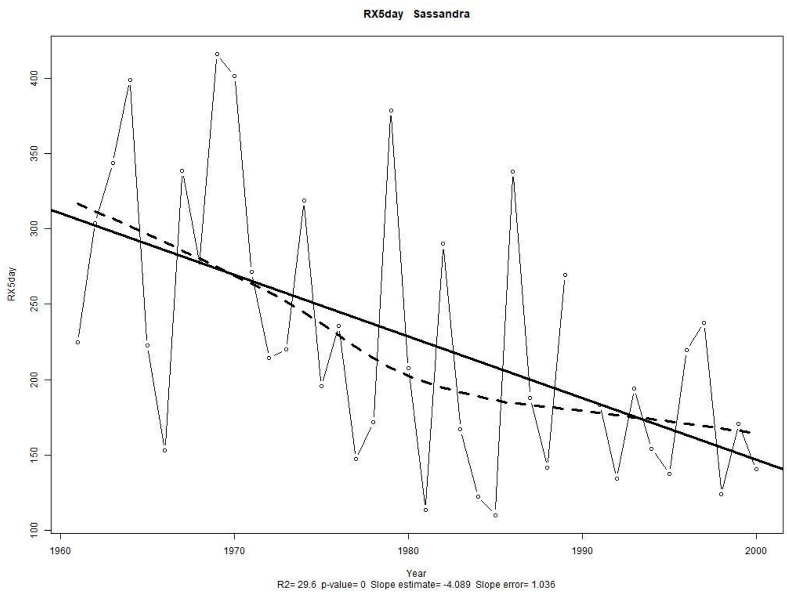

R 40 mm Sassandra
Rmmmm
Year
R2= 40.2 p-value= 0 Slope estimate= -0.194 Slope error= 0.039

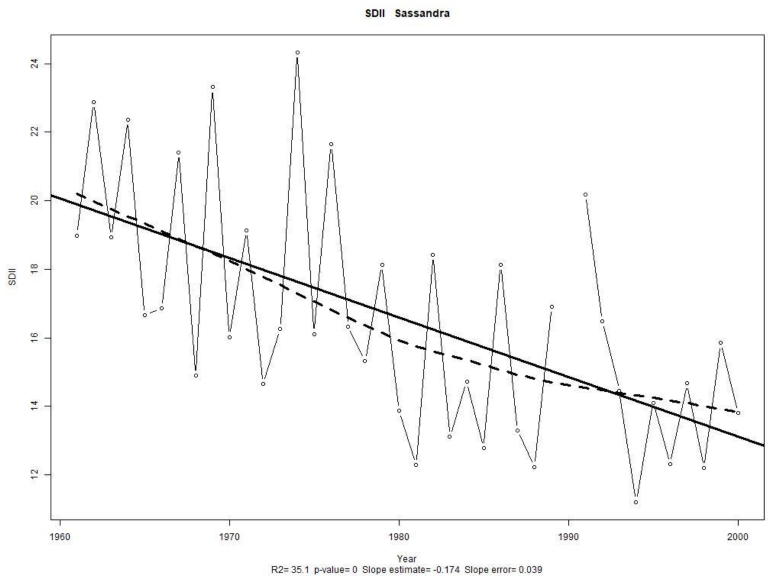

R 50 mm Sassandra
Rnnmm
Year
R2= 43.5 p-value= 0 Slope estimate= -0.169 Slope error= 0.032


R95p Sassandra
R95p
Year
R2= 37.6 p-value= 0 Slope estimate= -13.256 Slope error= 2.808


R99p Sassandra
R99p
0
100
200
300
400
1960
1970
1980
1990
2000
Year
R2= 17.6 p-value= 0.008 Slope estimate= -5.137 Slope error= 1.826

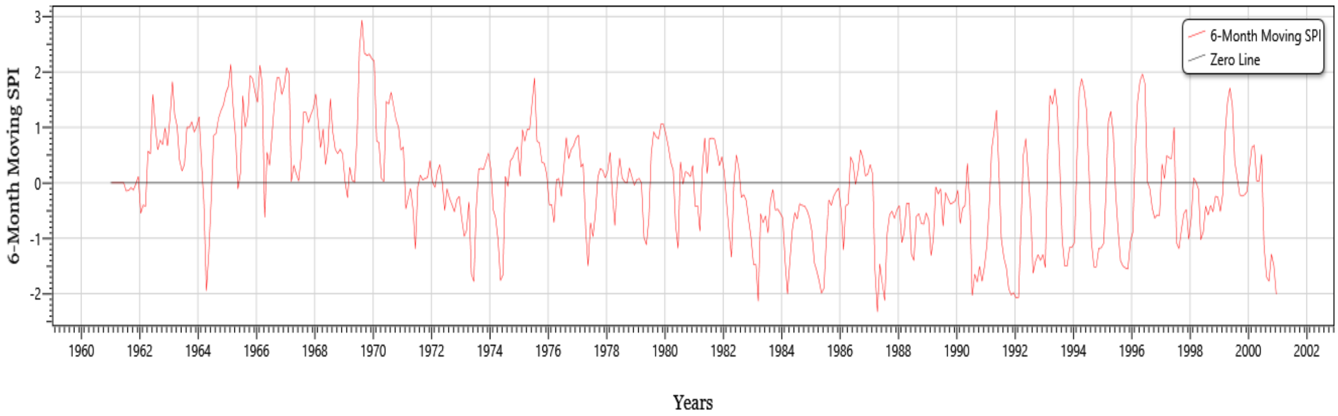

RX1day Sassandra
RX1day
100
150
200
1960
1970
1980
1990
2000
Year
R2= 16.5 p-value= 0.01 Slope estimate= -1.613 Slope error= 0.596


RX5day Sassandra
RX5day
Year
R2= 29.6 p-value= 0 Slope estimate= -4.089 Slope error= 1.036

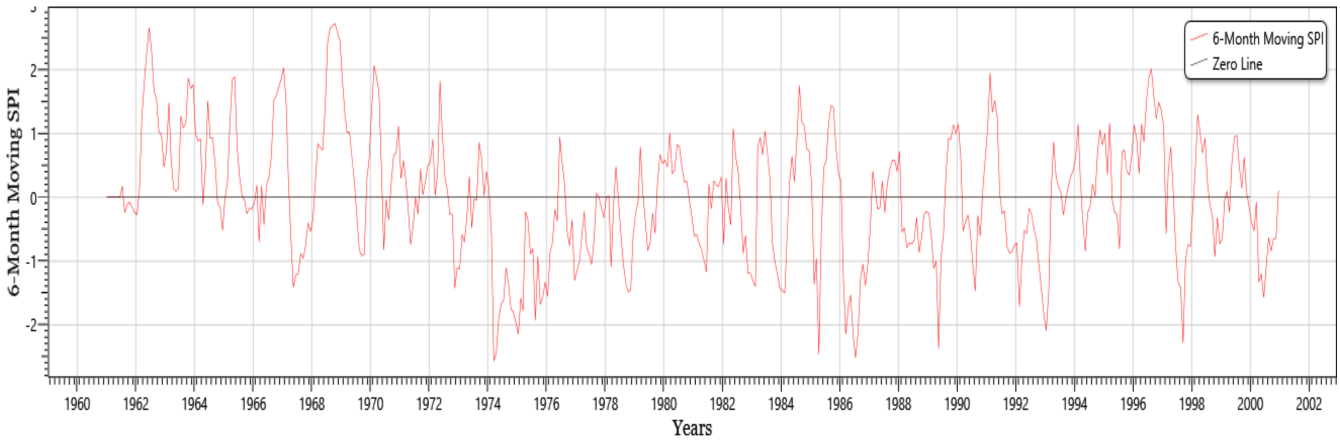

SDII Sassandra
SDII
Year
R2= 35.1 p-value= 0 Slope estimate= -0.174 Slope error= 0.039

Standardized Precipitation Index (SPI)

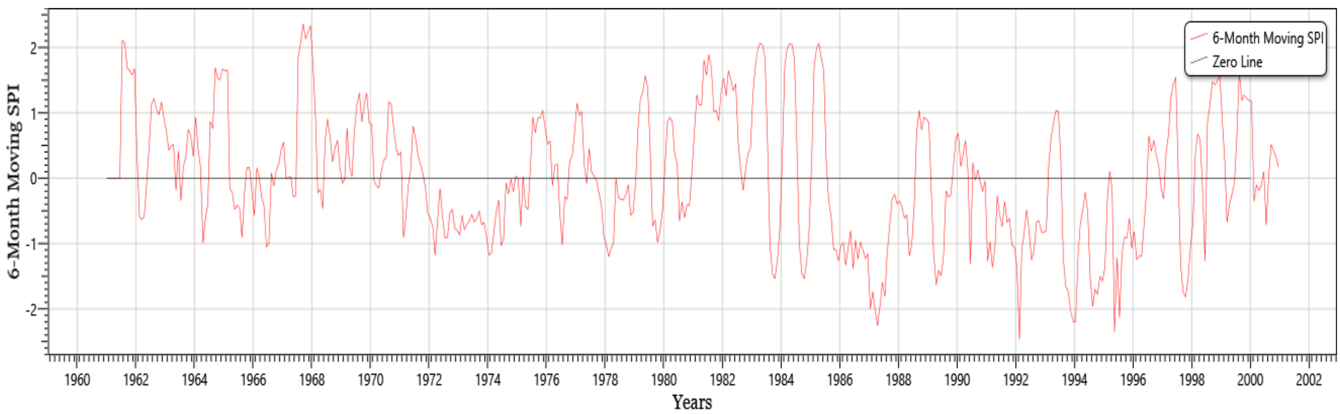
SPI-6 Manignan



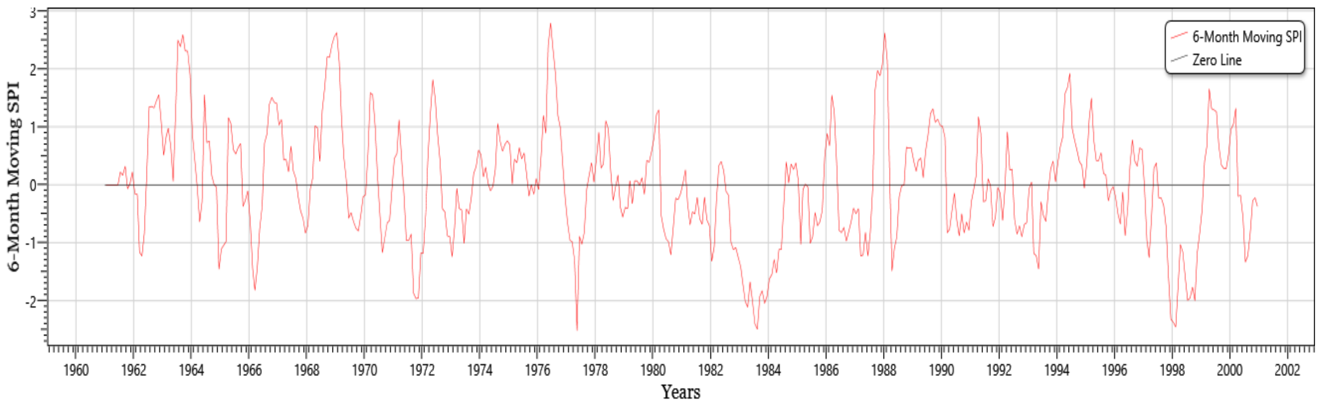
SPI-6 Soubré



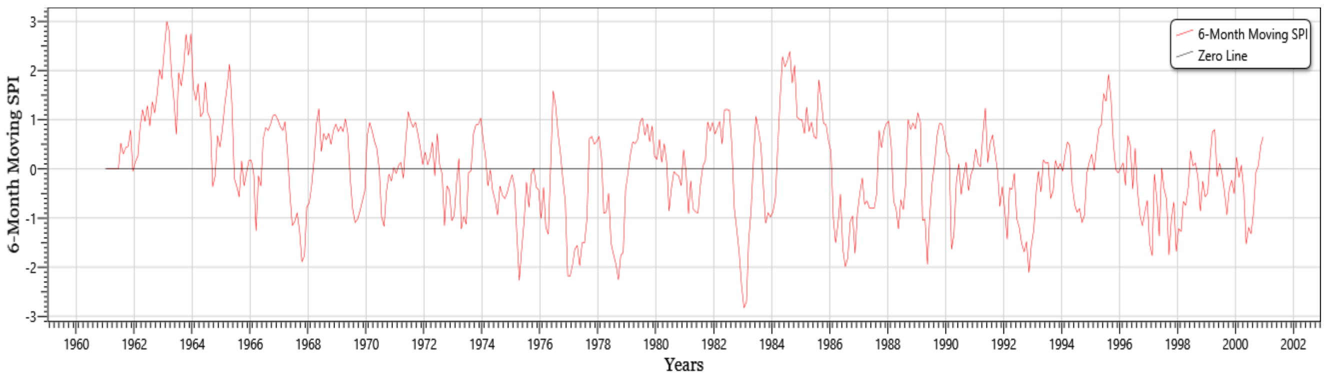
SPI-6 Tengrela



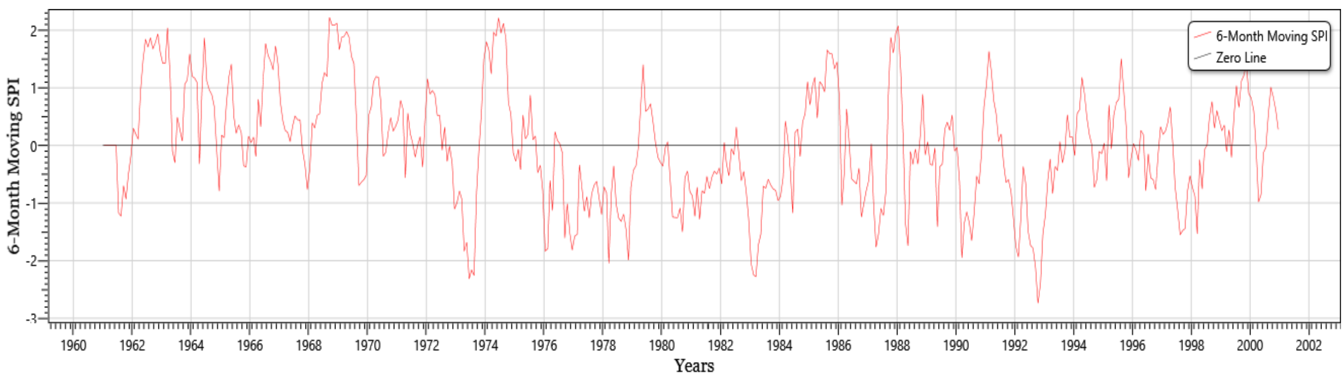
SPI-6 Adzope



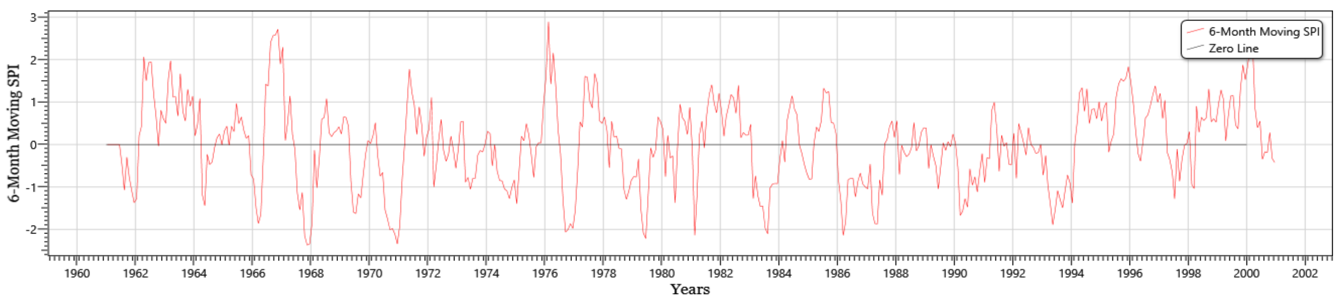
SPI-6 Gagnoa



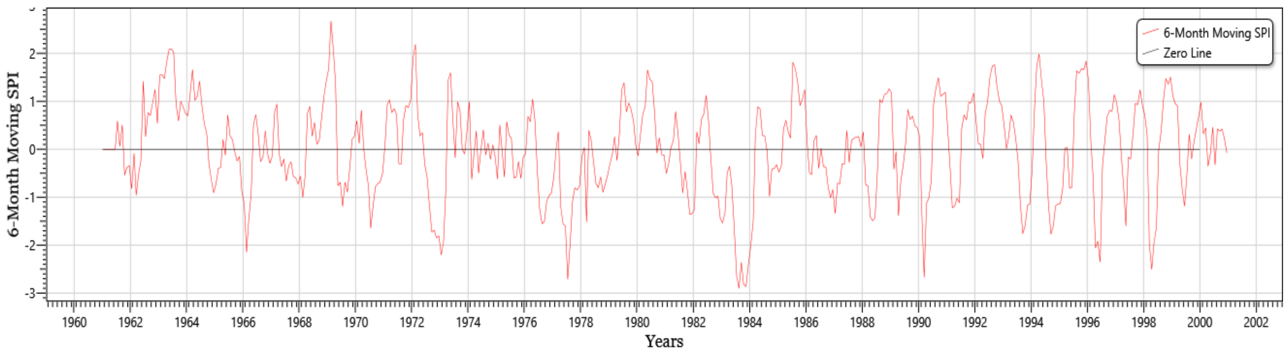
SPI-6 Lakota



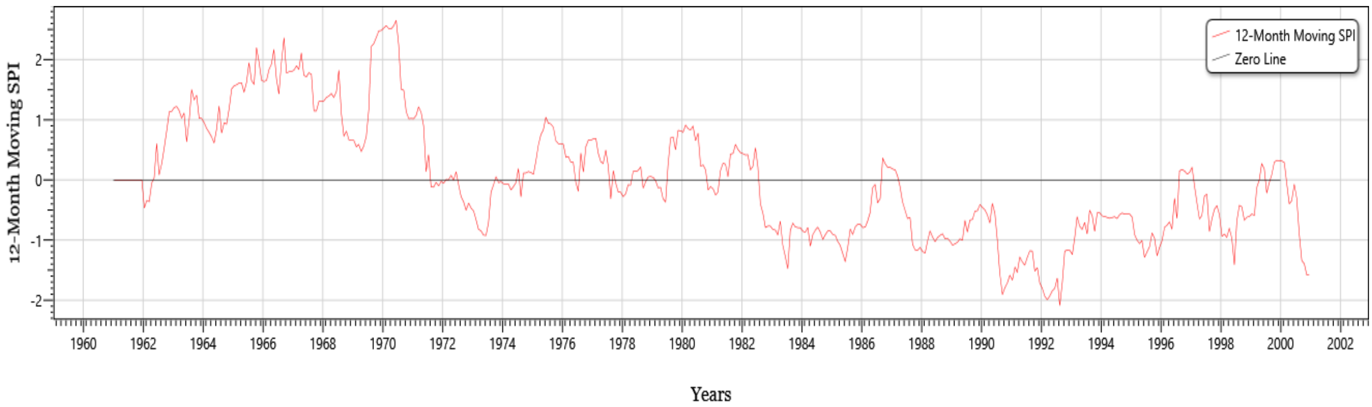
SPI-6 Man aero



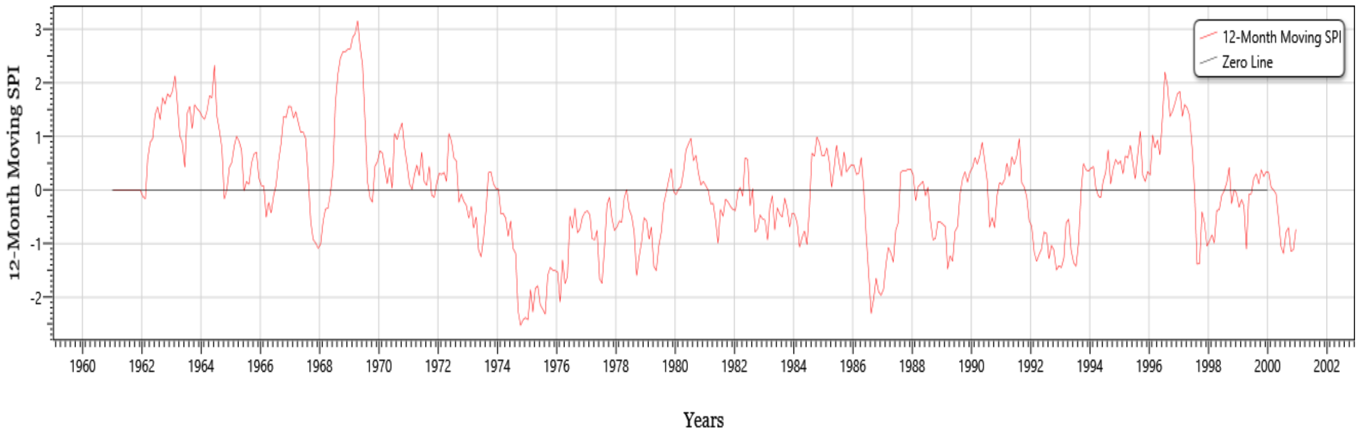
SPI-6 Mankono



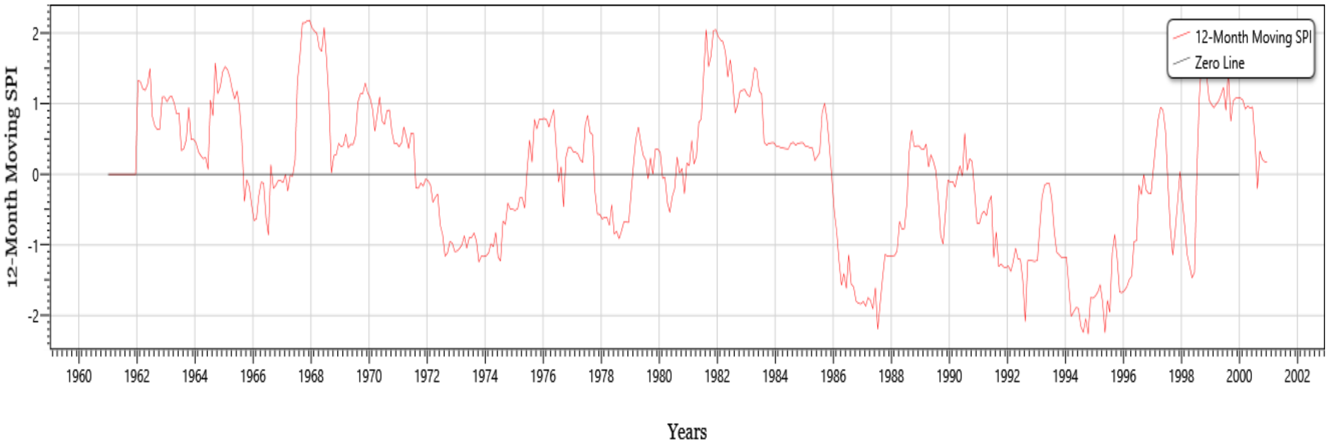
SPI-12 Manignan



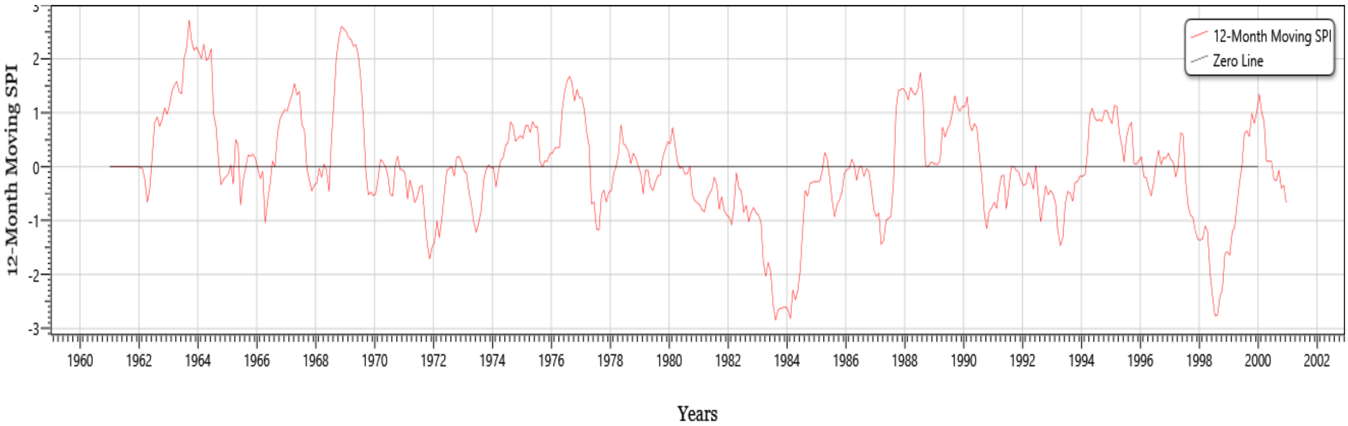
SPI-12 Soubré



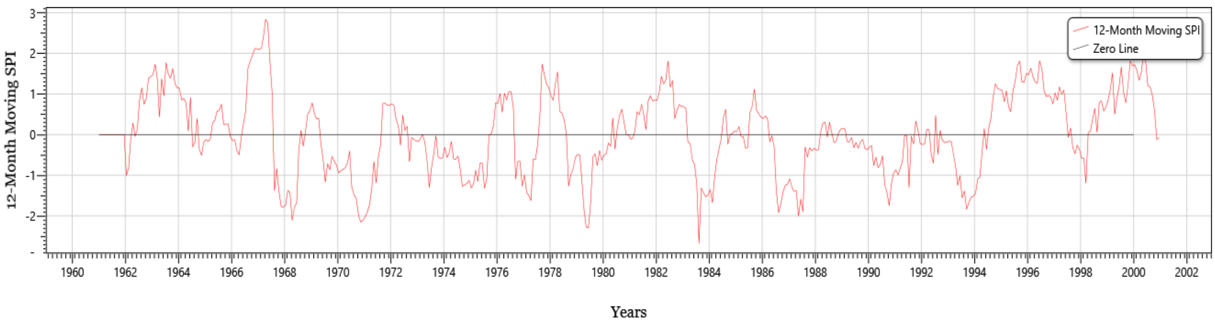
SPI-12 Tengrela



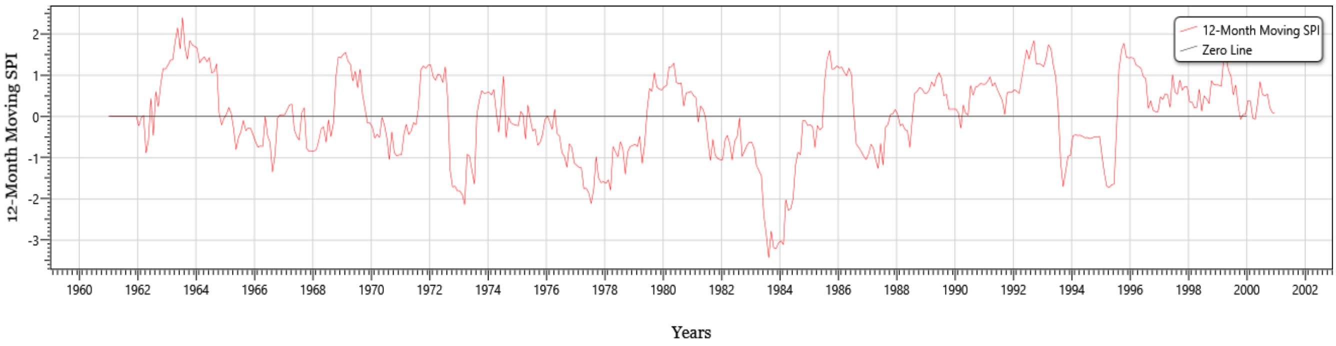
SPI-12 Adzope



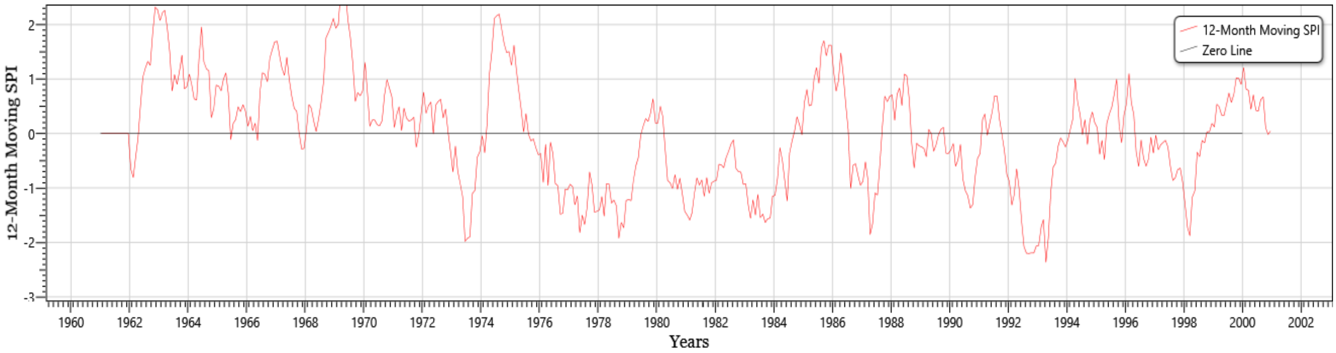
SPI-12 Mankono



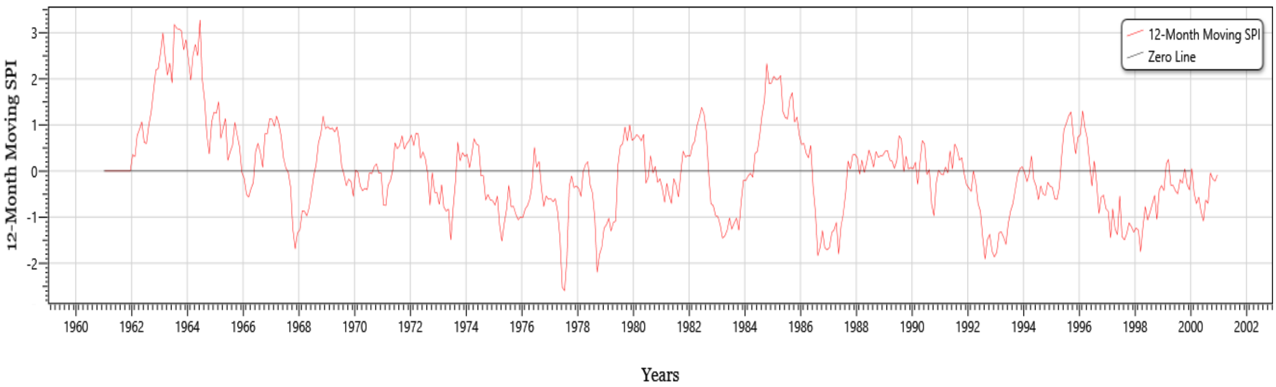
SPI-12 Man aero



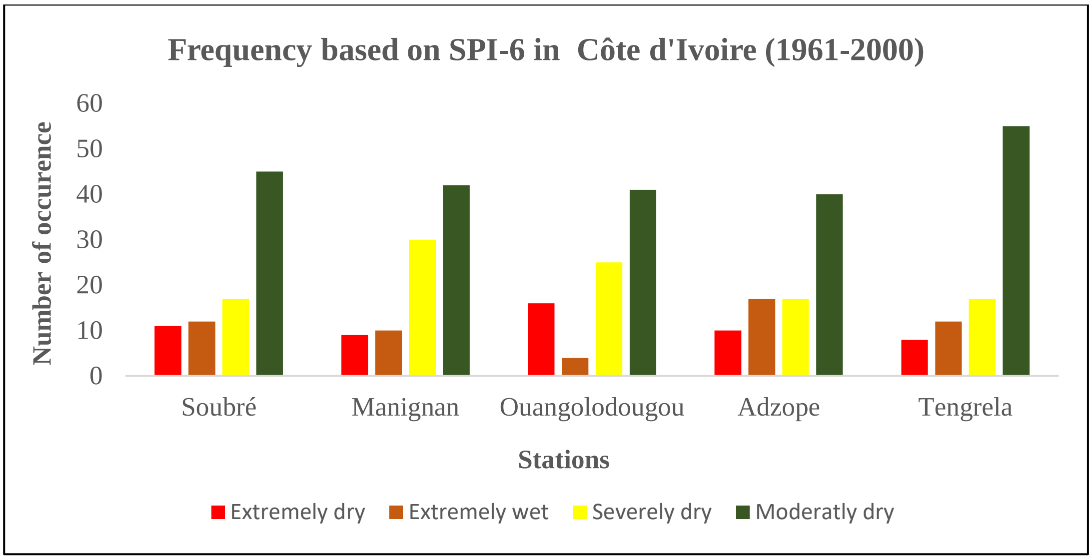
SPI-12 Lakota

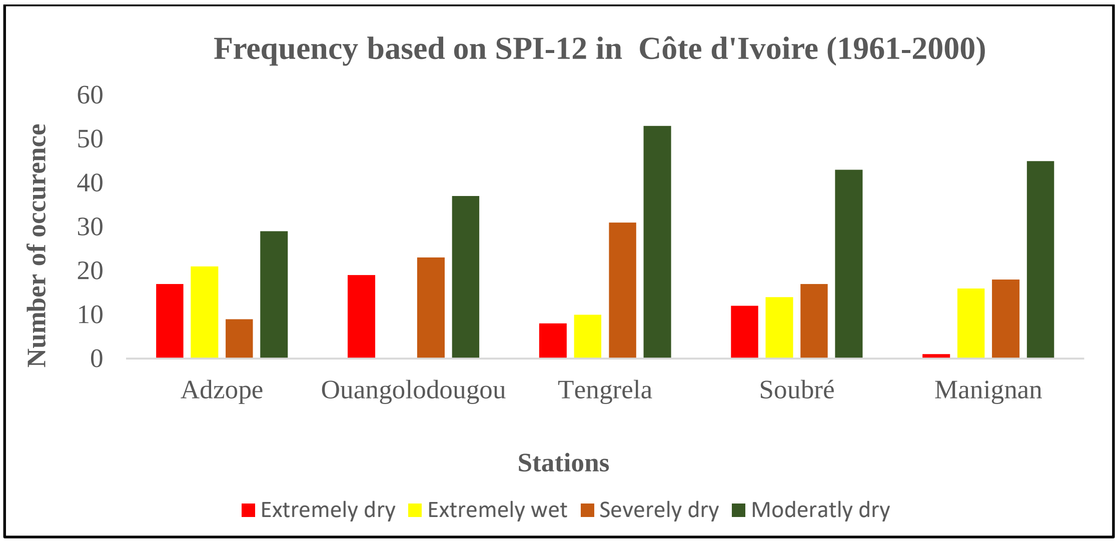


SPI-12 Gagnoa



Floods and droughts occurrence


Frequency based on SPI-6 in Côte d'Ivoire (1961-2000)
Number of occurence
60
50
40
30
20
10
0
Soubré
Manignan
Ouangolodougou
Adzope
Tengrela
Stations
Extremely dry
Extremely wet
Severely dry
Moderatly dry


Frequency based on SPI-12 in Côte d'Ivoire (1961-2000)
Number of occurence
60
50
40
30
20
10
0
Adzope
Ouangolodougou
Tengrela
Soubré
Manignan
Stations
Extremely dry
Extremely wet
Severely dry
Moderatly dry

APPENDIX 4: 5-years sliding calibration period

Semien station				Nzienoa station			
Calibration Periods	X1	X2	Nash (Q)	Calibration Periods	X1	X2	Nash (Q)
1950-1954	396.76598	1.078864	54.81	1950-1954	396.76598	1.078864	54.81
1951-1955	474.76896	1.165445	55.4	1951-1955	474.76896	1.165445	55.4
1952-1956	439.07459	1.104054	58.87	1952-1956	439.07459	1.104054	58.87
1953-1957	380.37098	1.091985	56.12	1953-1957	380.37098	1.091985	56.12
1954-1958	355.89417	1.036601	58.41	1954-1958	355.89417	1.036601	58.41
1955-1959	370.59143	1.072491	57.87	1955-1959	370.59143	1.072491	57.87
1956-1960	376.86545	1.056884	50.4	1956-1960	376.86545	1.056884	50.4
1957-1961	380.96019	1.053755	49.94	1957-1961	380.96019	1.053755	49.94
1958_1962	517.60972	1.096227	42.72	1958_1962	517.60972	1.096227	42.72
1959-1963	453.42072	1.104365	51.19	1959-1963	453.42072	1.104365	51.19
1960-1964	480.69563	1.096239	52.41	1960-1964	480.69563	1.096239	52.41
1961-1965	477.52722	1.119068	54.09	1961-1965	477.52722	1.119068	54.09
1962-1966	518.02352	1.198719	48.38	1962-1966	518.02352	1.198719	48.38
1963-1967	420.36468	1.127035	54.5	1963-1967	420.36468	1.127035	54.5
1964-1968	407.46939	1.167592	53.07	1964-1968	407.46939	1.167592	53.07
1965-1969	331.06525	1.079338	60.15	1965-1969	331.06525	1.079338	60.15
1966-1970	325.00296	1.065027	60.95	1966-1970	325.00296	1.065027	60.95
1967-1971	330.2996	1.04	60.37	1967-1971	330.2996	1.04	60.37
1968-1972	355.40813	1.039125	54.83	1968-1972	355.40813	1.039125	54.83
1969-1973	438.92569	1.00534	46.74	1969-1973	438.92569	1.00534	46.74
1970-1974	435.21078	1.008604	48.59	1970-1974	435.21078	1.008604	48.59
1971-1975	436.78204	0.9899272	57.57	1971-1975	436.78204	0.9899272	57.57
1972-1976	422.67227	0.9500839	71.67	1972-1976	422.67227	0.9500839	71.67
1973-1977	408.25962	0.9596844	65.16	1973-1977	408.25962	0.9596844	65.16
1974-1978	399.94275	0.9421122	52.77	1974-1978	399.94275	0.9421122	52.77
1975-1979	421.24524	0.9761138	53.97	1975-1979	421.24524	0.9761138	53.97
1976-1980	450.17364	1.020207	46.94	1976-1980	450.17364	1.020207	46.94
1977-1981	462.88438	1.030834	44.26	1977-1981	462.88438	1.030834	44.26
1978-1982	451.75647	1.017821	45.93	1978-1982	451.75647	1.017821	45.93
1979-1983	474.26873	1.033759	45.49	1979-1983	474.26873	1.033759	45.49
1980-1984	538.30372	1.051302	41.09	1980-1984	538.30372	1.051302	41.09
1981-1985	516.99801	1.077891	48.41	1981-1985	516.99801	1.077891	48.41
1982-1986	505.70604	1.064341	49	1982-1986	505.70604	1.064341	49
1983-1987	575.64139	1.099977	47.75	1983-1987	575.64139	1.099977	47.75
1984-1988	560.51849	1.104119	47.6	1984-1988	560.51849	1.104119	47.6
1985-1989	561.38358	1.136386	44.06	1985-1989	561.38358	1.136386	44.06
1987-1991	562.09685	1.095781	41.02	1987-1991	562.09685	1.095781	41.02

1988-1992	473.29192	1.045927	41.58	1988-1992	473.29192	1.045927	41.58
1989-1993	481.70818	1.048911	40.17	1989-1993	481.70818	1.048911	40.17
1990-1994	357.4545	0.8844157	50.47	1990-1994	357.4545	0.8844157	50.47
1991-1995	375.55191	0.944627	52.02	1991-1995	375.55191	0.944627	52.02
1992-1996	347.2344	0.9425	54.78	1992-1996	347.2344	0.9425	54.78
1993-1997	371.62313	0.9740931	52.42	1993-1997	371.62313	0.9740931	52.42
1994-1998	386.89274	0.9982214	53.08	1994-1998	386.89274	0.9982214	53.08
1995-1999	431.08057	1.038947	49.87	1995-1999	431.08057	1.038947	49.87
1996-2000	442.82447	1.033021	47.31	1996-2000	442.82447	1.033021	47.31
1997-2001	522.29752	1.015648	49.36	1997-2001	522.29752	1.015648	49.36
1998-2002	517.82565	1.022994	46.38	1998-2002	517.82565	1.022994	46.38

Soubré station				**Mbasso station**			
Calibration Periods	X1	X2	Nash (Q)	Calibration Periods	X1	X2	Nash (Q)
1951-1955	378.1376	1.36832	75.27	1954-1958	347.2344	0.9375	42.02
1952-1956	358.77751	1.294459	77.06	1955-1959	343.7793	0.92	67.9
1953-1957	379.70948	1.322473	79.27	1956-1960	338.93217	0.9571743	58.4
1954-1958	403.75597	1.350141	77.5	1957-1961	347.2344	0.985	57.21
1955-1959	523.08128	1.455972	67.79	1958-1962	442.21452	1.056049	43.16
1956-1960	548.24792	1.463003	69.72	1959-1963	434.9782	1.042082	57.43
1957-1961	543.24714	1.444934	68.81	1960-1964	409.68074	1.040672	49.95
1958_1962	600.03057	1.438586	63.37	1961-1965	404.37753	1.119357	43.97
1959-1963	569.114	1.438339	63.21	1962-1966	400.05331	1.134579	42.94
1960-1964	469.72366	1.368955	63.51	1963-1967	365.01897	1.14044	48.4
1961-1965	455.95783	1.340584	61.52	1964-1968	344.77362	1.168021	56.08
1962-1966	468.48477	1.387673	61.86	1965-1969	360.36895	1.194882	53.69
1963-1967	458.77766	1.388527	64.55	1966-1970	351.10037	1.146063	56.16
1964-1968	418.82948	1.369275	64.75	1967-1971	337.64651	1.122447	57.23
1965-1969	410.41955	1.351846	66.98	1968-1972	350.7241	1.1075	55.59
1966-1970	408.77609	1.324379	66.8	1969-1973	343.7793	1.045	48.52
1967-1971	459.39459	1.36504	59.74	1970-1974	328.83014	1.027341	52.97
1968-1972	445.6434	1.340288	55.67	1971-1975	382.45593	1.079228	42.16
1969-1973	544.64416	1.341629	51.18	1972-1976	397.09937	1.051423	42.54
1970-1974	539.01869	1.301205	54.85	1973-1977	354.82808	1.00483	49.61
1971-1975	577.28452	1.302644	56.07	1974-1978	347.2344	0.99	45.42
1972-1976	522.5354	1.243039	62.53	1975-1979	361.4053	1.0025	46.06
1973-1977	504.6613	1.2146	67.47	1976-1980	327.4181	0.9805307	51.63
1974-1978	502.03751	1.236661	64.68	1977-1981	332.75372	1.005679	51.04
1975-1979	514.96126	1.345326	66.31	1978-1982	330.0642	1.00091	47.86
1976-1980	749.12416	1.422086	36.19	1979-1983	319.09105	0.9853777	50.18

1977-1981	818.70553	1.482232	33.7	1980-1984	397.43506	1.008859	41.38
1978-1982	919.26118	1.532557	30.09	1981-1985	414.41122	1.004074	63.14
1979-1983	976.10512	1.545057	29.02	1982-1986	407.49923	0.9884946	66.84
1980-1984	5046.6863	1.509547	3.5	1983-1987	437.71952	1.053137	60.87
1981-1985	1665.6537	1.510759	23.8	1984-1988	438.19144	1.086382	58.25
1982-1986	1793.7295	1.479943	19.62	1985-1989	442.1621	1.158247	50.56
1983-1987	1949.7589	1.445168	24.44	1986-1990	428.96639	1.16346	47.49
1984-1988	1935.9545	1.439462	27.56	1987-1991	450.51618	1.197704	45.8
1985-1989	2766.3315	1.528381	25.74	1988-1992	397.09937	1.130326	47.66
1986-1990	7635.2447	1.532029	2.64	1989-1993	375.6933	1.080848	46.62
1987-1991	5651.8386	1.517343	9.79	1990-1994	286.70521	0.9157036	64.84
1988-1992	15723.448	1.511133	10.77	1991-1995	308.0482	0.9474602	57.25
1989-1993	19228.776	1.463675	24.63	1992-1996	315.19768	0.9535358	56.83
1990-1994	12247.959	1.448114	-21.28	1993-1997	309.50359	0.9585867	57.66
1991-1995	8196.5924	1.44343	-21.23	1994-1998	322.36123	0.9900122	55.95
				1995-1999	413.44474	1.058079	42.33
				1996-2000	433.47734	1.06871	43.83

Bada station							
Calibration Periods	X1	X2	Nash (Q)	Calibration periods	X1	X2	Nash (Q)
1959-1963	618.32235	1.410521	42.59	1978-1982	404.40499	1.140986	47.71
1960-1964	594.70449	1.409037	40.98	1979-1983	392.00367	1.113325	49.54
1961-1965	552.58567	1.413518	45.01	1980-1984	459.17267	1.064921	50.05
1962-1966	588.78708	1.419037	44.69	1981-1985	483.63966	1.080732	73.42
1963-1967	542.48767	1.403854	48.3	1982-1986	478.03133	1.045341	74.05
1964-1968	515.42139	1.38659	49.77	1983-1987	551.81987	1.092827	66.81
1965-1969	528.2828	1.385587	50.97	1984-1988	558.22007	1.129028	64.73
1966-1970	539.73182	1.372558	51.4	1985-1989	561.22162	1.167567	61.72
1967-1971	512.87916	1.353371	54.04	1986-1990	589.8277	1.169843	54.18
1968-1972	504.90714	1.29687	53.59	1987-1991	604.29574	1.20157	51.15
1969-1973	482.2638	1.245627	57.76	1988-1992	531.2111	1.169337	55.53
1970-1974	440.04051	1.200152	63.21	1989-1993	526.37454	1.145498	52.85
1971-1975	406.2312	1.130495	73.17	1990-1994	477.94021	1.133138	46.64
1972-1976	334.7142	1.024109	80.04	1991-1995	484.73362	1.141407	47.63
1973-1977	312.91374	1.004534	83.9	1992-1996	458.82379	1.12471	49.88
1974-1978	310.38087	0.9774971	82.56	1993-1997	417.26066	1.105453	54.2
1975-1979	323.01105	1.034743	62.88	1994-1998	435.87775	1.149686	53.03
1976-1980	370.59143	1.09803	49.72	1995-1999	471.24199	1.137369	53.57
1977-1981	413.90757	1.183654	48.34	1996-2000	435.14485	1.133359	55.27

Proxy basin-test Nzienoa-Mbasso

Calibration on Nzienoa before 1970				Validation on Mbasso watershed before 1970			
Calibration before 1970				1954-1958	1959-1963	1964-1968	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1951-1955	474.76896	1.165445	55.4	-19.28	49.57	41.16	
1956-1960	376.86545	1.056884	50.4	20.24	44.47	45.45	
1961-1965	477.52722	1.119068	54.09	17.1	**55.87**	34.99	
1966-1969	307.16265	1.051281	64.21	**-43.54**	-31.08	54.75	
Nzienoa Watershed				Mbasso watershed			
Calibration on Nzienoa after 1970				Validation on Mbasso after 1970			
Calibrtion after 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1972-1976	422.67227	0.9500839	71.67	32.32	31.06	64	**25.77**
1977-1981	462.88438	1.030834	44.26	36.34	35.7	**65.41**	30.73
1982-1986	505.70604	1.064341	49	34.96	33.78	63.44	29.12
1987-1991	562.09685	1.095781	41.02	32.57	30.88	60.17	26.2

Proxy-basin differential split sample-test Nzienoa-Mbasso

Calibration on Nzienoa before 1970				Validation on Mbasso after 1970			
Calibration before 1970				1972-1976	1977-1981	1982-1986	1987-1991
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)
1951-1955	474.76896	1.165445	55.4	39.69	44.67	49.14	43.89
1956-1960	376.86545	1.056884	50.4	41.42	49.86	51.56	42.86
1961-1965	477.52722	1.119068	54.09	40.9	43.09	**60.66**	39.78
1966-1969	307.16265	1.051281	64.21	15.73	42.82	**-18.49**	29.7
Nzienoa				Mbasso watershed			
Calibration on Nzienoa after 1970				Validation on Mbasso before 1970			
Calibration after 1970				1954-1958	1959-1963	1964-1968	
Period	X1	X2	Nash (Q)	Nash (Q)	Nash (Q)	Nash (Q)	
1972-1976	422.67227	0.9500839	71.67	33.93	52.96	20.8	
1977-1981	462.88438	1.030834	44.26	36.85	**55.54**	24.98	
1982-1986	505.70604	1.064341	49	33.91	53.72	22.65	
1987-1991	562.09685	1.095781	41.02	29.78	50.35	**19.23**	

APPENDIX 5: Research grant

S/No	Item	Unit	Quantity	Rate(Unit price)	Amount (USD)	Link to research Activities
A) Materials and Supplies						
1	ArcGIS Licence	Year	1	250$	250$	This software be used for the watershed delineation and determination of some parameters.So there is a need to have a licence of this software in order to use it for my research.
2	Internet recharge+ SIM card	Months	6	50$	300$	Used for online research as for download articles,books and include communication.
3	Printings, scanning and bindings document	Page	5	150$	150$	It will cover reports printing (5copy for yhesis defence), as well as all photocopiying, printing during the whole of my research
4	External hard disk	_	1	100$	100$	1 Tera of capacity for data collection for a long period of time for the statiscal analysis.
Sub-total					**800$**	
B) Equipment						
1	Hardcopy/book	_	1	108$	108$	Book1: Fundamentals of Programming and Statistical Analysis
2		_	1	142$	142$	Book2: Statistics of Extremes E.J Gumbel
Sub-total					**250$**	

C) Travel + Visa costs						
1	Schengen visa+global VFS appointment	_	1	200$	200$	For the Internship in HydroSciences (France) where the study will be conducted
2	Field transportation	_	_	500$	500$	From HydroSciences Montpellier University to the lboratory of HydroSciences Montpellier
3	Flight ticket to Montpellier(Tlemcen-Algiers-Montpellier)	_	1	450$	450$	To the Internship place at HydroSciences Montpellier(France) where the research will be done.
4	Health Insurance	Days	90	100$	100$	Mandatory for Schengen Visa (Cover me during the Internship period in Montpellier)
Sub-total					**1250 $**	
D) Special Activities						
1	Publication	_	_	200$	200$	For visibility and good quality work
Sub-total					**200$**	
E) Contingencies						
1	Contingencies	_	_	100$	100$	
Sub-total					**100$**	
Total					**2600$**	