UNIVERSITE JOSEPH KI-ZERBO

ECOLE DOCTORALE INFORMATIQUE ET CHANGEMENTS CLIMATIQUES

BURKINA FASO

Unité-Progrès-Justice

MASTER RESEARCH PROGRAM

SPECIALITY: INFORMATICS FOR CLIMATE CHANGE (ICC)

MASTER THESIS

Subject :

Analysis of the recent evolution of dry spells in Burkina Faso

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Academic year 2022-2023

DEDICATION

I dedicate this thesis to:

My late beloved mother, may her soul rest in peace, as well as my father.

My sisters, brothers, and all the victims and internally displaced persons due to terrorism in Burkina Faso.

Acknowledgments

Thanks to the **Almighty Lord** for seeing me through my university education this far and successive completion of this Master's thesis. May His Holy Name be glorified forever. The author is deeply indebted to the **German Federal Ministry of Education and Research (BMBF)** through the **WASCAL PROGRAM** for providing me with a fully-funded scholarship to undertake the study in Burkina Faso to carry out the research work written in this thesis. Thanks. The author would like to take this earliest opportunity to thank the formal Director of the Master Program Informatic for Climate Change (MRP-ICC) **Prof. TANGA PIERRE ZOUNGRANA,** his deputy director Dr. COULIBALY OUSMANE and the scientific coordinator Dr. Jean Boscau Benewende. I would like to express my deep heartfelt gratitude and appreciation to my supervisors, the main supervisor **Prof. DAO TIZANE** and the co-supervisors **Dr. GUIGMA KISWENDSIDA** and **Dr. DIASSO ULRICH** for their continuous comments, suggestions, advices, and encouragements right from the early stage of proposal development up to the end. Without continuous follow-up, correcting the manuscripts, and constructive comments the research work may not take the current form. They did not only provide mentorship but showed genuine concern for my wellbeing. I am so grateful to them because they made me see the skies only as the beginning of what I am capable of achieving in the academy. I would like to express my sincere thanks to **Dr. DANGO** the department head of climate research at the National Meteorological Agency in Burkina Faso and all staff of the National Meteorological Agency. I owe a special thanks to my colleagues and to all those who provided voluntary assistance of all kinds and to everybody who takes the time to read this thesis, it was appreciated and is hereby acknowledged.

Abstract

Changes in the distribution of precipitation frequency and intensity can affect dry and wet spells, which will have an impact on climate-sensitive sectors, most notably agriculture. This study set out to analyze the variations of onset and cessation dates of the rainy season, to understand dry spells nature and their drivers in Burkina Faso. We used daily rainfall data of 10 synoptic stations from the National Meteorological Agency, the Madden-Julian Oscillation (MJO) and El Nino-Southern-Oscillation (ENSO) indices for the period 1991-2020 are then used to identify the onset and the cessation of the rainy season and their anomalies using the definitions of Sivakumar and (Kasei and Afuakwa) for season onset dates, and the definitions of Maikano and (Kasei and Afuakwa) for the season cessation dates, dry spells frequencies, longest dry spells, average dry spells duration and the modulation of the MJO and the ENSO in the occurrence of dry spells. All these parameters were computed between the onset and the cessation of the season and these dates were determined from May to October. Statistical analysis was made using Kendall's Nonparametric Test for Monotonic Trend, standard deviation, and simple linear model to assess trends in these variables. We used R programming language to extract and analyze the dry spells and the two modes, the onset and cessation dates are computed using second-order Markov chain with Instat software. We found that both changed with rainfall onsets having a more important change. The longest dry spells are identified at the cessation of the season compared with the onset of the season and there is a moderate frequency in the occurrence of DS. Across the studied period, most dry spells fluctuate between 5 and 15 days. Some phases of the MJO such as phases 5 and 7 increase the likelihood of DSs and phases 1 and 2 decrease it. At the interannual scale, the ENSO influences DS characteristics with El Nino that increase the likelihood of the DSs occurrence. To help different stakeholders with their decision-making, it would be helpful to identify the distributions and patterns of critical dry spells and explore the possibility of predicting the patterns of dry spells in the future.

Key words: Dry spell; Markov chain; Modulation; Burkina Faso; ENSO and MJO.

Résumé

Les changements dans la distribution de la fréquence et de l'intensité des précipitations peuvent affecter les périodes sèches et humides, ce qui aura un impact sur les secteurs sensibles au climat, notamment l'agriculture.. Cette étude vise à analyser les variations des dates de début et de fin de la saison des pluies, afin de comprendre la nature des périodes de sécheresse et leurs facteurs déclencheurs au Burkina Faso. Nous avons utilisé les données quotidiennes de précipitations de 10 stations synoptiques de l'Agence Nationale de la Météorologie, ainsi que les indices de l'oscillation de Madden-Julian (MJO) et El Niño-Southern Oscillation (ENSO) pour la période 1991-2020 afin d'identifier le début et la fin de la saison des pluies et leurs anomalies en utilisant les définitions de Sivakumar et (Kasei et Afuakwa) pour les dates de début de saison, et les définitions de Maikano et (Kasei et Afuakwa) pour les dates de fin de saison, les fréquences des périodes de sécheresse, les périodes de sécheresse les plus longues, la durée moyenne des périodes de sécheresse et la modulation de la MJO et de l'ENSO dans l'occurrence des périodes de sécheresse. Tous ces paramètres ont été calculés entre le début et la fin de la saison, et ces dates ont été déterminées de Mai à Octobre. L'analyse statistique a été réalisée en utilisant le test non paramétrique de tendance monotone de Kendall, l'écart type et le modèle linéaire simple pour évaluer les tendances de ces variables. Nous avons utilisé le langage de programmation R pour extraire et analyser les périodes de sécheresse et les deux modes, les dates de début et de fin, sont calculés en utilisant une chaîne de Markov d'ordre deux avec le logiciel Instat. Nous avons constaté que les deux dates (début et fin) changent, avec des débuts de précipitations présentant un changement plus important. Les périodes de sécheresse les plus longues sont identifiées à la fin de la saison par rapport au début de la saison et il existe une fréquence modérée dans l'occurrence des périodes de sécheresse. Au cours de la période étudiée, la plupart des périodes de sécheresse fluctuent entre 5 et 15 jours. Certaines phases de la MJO, telles que les phases 5 et 7 augmentent la probabilité de périodes de sécheresse, tandis que les phases 1 et 2 la diminuent. À l'échelle interannuelle, El Niño influence les caractéristiques des périodes de sécheresse en augmentant la probabilité de leur occurrence. Pour aider les différentes parties prenantes dans leur processus décisionnel, il serait utile d'identifier les distributions et les motifs des périodes de sécheresse critiques, ainsi que d'explorer la possibilité de prédire ces motifs de sécheresse à l'avenir

Mot clés : poche de sécheresse ; chaine de Markov ; modulation ; Burkina Faso ; MJO et ENSO

Acronyms and abbreviations

ADSD	Average Dry Spell Duration
ANAM	Agence Nationale de la Météorologie
ASO	August-September-October
DD	Dry Day
DFD	Dry spell Frequency Duration
DOY	Days of Year
DOY	Days of Year
DS	Dry Spell
DSF	Dry spell Frequency Duration
DSL	Dry spell length
ENSO	El Nino-Southern-Oscillation
Eq	Equation
FAO	Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
JAS	July-August-September
LDS	Longest Dry Spell
MAM	March-April-May
MJJ	May-June-July
MJO	Madden-Julian Oscillation
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OLR	Outgoing Longwave Radiation
ONI	Oceanic Niño Index
RMM	Real-time Multivariate MJO
SSA	Sub-Saharan-Africa
SST	Sea-Surface Temperature
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorology Organization

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Introduction

1. Background

Climate change has become one of the major challenges to development in the world. It has a definite direct impact on food production by changing agro-ecological conditions and has repercussions on economic growth and income distribution, hence on the demand for agricultural products. The African continent is the most vulnerable region of the world to long-term decreases in rainfall and seasonal rainfall variability with more than 95% of farmers living on rainfed agriculture.

Over the past five decades, Burkina Faso has suffered greatly from the adverse effects of the climate and the most important of these climatic shocks are droughts due to insufficient and unevenly distributed rainfall, floods from exceptional heavy rains, heat waves and low water tables distribution, floods from exceptional heavy rains, heat waves and intense dust events. The persistence of climate change will inevitably lead to an increase in the frequency and magnitude of extreme climatic phenomena; their repercussions in terms of impacts will be detrimental to certain sectors and socio-professional groups with limited means. As the country is vulnerable to climatic shocks, preparation to cope with them is naturally necessary.

In West Africa, Burkina Faso in particular experienced a continuous rainfall deficit in the 1980s (Landsberg 1975; Dai et al. 2004). The average annual rainfall during the period (1970-2009) remained below the average annual rainfall recorded during the period 1900-1970, according to an analysis of rainfall data for West Africa (1896-2006) (Mahé and Paturel 2009). This continuing rainfall deficit is not without consequences for the country's socio-economic situation, as agriculture and livestock farming are the main activities practiced by more than half the population, and are dependent on the amount of rain that falls during the rainy season. In addition to this rainfall deficit, repeated droughts, and the lowering or total drying of groundwater that feeds the springs are effects of climate variability and change in Burkina Faso. Combined with socio-economic and desertification factors, they have several consequences such as the decline in soil fertility, accelerated soil erosion, vegetation depletion, reduction of harvesting products, depletion of wildlife, and genetic depletion of animal and plant species.

2. Statement of problem

Africa has experienced rainfall fluctuations of varying length and intensity. The droughts of the 1910s caused enormous damage and were destructive in many ways, and East and West Africa were not spared the damaging effects of these droughts. They were generally followed by increasing rainfall amounts, but negative trends were observed again from 1950 onwards (Gommes et al.1996). These droughts continued until 1973 in the Sahel and had a global impact because the phenomenon was presented as a regional disaster in the same way as an earthquake or volcanic eruption. These droughts have affected most West African countries and Burkina Faso has not remained indifferent, because in recent history, Burkina Faso and the Sahel as a whole has suffered dramatic droughts (1913, 1939, 1970), generally followed by relatively more favorable years. Severe Droughts similar to those of 1973 are becoming less frequent. However, drought impacts are still there and can be attributed to “dry spells” on an intraseasonal scale, driven by certain features of which we will pay a particular intention. A dry spell, according to Wilhite DA and Glantz MH (1985), is a time when the weather has been dried for an unusually long time but not as severe as a drought. Dry spells have not been well studied in the Sahel, with little documentation available. Understanding their characteristics and natures is of crucial importance considering the enormous impact they have. It should also be noted that the impacts of these dry spells are not well understood, hence the importance of improving our knowledge of these dry spells. Dry spells in the rainy season are relatively frequent in Burkina Faso and are therefore a threat to the smooth running of agricultural activities. The persistence of dry spells in the rainy season shows the importance of studying their characteristics further for a better understanding of this phenomenon. In this sense, prior knowledge on the starting dates and lengths of dry spells has a significant importance in rain-fed agriculture, irrigation planning, and various decision-making processes related to climate, as a result, it has been noted that the long dry spells cost the affected communities a huge amount of money (Mathugama, S. C et al.2011). The success or failure of crops, particularly during the rainy seasons, is closely linked to the distribution of drought periods, for example in humid countries. For achieving maximum benefits from dry land agriculture, the knowledge of distribution of dry spells within a year is useful (Peiris, 2011).

Due to their reliance on agricultural and water resources, West African nations are particularly vulnerable to variations in rainfall, particularly at intraseasonal time scales (Gadgil and Rao 2000;

Sultan et al. 2005). The crop yield which varies depending on the rainfall distribution throughout the season can be considerably affected by the occurrence of wet and dry spells (Janicot and Sultan 2001). In West Africa, there are two dominant modes ranging from 10 to 25 days and from 25 to 60 days at different scales (Janicot and Sultan 2001). The length of dry spells could be used to determine the best crop or variety for a location, as well as to breed varieties with different maturation times. It is important to know that these dry spells are influenced by various determinants that condition their frequency and occurrence. Among these potential determinants we have the MJO (Madden-Julian Oscillation) which is the dominant mode of variability in the tropical atmosphere on an intraseasonal time step (Kurita et al.2001) While large-scale convective clusters are only present in the equatorial at this time of year, the MJO appears to play a significant role in the occurrence of dry spells over the Sahel during the monsoon (Pohl et al., 2009), the Guinean belt also has a brief dry season that is affected by latitude. The understanding of these dry spells through the MJO and ENSO could be crucial for better decision making because there is also little research on the link between these dry spells and this potential mode to improve our understanding about this relationship.

3. Research Questions

3.1. Main question

Given the foregoing, prior knowledge of the occurrence of dry spell analysis would be beneficial to minimize unexpected damage due to dry spells and to have effective and efficient planning for various stakeholders. Therefore, a main question arises to know what the recent evolution of dry spells in Burkina Faso is?

3.2. Specific questions

In order to carry out this study we will first of all try to find out:

- How have the onset and cessation dates of seasons evolved over the past three decades?
- What are the characteristics and different evolutions of dry spells in Burkina Faso?
- What are the relationships between dry spells and its drivers such as the Madden-Julian Oscillation (MJO) and the El Nino-Southern-Oscillation (ENSO)?

4. Hypotheses

4.1. The main hypothesis

The main hypothesis of this study is that the analysis of seasonal and intraseasonal changes over the past three decades uncover significant temporal shifts influenced by long-term climatic variations and regional factors like rainfall patterns in Burkina Faso.

4.2. Specific hypotheses

Based on the main hypothesis, three hypotheses were put forward in the context of this study:

- ✓ The analysis of the observed changes in the onset and cessation dates of seasons over the past three decades reveal significant temporal shifts and patterns;
- ✓ In Burkina Faso, variations in rainfall patterns have a significant impact on the characteristics and evolution of dry spells;
- ✓ There is a significant association between dry spells and the drivers of the Madden-Julian Oscillation (MJO) and the El Niño-Southern Oscillation (ENSO);

5. Objectives

5.1. General Objective

The main objective of this study is to understand dry spell nature, its drivers during the rainy season of study area.

5.2. Specific Objectives

This main objective is divided into three specific objectives:

- To analyze the various change observed in the onset and cessation dates of seasons over the past three decades;
- To determine the characteristics and different evolutions of dry spells in Burkina Faso;
- To determine the association between dry spells and its drivers such us the Madden-Julian Oscillation MJO and the El Nino-Southern-Oscillation (ENSO)

6. The Significance of the Study

Studies on the effects of dry spells on agriculture are essential for planning and managing water use. It offers crucial data for scheduling cropping times and managing rainfall water using various methods that can boost crop productivity and production. The knowledge gained from this study will facilitate practitioners, planners for future development, and decision-makers in managing water resources, environmental protection, water projects, and other water-related issues. Therefore, there is need to determine accurately the onset and the cessation dates, hence distribution of the rainfall season for any given place. The farmers need to be educated on how to fully utilize the seasonal rains. This will help in improving the economy of the country as well as enhancing food production that will lead to food security for the increasing population in the country.

7. Scope of the study

It is advised to limit the scope of the analysis to dry spells and their impact on agriculture as it was not possible to cover all aspects of the study area, such as plant cover and other agricultural activities in the time available. Utilizing downscaled dynamic data of the primary modes dominating the general atmospheric circulation the current and future climatic influence can be investigated.

8. Organization of the thesis

There are three chapters in this study. The study's context, problem statement, objectives, importance and scope of the study are all briefly discussed in the introduction. The relevant literature on precipitation, dry spells, the onsets and cessation of seasons, climate variability and agriculture are presented in the first chapter. The second chapter shows the analysis and research methodology. The third chapter presents and discusses the study's results including its recommendations and conclusions.

CHAPTER 1: LITERATURE REVIEW

In this chapter, we will discuss the theoretical framework of our study, which essentially includes the definition of concepts, analysis of inter-seasonal climate variability and the global and regional modes of climate variability in relation to dry spells.

1.1. Definitions and concepts

This section provides definitions and descriptions of important terms used in this thesis.

Dry Day (DD): the most typical method for defining a dry day is to establish a fixed threshold below which precipitation is regarded as being equal to zero. Yet, this threshold could vary in time according to the seasonal cycle and in the context of long-term trends, such as the increase in temperature due to climate change (Pauline Rivoire et al.,2019).

Dry Spell (DS): a sequence of dry days with no precipitation or only a trace amount of precipitation is known as a dry spell in meteorology. Dry spells are extremely helpful for assessing spatial differences in the drought hazard probability (Lana et al., 2006) and determining potential trends associated with climate change (Raymond et al., 2016), even though they cannot be used to determine drought severity due to climatological differences.

Dry Spell Frequency (DSF): it is defined as how many times successive number of years dry spells took place during the time period under study (McKee *et al*., 1993).

Dry spell length (DSL): defined as the number of consecutive days with precipitation less than from decided threshold value of rainfall (Serra, C., 2006; Lana, *et al*, 2008).

Dry Spell Duration (DSD): is the total number of dry days before the next rainy day.

The longest dry spell duration (LDSD): the maximum sum of any subsequent dry spells is known as LDSD.

Climate: The term "climate" is typically used to refer to the "average weather" or, more precisely, to the statistical description of relevant quantities over timescales ranging from months to thousands or millions of years. The traditional period is 30 years, according to the World Meteorological Organization (WMO, 2007).

Weather: describes the atmosphere, daily air temperature, pressure, humidity, wind speed, and participation over a short period of time (IPCC, 2007).

Vulnerability: a community, system, or asset's traits and circumstances that make them vulnerable to a hazard's destructive effects (UNFCCC, 2007).

Climate variability: it transcends the size of a single weather event, changes in the mean state and other climate statistics (such as standard deviations, frequency of extremes, etc.) (Fussel and Klein, 2006).

Climate change: is a change in the mean and/or variability of a climate's properties that can be used to identify the change over an extended period of time, usually decades or longer (e.g., using statistical tests). According to the IPCC (2007), "permanent anthropogenic changes in the composition of the atmosphere or in land use may be the cause of climate change in addition to natural internal processes, external forcing, or both.

1.2. Inter-seasonal climate variability analysis

1.2.1. Onset and cessation of the rainy season

Previous research on the onset of rainfall has used a variety of methods depending on the region's rain-generating mechanisms. Ilesanmi (1972) developed an empirical formula for the onset and cessation of the rainy season in Nigeria. Similarly, Oshodi (1971) used a straightforward pentad method to reach similar isochrones of the onset of the rainy season in Nigeria. Further, the existence of seasonal rainfall predictability in Australia was established beyond a reasonable doubt by Nicholls (1984) using a wet season onset index. A water balance method was used by Lineham (1983) to determine the start and end of the rainy season in Zimbabwe. With the same aim of determine the onset and the cessation of the season, the onset of the growing season according to FAO (1978), is the day on which precipitation exceeds 50% of the annual potential evapotranspiration. Using a water balance method, Stewart and Hash (1982) assessed the suitability of a given crop for a semi-arid location in Kenya. Depending on when the rainy season began and how much rain was required for maize, different seasons were classified. This allowed recommendations on seed and fertilizer rates and thinning out of plants to be made and yield predicted for planning purposes, the same author in 1985 demonstrated that in Kenya's bimodal rainfall regions, maize can be grown if the rains start early but not if they start later which occurs in about half the number of years, sorghum and millet should be favored over maize. Raes et al. (2004) used a soil water balance model to evaluate the first planting dates in Zimbabwe and suggested the depth (40 mm of rain in 4 days) criterion as an appropriate wet season sowing criterion based on the farmers' practices. Planning activities during the season will benefit greatly from the existence of a relationship between the onset and cessation dates as well as between the length of the season and the onset and/or cessation dates. In the southern Sahelian and Sudanian climatic zones of West Africa, Sivakumar (1988) examined long-term daily rainfall data for 58 locations and the study showed that a significant relationship between the length of the growing season and the beginning of rainfall. With the same vision of supporting Sivakumar's previous result, Oladipo and Kyari (1993) investigated the fluctuation in the onset, cessation and length of the growing season in Northern Nigeria and reported also that the growing season's length and the beginning of the rains have a bigger impact on the season than their end. In order to choose a less risky planting date, planting method, or sowing of less risky types/varieties of crops in responsive farming, reliable rainfall characteristics prediction is required, particularly the onset (Stewart, 1991). According to Salack et al. (2015), the first day between April 1 and July 31 when the soil moisture in the top 20 cm is at least 40%, the minimum temperature for millet cultivars is not below 11°C, and the maximum temperature is not higher than 35°C, is when the season officially begins. According to Tesfaye and Walker (2004), the day following September 11 when the soil water content drops to 10 mm/m is when the rainy season ends (in Ethiopia). Hadgu et al. (2013) and Kassie et al. (2014) adopted the same definition of the end of the rainy season. Mesay (2006) defined this date as any day after the first of September (for Kiremt) on which the water balance reaches zero. The minimum threshold for daily precipitation of 25 mm, according to Zargina (1987), may signal the end of the growing season.

1.2.2. Dry Spells analysis

The definition of dry spell may vary depending on the aims, methodology used in search study, based the length of consecutive dry days, different threshold values used by different authors and depending on the particular problem (Mathugama *et al*., 2011).

The term "dry spell" was first used in British Rainfall in 1919, which defined it as a period of at least 15 consecutive days during which none of the days received 1.0mm of rain. An extended stretch of dry days, including those lasting just one day, is referred to as a "dry spell."

The most common definitions of a dry spell come from meteorology. They frequently use the length and severity of the dry period alone to define what a "dry spell" is. Therefore, a meteorological dry spell is defined as a stretch of time lasting longer than a certain number of days during which there has been less precipitation than a predetermined small amount (Wilhite and Glantz, 1985).

According to several climate change studies (Held and Soden, 2006; Giorgi et al., 2011; Trenberth, 2011; Kendon et al., 2019; Berthou et al., 2019), global warming will intensify hydrological cycles increasing the probability of heavy rainfall and dry spells. The recovery of Sahel rainfall has been accompanied by a significant increase in extreme events (Alhassane et al., 2013; Descroix et al., 2016; Panthou et al., 2014, 2018; Taylor et al., 2017; Wilcox et al., 2018). Since the second half of the 2000s, floods have reportedly affected 1.7 million people in Benin, Burkina Faso, Chad, Ghana, Niger, Nigeria, and Togo (Sarr, 2012). Benin, Burkina Faso, Niger, and Senegal all experienced significant flooding in 2009 (Engel et al., 2017; Fowe et al., 2018; Salack et al., 2018), while more than 80% of Nigeria was affected by heavy rains in 2012. In Burkina Faso, there were also extreme occurrences such as the 263 mm record rainfall that fell in Ouagadougou in September 2009 (Lafore et al., 2017). To further enrich research into these climatic events, numerous authors have concentrated on the multi-scale variability in these potentially high-impact events using rain gauges, rainfall estimates from satellite imagery, and numerical weather prediction (NWP) (Washington et al., 2006; Sane et al., 2018; Nicholson et al., 2018). In fact, the Sahel experiences mixed dry/wet seasonal rainfall features known as hybrid rainy seasons with partial rainfall recovery (Salack et al., 2016). Giorgi et al. (2011) defined these hybrid rainy seasons as "hydroclimatic intensity," which is characterized by longer dry spells and more intense rainfall (Trenberth et al., 2003; Trenberth, 2011).

Even though other studies examined the spatio-temporal variability in dry/wet spells over West Africa and showed a close correlation to west African monsoon spatio-temporal variability (Froidurot and Diedhiou, 2017), a more thorough analysis of the components of these hybrid seasons is still lacking. These longer dry spells are also important for agro-climatic monitoring because, according to seasonal cycles, they typically occur at the beginning and end of rainy seasons (Salack et al., 2013). According to a study by Dieng et al. (2008), higher/lower cumulative seasonal rainfall in July through September in northern Senegal is related to an earlier/later long dry spell. In very few studies has the distribution of dry/wet spells over the Sahel been detected using satellite imagery, reanalysis products, and ground observations. The inter-annual variability in seasonal rainfall amounts has received the majority of attention in the few comparative studies that have been conducted in Africa (Thorne et al., 2001; Ali et al., 2005).

Dry spells raise the possibility of a drought occurring and increase the likelihood of food insecurity in the affected areas. According to studies, a significant portion of the world's population depends on rain-fed agriculture for food security (Fischer, 2012). Dry spells have become more frequent and longer-lasting over the past few decades as a result of climate change, which has raised concerns about rainfall variability in the world's rain-fed agricultural regions (Mugalavai and Kipkorir 2015). Dry spells have continuously had an impact on small-scale agriculture in many African regions, including livestock production, which is relied upon by 80% of the population for subsistence and by 90% of the population for food production (Rockstrom et al., 2003). The general predominance of monsoons and the corresponding agricultural practices in many parts of Kenya define the spatial and temporal distribution of short and long rains (Stewart, 1988), there are dry spells during both short and long rainy periods, especially in rangeland and subhumid lands, which have a significant impact on agriculture and particularly livestock production.

1.3. Global and regional modes of climate variability

A climate pattern with distinguishable traits, particular regional effects, and frequently oscillatory behavior is referred to as a mode of variability. Many modes of variability are used as indices to represent the general climatic state of a region affected by a given climate pattern. Such modes of variability may be found closer or far away from the target area, yet have an effect on the latter. Climate dynamics research has demonstrated the existence of several modes of climate variability (Gitau, W.,2011).

1.3.1. Rainfall and ENSO

According to Godínez-Dominquez et al. (2000), ENSO is the largest coupled ocean-atmosphere phenomenon that causes climatic variability on interannual time scales. The global climate community has taken notice of ENSO's extensive influence, in part because of its well-recorded effects on the economy and society both now and throughout history, both locally and globally, and within a broad latitudinal band around the equator. El Niño which is the oceanic component of ENSO refers to the anomalous and sustained warming of the Sea Surface Temperature anomalies of magnitude greater than 0.5°C across the central and eastern tropical Pacific Ocean. La Niña refers to the cooling phase. When the anomaly is present for fewer than five months, it is categorized as El Niño or La Niña conditions; if the anomaly continues for five months or longer, it is categorized as an El Niño or La Niña episode. On interannual and decadal time scales, precipitation over West Africa is highly variable and strongly correlated with sea surface temperature (SST) (Zhang et al. 2015). Globally, El Niño and the Southern Oscillation, positive SST anomalies in the southern hemisphere Atlantic and negative anomalies in the northern hemisphere Atlantic (the Atlantic Dipole), and positive SST anomalies in the tropical Indian Ocean are associated with dry conditions over the Sahel and wet conditions over Guinea (Folland et al. 1986; Janicot et al. 1998; Rowell 2001; Matthews 2004). The majority of these studies have concentrated on vast regions of West Africa, like the Sahel and Guinea. The significant variability at a more local scale may therefore not be captured by the rainfall teleconnection mentioned (Diro et al. 2011). Numerous countries have studied the effects of ENSO on crop production (Handler 1990; Cane et al. 1994; Carlson et al. 1996; Meinke et al. 1998). In general, yields have been higher in countries west of the Pacific during La Nina years and lower in countries east of the Pacific. Additionally, simulations were done to look into how ENSO phases affected the yields of various crops in other countries including maize in Zimbabwe (Phillips et al. 1998), peanuts in Australia (Meinke and Hammer 1995), and several others (Hansen et al. 1998; Messina et al. 1999).

Using data from nearby stations, no study has yet accurately examined how ENSO affects dry spells and agro-meteorological indices during crucial growing seasons in Burkina Faso.

1.3.2. Rainfall and MJO

The Madden Julian Oscillation (MJO) is an intraseasonal fluctuation or "wave" that occurs in the global tropics and travels eastward in a recognizable wave pattern. The MJO causes variations in several significant atmospheric and oceanic parameters, including lower and upper-level wind speed and direction, cloudiness, rainfall, sea surface temperature (SST), and ocean surface evaporation. The MJO is largely responsible for the weather variability in these areas and our coupled ocean-atmosphere model involves naturally the MJO and its typical cycle or wave lasts for 30 to 60 days (Madden and Julian, 1971, 1972; 1994; Zhang, 2005). Specifically, over the Indian and Pacific Oceans, the MJO is characterized by the eastward propagation of areas of enhanced and suppressed tropical rainfall. Frequently, the unusual rainfall first becomes visible over the Indian Ocean and continues to be visible as it moves eastward over the extremely warm waters of the western and central tropical Pacific. Tropical rainfall patterns typically become unremarkable over the eastern Pacific's cooler ocean waters, but they frequently reappear over the tropical Atlantic and Africa. There are distinct patterns of anomalous lower- and upper-level atmospheric circulation in the tropics and subtropics in addition to these variations in tropical rainfall. These characteristics are widespread and do not only exist in the eastern hemisphere. As a result, they offer crucial information about the regions of descending and ascending motion connected to specific oscillation phases.

Depending on its phase, MJO introduces organized convection and associated circulation that favor a region for wet or dry conditions. According to earlier research (Wheeler et al., 2009; Zhou et al., 2012), MJO can affect the frequency and severity of global precipitation and temperature events. Days with an MJO amplitude greater than or equal to 1 were considered to be active MJO days, and days with an MJO amplitude less than 1 were considered to be inactive MJO days, as suggested by earlier studies such as (LaFleur et al. 2015). For Equatorial Africa, phases 5 and 6 of the Real-time Multivariate MJO (RMM) were viewed as the dry phases (suppressed rainfall), while phases 2 was viewed as the wet phase enhanced rainfall (Gottschalck et al. 2010; Raghavendra et al. 2017; Zaitchik 2016). The most significant distinction between wet and dry conditions was produced by these RMM phase combinations used to define the wet and dry MJO regimes. According to Ajay Raghavendra et al. (2020), Phase 1 of the MJO describes the movement of the convective center eastward from west Africa, passing over the Indian Ocean in phases 2 and 3, the Middle East in phases 4 and 5, and the western Pacific in phases 7 and 8 before degenerating. He also shows that, moderately negative OLR anomalies (indicating enhanced convection) are present in phases 8, 1, and to a lesser extent, phase 2, whereas positive OLR anomalies (indicating suppressed rainfall) are present in phases 4 and 5. JAS, on the other hand, only shows marginal anomalies. Weakly positive in JAS but negative in MAM West African OLR anomalies in phase 7.

By modifying precipitation through a combination of the direct influence of the MJO's convective core advecting moisture from the Atlantic and a remote response to MJO activity in the Indian Ocean (Lavender & Matthews, 2009; Matthews, 2004), the MJO influences maize yields in West Africa. A study conducted in 2020 by (W. B. Anderson et al.) demonstrates how the MJO affects maize yields in West Africa by changing rainfall. Phases 1-2 of the MJO, which increase convection in the Indian Ocean while suppressing it in the warm western Pacific basin, produce atmospheric equatorial Kelvin waves and Rossby waves that move westward and eastward, respectively. These waves arrive in West Africa about a week later, destabilizing the atmosphere and causing an increase in precipitation there (Lavender & Matthews, 2009; Matthews, 2004). The same study showed that Phases 1 and 2 are consequently characterized by higher-than-expected maize yields, increased rainfall, wet soils, and a lack of high temperatures. Phases 3 to 6 are characterized by dry, hot weather, which reduces the modelled maize yields. The MJO tends to spread from phases 4 to 8, which may be why the fourth phase is the most detrimental to maize yields in western Africa. The sixth phase is also the longest before the rains finally sooth the cultures possibly because the dry and hot conditions of the sixth phase coincide with the MJO's tendency to spread from phases 4 to 8.

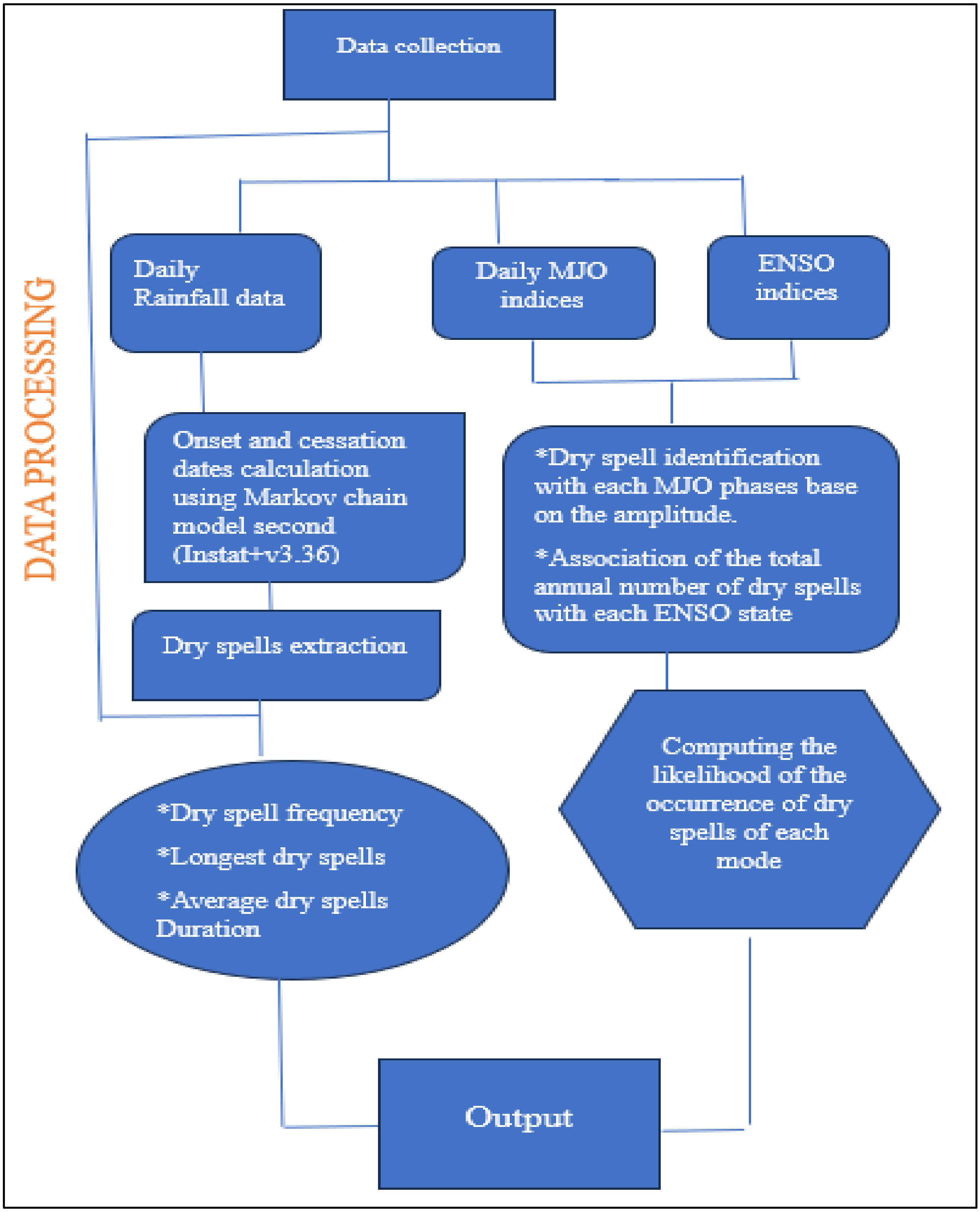


Figure 1 : Conceptual frame work of the study

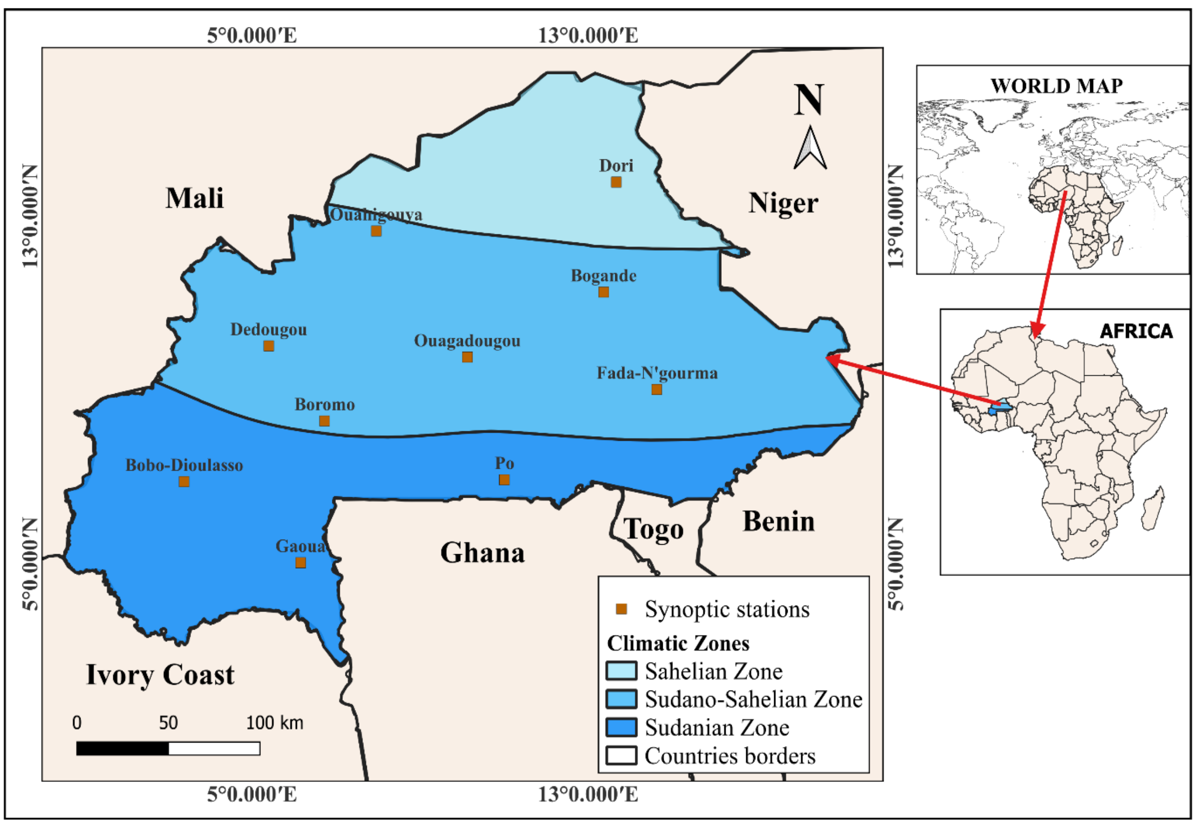
CHAPTER 2: MATERIALS AND METHODS

This chapter includes two essential points, the first one is the presentation and description of the geographical context of our study area and the second point presents the methodological approach used in this study.

2.1. Description of the study area

2.1.1. Location

This study was conducted in Burkina Faso considering the three climatic zones namely the Sahelian zone which is geographically between the 13° and 15° north parallels, Sudano-Sahelian zone which can be located to the zone between parallels 13° North and 11° 30' North and the Sudanian zone located below the parallel 11°30' North (Ganaba S. 2008). The study area map is illustrated in Figure 1.



Source: ANAM, Climatologie 1991-2020 *Date: 08/04/2023*

Figure 2 : Map of study area

2.1.2. Climate and hydrology

The Sahelian climatic zone has a hot semi-arid climate. The dry season is very long (around 9 months) and intense. During the dry season, the continental trade winds, such as the harmattan, constantly sweep across the region: the air is very hot and dry, often laden with fine particles of sand or dust. Overall, there is increasing aridification, with isohyets descending towards the south (Ouattara and Ouédraogo, 2004). Average temperatures range from 16°C to 47°C (Regional Council, 2019). The lowest temperatures are generally observed in December and January, while the highest are in April and May. The Sahelian hydrographic network is made up of ephemeral watercourses flowing into temporary (endoreic) ponds and small lakes. These play an important ecological role, as they are generally the only means of supplying water to wildlife during the dry season, with some retaining water until the rainy season. The hydrographic network consists mainly of the Béli, Feildégassé or Goudébo in the Oudalan, Gorouol (Séno/Ouadalan), Sirba, Yali and Faga (Yagha) rivers. The network also includes a large number of natural ponds, such as the Oursi pond in the Oudalan, and low-lying areas. Large dams, such as the Yakouta dam in the Séno, reinforce the network. According to the 2019 Yearbook of Environmental Statistics, on the surface area of land-use units by category in 2012 show that the Sahel has 18,363 hectares of water.

In the Sudanian-Sahelian climatic zone, annual rainfall is higher, varying between 600 and 700 mm. The dry season lasts no more than 8 months and temperatures are around 48°C in the middle of the dry season and 25°C during the rainy season. The region's hydrographic network is organized around two (02) main watersheds: the Nakambé watershed and the Niger sub-watershed, not forgetting the Mouhoun River and its tributaries which also cross the area. The Nakambé catchment covers the whole of Bam province and the western and southern parts of Sanmatenga. The Niger watershed is made up of the Faga, which covers the eastern and northern parts of Sanmatenga and a large part of Namentenga, the Sirba, which covers the extreme south of Namentenga and a small part of southern Sanmatenga, and the Gourouol, which is located in a small part of north-eastern Namentenga. The Nakambé is the most important river and only dries for part of the year. The region's bodies of water are made up of lakes Bam, Bourzanga, Sian and Dem, as well as dams, ponds and boulis. In addition to these watercourses, there is also groundwater, which is currently under-exploited, although river levels have been falling in recent years.

Located in the southern part of the country, the Sudanian climatic zone has the most abundant rainfall, at around 1100 mm per year. Thermal amplitude is less pronounced during the dry season, with temperatures ranging from 28c at night to 41c during the day. This area is covered by two watersheds: the Mouhoun and the Comoé. The Mouhoun is the most influential river in the area, and its tributaries are the Bougouriba and Bambassou. However, other permanent rivers of no less importance are scattered throughout the region: the Poni, the Déko, the Kamba and the Pouéné. The Comoé River is a major watercourse that rises in the northern part of the Comoé province. It flows southwards where it meets the river Léraba, with which it forms a natural border between the region and the Republic of Côte d'Ivoire. Its main tributaries are the Lakoba and Pa rivers. The river Léraba is made up of two main branches, the Léraba orientale and the Léraba occidentale. The two branches join in the Niangoloko department to form the natural border between the Republic of Côte d'Ivoire and Burkina Faso.

2.2. Data Types and Sources

Various types of data were obtained from different sources in order to analyze and examine the evolution of DS (Dry Spells) and their impacts on crop yields for decision making process supporting at farm level in the study areas. The data used for this study were daily rainfall records of 10 synoptic stations collected from ANAM (Agence Nationale de la Meteorologie) covering the three different agro-climatic zones of Burkina Faso and the period from 1991 to 2020 was considered for this study and, the entire series in our dataset has no missing values. The MJO was assessed the Real time Multivariate MJO (RMM) index from 1991 to 2020. RMM is obtained from the combination of winds at 850 and the ORL (Outgoing Longwave Radiation) and was available online from at the NOAA website from the URL: http://www.esrl.noaa.gov/psd/mjo/mjoindex/omi.1x.txt. The MJO RMM phase and amplitude are used in this study to decompose the interannual variability of the seasonal rainfall and the number of days in each MJO phases. The RMM index is better suited to assess rainfall over Burkina Faso because it takes into account the lower- and upper-tropospheric zonal wind, which affect vertical motion over Africa through interaction with topography or through confluence of flow. Additionally, the RMM index is less affected by emitted longwave radiation (OLR) than by the upper and lower tropospheric zonal windfield (Wheeler and Hendon 2004). ENSO indices have also been used in this study and The National Oceanic and Atmospheric Administration (NOAA) define El Niño and La Niña events based on a threshold of +/- 0.5°C for the Oceanic Niño Index

(ONI) (3 months running mean of SST anomalies over equatorial eastern Pacific) (http://ggweather.com/enso/oni.htm). ENSO years segregated into two groups as El Niño and La Niña and remaining years were classified under neutral category. None of our datasets used in this study have any missing values, although a data quality check has been carried out for greater transparency in order to carry out the various analyses. It should be noted that this study was only conducted during the rainy season in Burkina Faso, i.e., the period from May to October.

2.2.1. Data analysis

There are a number of standard methods for analyzing climate data for agricultural production planning and decision support. Seasonal and annual spatial distributions of rainfall were calculated on the basis of rainfall data using various statistical analysis tools such as Instat software. The study assesses the onset of rainfall, the cessation of rainfall, the analysis DS and their relationship with the various drivers that determine them and these parameters have been computed using the R language. Seasonal rainfall characteristics such as rainfall onset and intra-seasonal rainfall distribution can be used to promote good crop yield products.

2.2.2. The characteristics and different evolutions of dry spells in Burkina Faso

Based on a quantitative study of this thesis research, daily rainfall data observed from 1991 to 2020 on ten synoptic stations were taken, the onset and cessation dates, and dry spell risk were analyzed. For the purposes of this study, we have chosen three different definitions of authors to compute the onset and cessation dates of the seasons, the onset dates of the season were computed only during from May to July (MJJ) period and the season cessation dates were computed during from Auguste to October (ASO) period. To compute the onset dates of the seasons, the first approach is that of Sivakumar (1998) who defines the onset date as the first day after 1st May on which three consecutive days of rainfall totaled at least 20 mm and no dry spell lasted longer than seven days within the following 30 days; the second one is that of (Kasei and Afuakwa, 1991**)** as when there is a total rainfall of 30 mm within 10 days followed by no dry spells more than seven days in the following 30 days. To compute the cessation-of-season dates, we have used the definition of Maikano(1966) who defines the cessation dates After 1st September, when there is no soil water content down to a depth of 60 cm and a daily potential evapotranspiration of 5 mm; the second definition is from (Kasei and Afuakwa, 1991 who define the season's cessation as when

10 mm of rain have fallen in total over a period of 10 days and then there is no more rain for the following 10 days. Given with the above definitions, Instat+ 3.36 which is a statistical package and that also includes a range of special facilities and the second-order Markov chain model to compute theses dates, to simplify the processing of climatic data was used to analyze the daily rainfall data for onset and cessation of rainy season. According to an empirical study on the onset of the rainy season by Salack et al. (2012), a DS of more than two weeks can be linked to major rainfall events occurring in May-June-July (MJJ) and in the West African Sahel, these "false start" rainfall events lead to seed abortion caused by water stress in the early life stages of plants such as millet and sorghum (Ati et al. 2002; Sultan et al. 2005).

Variability of onset and cessation of rainfall can be expressed by various statistical parameters and we have calculated some of them:

Table 1 : Summary of the different definitions used to determine season onset and cessation dates

Approach for defining the onsets of seasons	**Approach for defining the cessation of seasons**
Sivakumar (1998) definition: the first day after May 1st on which three consecutive days of rainfall totaled at least 20 mm and no dry spell lasted longer than seven days within the following 30 days.	**Maikano (2006) definition:** After September 1st , when there is no soil water content down to a depth of 60 cm and a daily potential evapotranspiration of 5 mm
Kasei and Afuakwa (1991) definition: when there is a total rainfall of 30 mm within 10 days followed by no dry spells more than seven days in the following 30 days.	**Kasei and Afuakwa (1991) definition:** when 10 mm of rain have fallen in total over a period of 10 days and then there is no more rain for the following 10 days.

2.2.3. Statical metrics

Standard deviation: is the measure of the dispersion of the values**.** The higher the standard deviation, the wider the spread of values. The lower the standard deviation, the narrower the spread of values. The standard deviation can be computed as:

$$Sd = \sqrt{\left[\sum_{i=1}^{n} \frac{(Xi-\bar{X})\ 2}{n}\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Eq.1$$

where:

Sd: Standard deviation
Xi: each value
$\underline{X}$: sample mean
n: number of values in the sample

Kendall's Nonparametric Test for Monotonic Trend: It Performs a nonparametric test for a monotonic trend based on Kendall's tau statistic, and optionally compute a confidence interval for the slope. The formula is given as:

$$S=\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Xj - Xi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.2$$

Where:

S is the Mann-Kendal's test statistics

Xi and Xj are the sequential data values of the time series in the years i and j (j > i)

n is the length of the time series.

2.2.4. Dry Spells extraction

A threshold value of rainfall below which a day was considered dry was defined to identify wet and dry days and subsequently dry spells. For this study, therefore, a threshold of 1 mm was defined. A day with rainfall equal to or greater than 1 mm was considered a wet day and one with less than this threshold was regarded as dry. After determining the parameters of the dry period, we have used the R language to compute DS and we have developed a function that allows us to easily extract these DS. After introducing the dataset into the function, it returns a new dataset containing the stations, the years, months and days, the dry spells including the onset and cessation dates for each dry spells, a dry spell representing the consecutive number of dry days.

It should be pointed out that we have combined the Sivakumar and Maikano definitions to carry out our calculations, given that (Kasei and Afuakwa) have definitions for the onset and cessation dates of the season. The DS have only been computed between the onset and cessation dates of the seasons on a continuous basis and all the parameters determined (described below) are included in this period.

The longest dry spell duration (LDSD) is the maximum summation of any successive dry spells and it is calculated using the equation below:

$$\boldsymbol{LDSD = \sum_i^n Di : i = 1, 2, 3, \ldots\ldots N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 3}$$

Where:

Di=individual dry spell

n=number of data recorded period

If LDSD=N, then this implies a zero frequency of wet spells which means the whole record is dry spell. The average annual dry spell duration (ADSD) is also the indicator of dry spell length and it can be calculated as follows:

$$\boldsymbol{ADSD = \frac{\sum DS}{NE} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 4}$$

Where:

DS = Dry Spell, NE = number of events.

Which means ADSD is given by the summation of dry spells cases (D) divided by the total number of events (NE).

The average maximum duration of the DS has been computed as the sum of the maximum durations of the longest DS divided by the total number of years. The formula is given by:

$$\boldsymbol{AMD = \frac{\sum Lmax}{Tn} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 5}$$

Where:

Lmax = maximum duration of longest DS

Tn = Total number of years

To compute the LDS at the onset of the season, 50 days were added to each onset date and the longest DS was extracted within this interval. To compute the LDS at the cessation of the season, we maintained the previous interval, i.e., the one determined for the onset of the season, and added

50 days to the cessation date of this interval to determine the longest DS at the cessation of the season. For example, if for a given station the onset date of the season is 128 (DOY), the interval for determining the longest DS at the onset of the season would be 128+50, which would give [128......178], and the longest DS at the cessation of the season would be determined by doing 178+50, which would give the interval [178......228]. This method was established by the ANAM agrometeorologists, who use these criteria to calculate the longest DS at the beginning and cessation of the season.

Onset_Interval = Onset_Date + 50 …………………………………….Eq.6

Cessation_Interval = Onset_Interval + 50 ………………………………..Eq.7

Where:

Onset_Date: onset date of the season (in DOY)

Onset_Interval: interval for determining the LDS at the onset of the season

Cessation_Interval: interval for determining the longest DS at the cessation of the season

2.3. The association between dry spells and the Madden-Julian Oscillation

In the case of the MJO, given that the indices are daily, we have extracted the indices corresponding to our study period, i.e., the period 1991-2020. These data are then merged with the precipitation data to obtain a perfect identification of these 2 sets of data. We looked at the 5-day DS and then identified them with our different phases to see which phase had the highest number of DS. The modulation of the probability of occurrence of DS is evaluated between the onset and cessation dates of the season by modifying a method initially used by Xavier et al. (2014) for extreme precipitation, we compared the probability of a DS when a given mode is active on a specific phase against the climatological probability. The modulation of the probability of DS (MP) is thus given by the formula:

$$MP = \frac{Px - Pa}{Pa} \quad \text{………………………………….Eq.8}$$

Where:

Px: this is the probability of DS when the MJO is in phase x (1 to 8), i.e., the number of days on which SDs occur during phase x out of the total number of days on which the MJO is in that phase;

$$\boldsymbol{Px} = \frac{\sum \boldsymbol{number\ of\ days\ of\ DS}}{\boldsymbol{number\ of\ days\ in\ a\ phase\ x}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{\textit{Eq.9}}$$

Pa: climatic frequency of DS, i.e., the sum of the number of days of DS over the total number of days in the series, the formula is:

$$\boldsymbol{Pa} = \frac{\sum \boldsymbol{DS}}{\boldsymbol{total\ number\ of\ days}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{\textit{Eq.10}}$$

2.4. The association between dry spells and the ENSO

For the computation of the modulation of ENSO in the occurrence of the DS it is necessary to know that the periods of seasons from MJJ to SON were considered to determine the various states of ENSO of each year. We used the methodology described on the NOAA platform for the ONI indexes. On this platform, the events have been defined to identify each phase of ENSO. Thus, 5 consecutive periods of 3 months overlapping and greater than or equal to the anomaly of +0.5o for warm events is considered as an El Niño state, and in the opposite case if it is less than or equal to the anomaly of -0.5o for cold events, this period is qualified as a La Niña state. After making this classification, to overcome the problem of years with overlapping states, we have decided to choose the state that has manifested itself at least 3 times this year as the final state of ENSO. After identifying the different states of the ENSO per year, we used the same equation used to compute the modulation of the MJO to determine that of the ENSO, albeit with a slight difference in parameters to those of the MJO, because unlike the MJO, where the calculation was made on a daily basis, the ENSO was calculated on an annual basis. This work was made possible by a script that we created using the R programming language to automate the various tasks., (see annex….).

$$\boldsymbol{ME} = \frac{\boldsymbol{Px - Pa}}{\boldsymbol{Pa}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{\textit{Eq.11}}$$

Where:

Px: this is the probability of DS when the ENSO is in state x, i.e., the total number of days on which SDs occur during state x out of the total number of years on which the ENSO is in that state;

$$\boldsymbol{Px} = \frac{\sum \boldsymbol{Number\ of\ days\ of\ DS}}{\boldsymbol{number\ of\ years\ in\ a\ state\ x}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{\textit{Eq.12}}$$

Pa: climatic average of DS, i.e., the sum of the number of days of DS over the total number of years (in this case 30 years), the formula is:

$$\boldsymbol{Pa} = \frac{\sum \boldsymbol{DS}}{\boldsymbol{total\ number\ of\ years}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \boldsymbol{Eq.13}$$

CHAPTER 3 : RESULTS AND DISCUSSIONS

The preceding chapters have enabled us to put our research subject into context and to define the conceptual and theoretical bases for our research objectives. In this chapter, we present the results of our research based on our statistical analyses.
These results are grouped under headings.

3.1. Onset and cessation of the rainy season characteristics and variability

- **Sahelian climatic zone : Dori synoptic station**

In Figure 3, the rainy season onset dates at the Dori synoptic station are shown using the definitions put forth by Sivakumar and (Kasei & Afuakwa). Both curves exhibit year-to-year variations over the entire 30-year period. The average onset dates for these two definitions are the 189th Day Of Year (DOY) (Jul 7) for the (Kasei & Afuakwa) curve and the 190th DOY (Jul 8) for Sivakumar's curve. Notably, the (Sivakumar) curve showed a delayed onset of the season on the 201st DOY (Jul 19) in 1995, whereas the (Kasei & Afuakwa) curve shows an early onset on the 158th DOY (Jun 6). For the years 1996 to 1999, 2001 to 2004, 2009 to 2011, and 2013 to 2016, these two definitions produce the same onset dates. The seasons' onset dates for the remaining years show more similarity than divergence. The Sivakumar definition's standard deviation is approximately $\pm$21.35 days, whereas the Kasei & Afuakwa definition's is approximately $\pm$17.62 days.

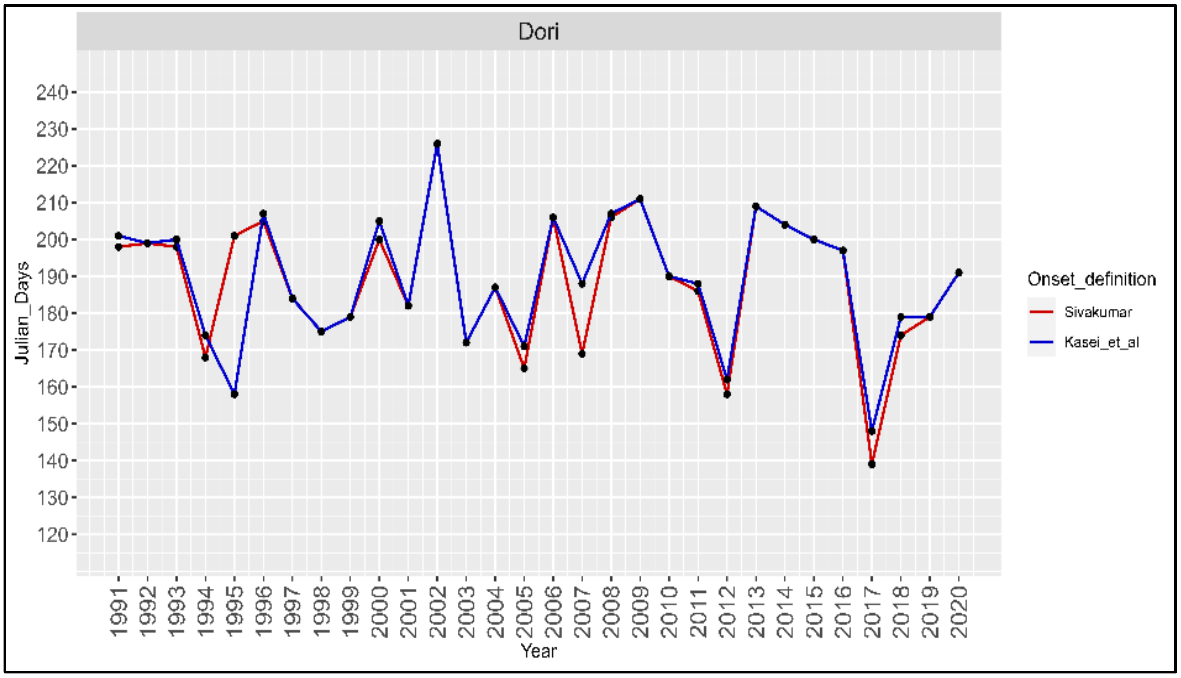


Figure 3: Onset dates of the seasons of the Dori station taking into account the two definitions

The average dates for the cessation of the rainy season using the definitions of Maikano and (Kasei & Afuakwa) are the 254th DOY (September 10th) and the 282nd DOY (Oct 8) respectively, as depicted in figure 4. Both curves exhibit some variation, but consistent with observations made at other stations, the Kasei & Afuakwa curve consistently ends the season later than the Maikano curve. This suggests that the cessation of season dates according to Kasei & Afuakwa are typically later than those according to Maikano. It's crucial to know that the Maikano curve states that the majority of seasons end in early September. The standard deviation for Maikano's definition is roughly $\pm$9.16 days, whereas it is roughly $\pm$13.82 days for the (Kasei & Afuakwa) definition.

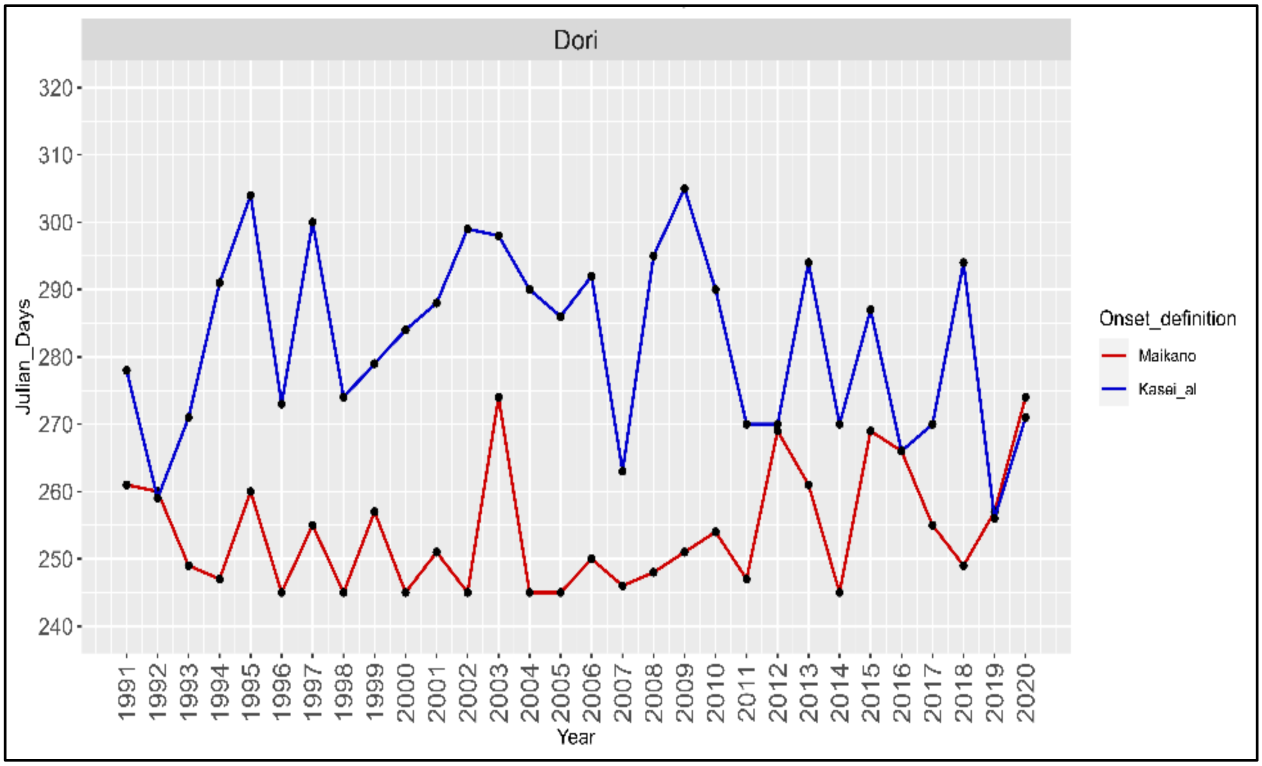


Figure 4: Cessation of season dates of the Dori station taking into account the two types of definitions

Table 2 : summary of the various statistics concerning the onset and cessation dates of the season at the Dori station

Stations	Sivakumar_mean	Kasei_al_mean	Sivakumar_std	Kasei_al_std	Sivakumar_P_value	Kasei_al_P.value	Sivakumar_slope	Kasei_al_slope
Dori	190	189	21.35	17.62	0.48	0.94	-0.4	-0.01
Dori	254	282	9.16	13.82	0.22	0.4	0.22	-0.21

The anomalies for the two definitions at the onset of the seasons are shown in figure 5. Except for the year 2000, when the Sivakumar anomaly curve had 58 late days and the Kasei and Afuakwa anomaly curve had 16 early days, these two anomaly curves do not show much differences significantly from one year to another. The year 2017 similarly displays 51 and 38 days of precariousness for the Sivakumar and (Kasei and Afuakwa) anomaly curves, respectively.

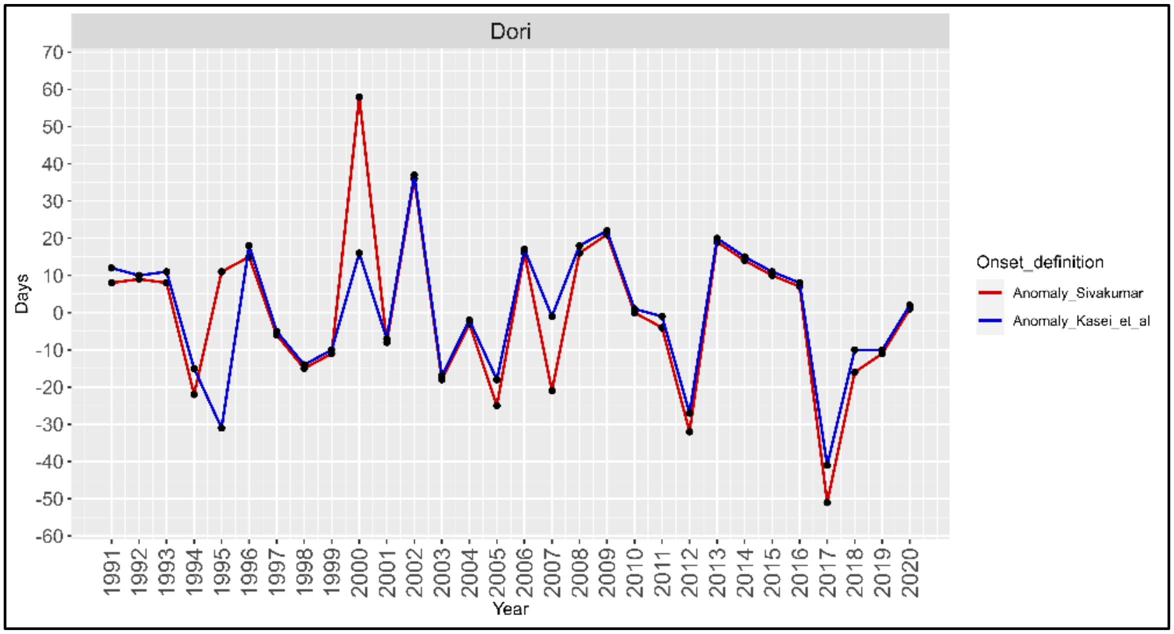


Figure 5: Anomalies of the two types of definitions on the onset of the seasons of the Dori station

Over the 30 years period, the Maikano anomaly curve shows an increase of number of early days than the (Kasei & Afuakwa) anomaly curve. The Maikano curve was marginally ahead of the (Kasei & Afuakwa) curve in the years 2003 and 2012-2017. Except these years the (Kasei & Afuakwa) curve typically exceeds the Maikano cuve in terms of days of delay, figure 6 illustrate this analysis).

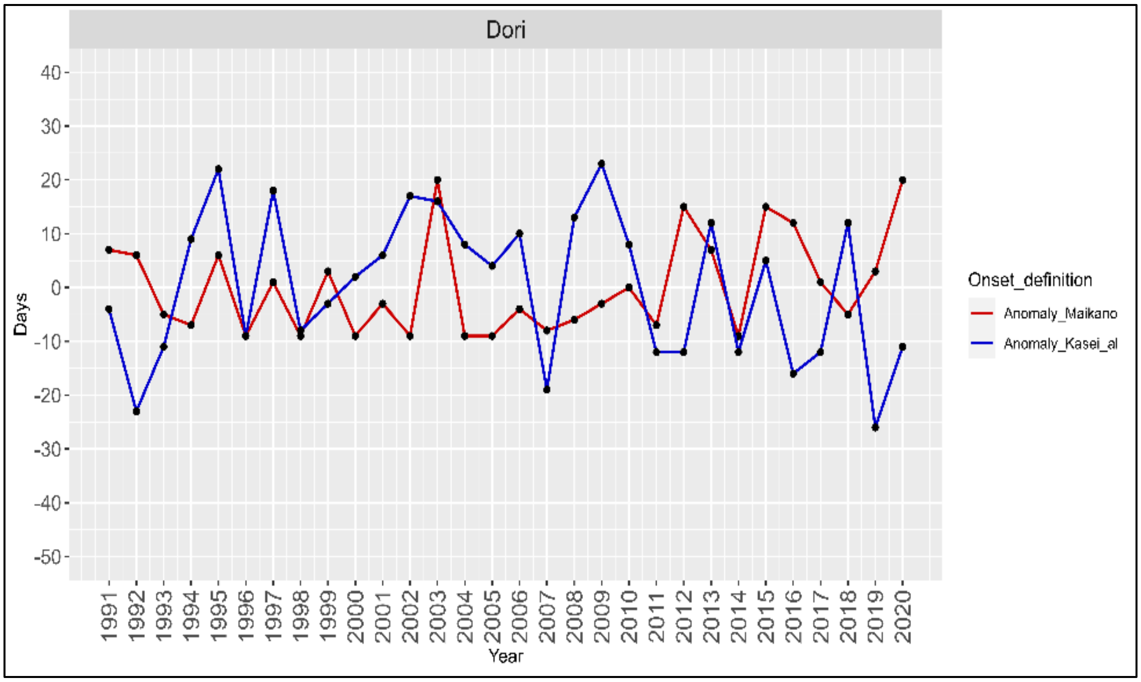


Figure 6: Anomalies of the two types of definitions on the cessation dates of the seasons of the Dori station

- **Sudano-Sahelian climatic zone: Fada-N'Gourma synoptic station**

Over the 30-years period, both curves illustrate some variabilities of the rainy season's onset dates at the Fada-N'Gourma synoptic station with notable peaks seen in both cases (Figure 7). Sivakumar's average onset date is the 164th DOY (Jun 8), while Kasei & Afuakwa's average onset date is the 160th DOY (Jun 12). The years 1994 and 1996, however, show differences between Sivakumar and (Kasei & Afuakwa) definitions, so it is important to note that both curves evolved similarly overall over the past 30 years. For the periods 1995-1999, 2002-2006 and 2018-2020 the onset dates are the same for both definitions. In comparison to Sivakumar's, the (Kasei & Afuakwa) definition curve tends to show slightly earlier onset dates. According to the (Kasei & Afuakwa) definition, the years 2005 and 2014 stand out with the earliest onset dates of the 123rd DOY (May 2) and the 122nd DOY (May 1) respectively. On the other hand, we see delayed onset dates like the 202nd DOY (Jul 20) for Sivakumar's curve in 1994 and the 203rd DOY (July 21) for (Kasei & Afuakwa) curve in 1996. The Sivakumar definition's standard deviation is $\pm$22.4 days while Kasei & Afuakwa's is $\pm$22.2 days.

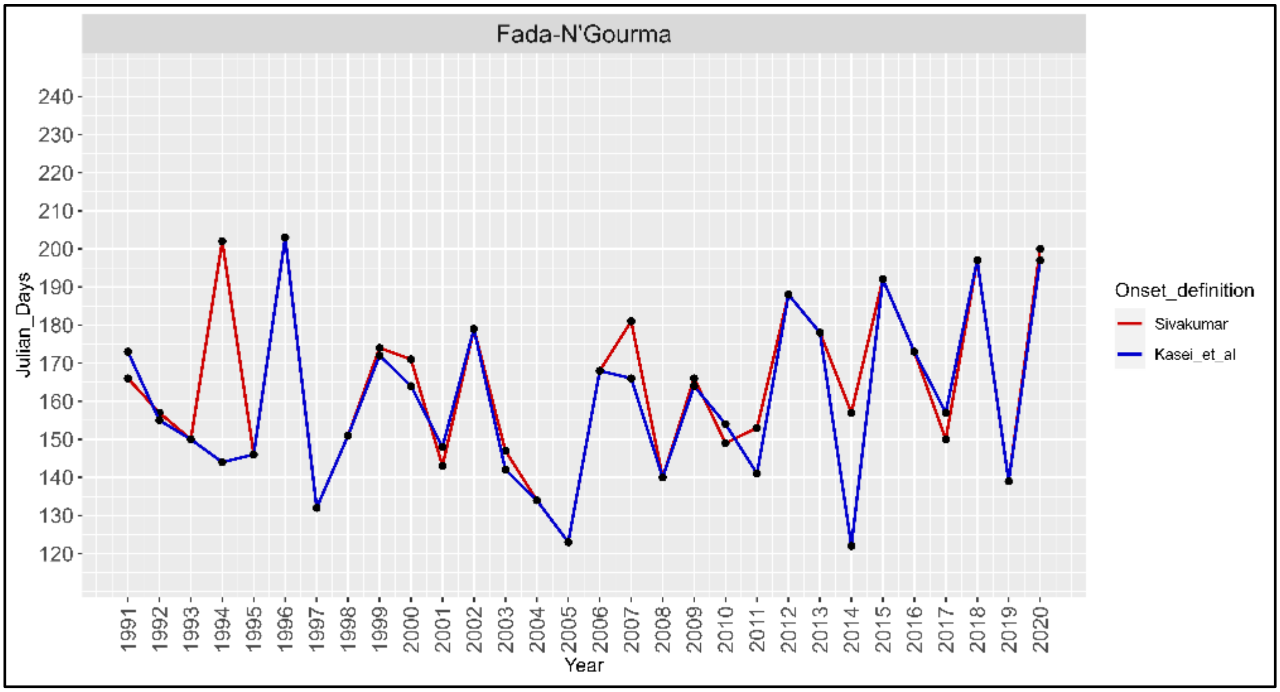


Figure 7: Onset dates of the seasons of the Fada-N'Ggourma station taking into account the two definitions

Figure 8 shows the seasons' cessation dates at the Fada-N'Gourma station according to the two different definitions. While the (Kasei & Afuakwa) definition places the average cessation of the season on the 296th DOY (Oct 22), the Maikano definition places it on the 273rd DOY (Sep 29). The (Kasei & Afuakwa) curve consistently exceeds the Maikano curve indicating that the seasons end later based on the (Kasei & Afuakwa) definition than the Maikano definition and this variation reveals important temporal variability. The earliest date for the Maikano's curve is the 252nd DOY of the years 1991 and 2000 while the latest date is the 301st DOY (27 Oct) of the year 1994 and for the (Kasei and Afuakwa) curve, the 262nd DOY (18 Sep) of the year 2007 represents the earliest date and also the 319th DOY (14 Nov) of the year 2002. The standard deviation is $\pm$11.3 days for the Makaino definition and $\pm$12 days for the (Kasei and Afuakwa) definition from one year to the next.

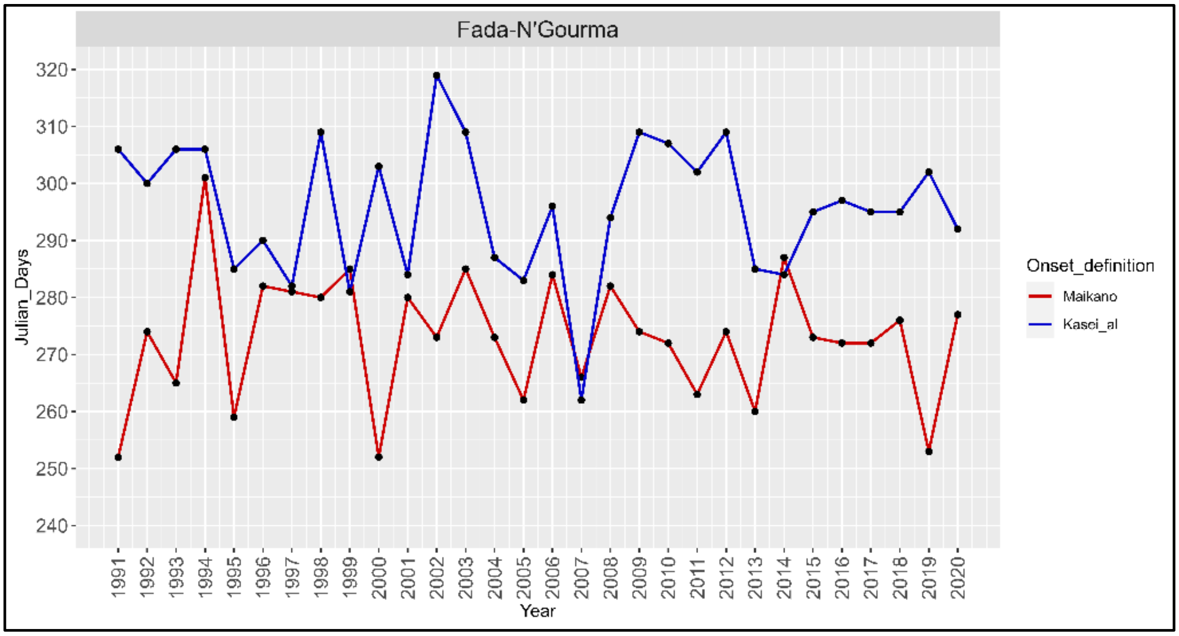


Figure 8: Cessation of season dates of the Fada-N'Gourma station taking into account the two types of definitions

Table 3 : summary of the various statistics concerning the onset and cessation dates of the season at the Fada-N'Gourma station

Stations	Sivakumar_mean	Kasei_al_mean	Sivakumar_std	Kasei_al_std	Sivakumar_P_value	Kasei_al_P.value	Sivakumar_slope	Kasei_al_slope
Fada-N'Gourma	164	160	22.4	22.2	0.4	0.42	0.5	0.56
Fada-N'Gourma	273	296	11.3	12	0.6	0.7	-0.1	-0.09

There are not many differences between the two definitions when comparing the anomaly onset, as shown in Figure 9 except the year 1994 where the (Kasei & Afuakwa) anomaly curve showed 16 days of early onset whereas the Sivakumar curve was 38 days late in the same year. Additionally, the year 2014 displays 7 days and 38 days of precariousness for the anomaly curves of Sivakumar and (Kasei & Afuakwa) respectively.

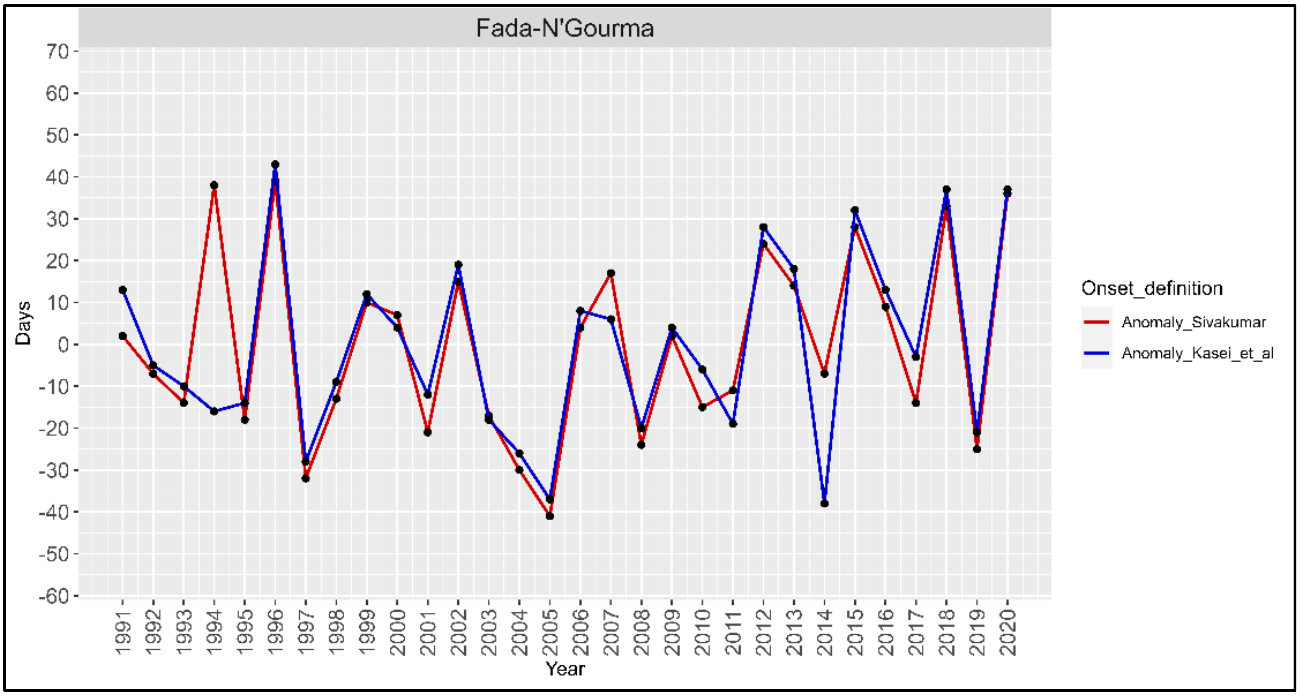


Figure 9**:** Anomalies of the two types of definitions on the onset dates of the seasons for the Fada-N'Gourma station

Regarding the cessation anomalies as shown in Figure 10, from 1991 to 1994 we note that the (Kasei & Afuakwa) curve ranged between 4 and 10 days while the Maikano anomaly curve ranged from -21 to 28 days. In 2007, the anomaly curve (Kasei & Afuakwa) showed an early end to the rainy season of 34 days, while the Maikano curve showed an early end to the rainy season of 7 days compared with the average for the same year. Particularly in 2019 the (Kasei & Afuakwa) curve showed a delayed end of 6 days whereas the Maikano anomaly curve indicated an early end of 20 days.

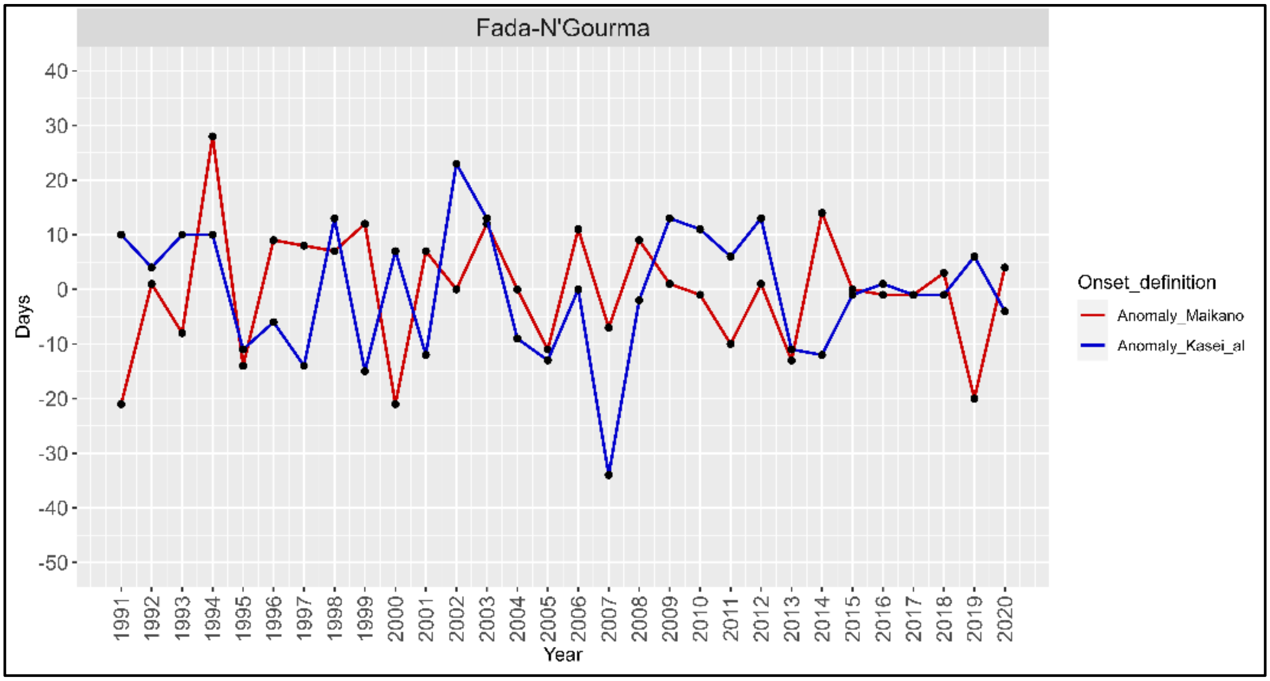


Figure 10: Anomalies of the 2 types of definitions on the cessation of the seasons for the Fada-N'Gourma station

- **Sudanian climatic zone: synoptic station of Bobo-Dioulasso.**

The analysis of the rainy season onset dates at the Bobo-Dioulasso station reveals year-to-year variations in their patterns over a 30-year period with notable fluctuations or peaks in some years (see Figure 11). The average onset dates for the Sivakumar and (Kasei & Afuakwa) definitions are the 149th DOY (May 28) and the 146th DOY (May 25) respectively. A notable example of the Sivakumar definition's discernible variability is the year 2002 which showed the most delayed onset on the 203rd DOY (Jul 28). On the other hand, throughout the 30-year period the year 2019 showed the earliest season onset on the 123rd DOY (May 2) for the two definitions. The (Kasei & Afuakwa) definition indicates that the latest season onset date was observed in 2012 on the 182nd DOY (Jun 30) while the earliest season onset date was noted on the 122nd DOY (May 1). Furthermore, it is noteworthy that for the years 1995-1997, 2005-2007, and 2009-2013 the two curves produce the same season onset dates. With the exception of 2002 these two curves show a closely aligned evolution for the remaining years. For the Sivakumar definition and the (Kasei & Afuakwa) definition. The standard deviation which measures the year-to-year variability over the entire study period is roughly $\pm$19.66 days and $\pm$18.23 days respectively for the 2 definitions.

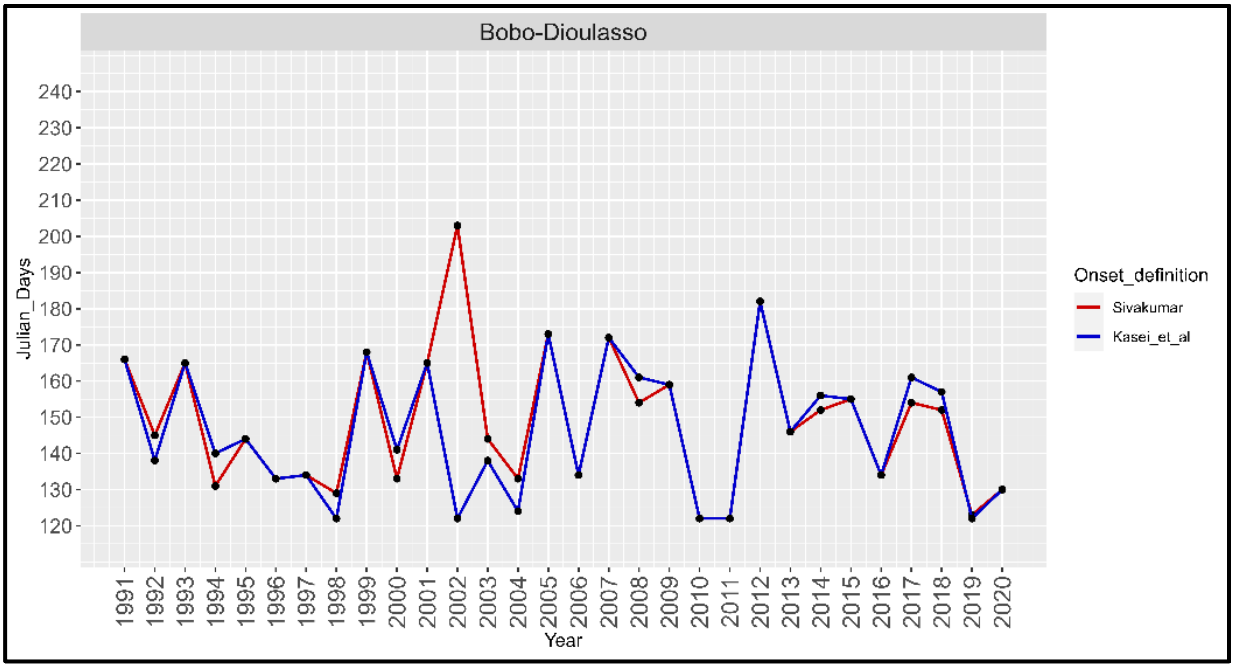


Figure 11: Onset dates of the seasons of the Bobo-Dioulasso station taking into account the two definitions

According to the definitions provided by Maikano and (Kasei & Afuakwa), the seasons in Bobo-Dioulasso end on 284th DOY (Oct 10) and on 300th DOY (Oct 26) respectively which are considered to be the average cessation of season dates (figure 12). The Maikano's curve shows an inter-annual variation that begins to become more pronounced from 2003 onwards indicating a high degree of variability. In addition, the 247th DOY (Sep 3), 249th DOY (Sep 5) and the 253rd DOY (9 Sep) in 2009, 2012 and 2017 respectively mark the earliest cessation dates of the season while the 308th DOY (Nov 3) and the 306th DOY (Nov 1) indicate the latest cessation dates of the season. The (Kasei and Afuakwa) curve also shows interannual variations although less fluctuating than the Maikano curve. In 2016, its earliest cessation date of the season is the 284th DOY (Oct 10) followed by the 305th DOY in 2019. The standard deviations are $\pm$15.31 days for the Maikano definition and $\pm$6.54 days for the (Kasei and Afuakwa) definition from one year to the next. It has also been observed that the (Kasei and Afuakwa) curve is generally higher than that of Maikano with except the year 2006 which reflects an advance in the cessation dates of season according to the (Kasei and Afuakwa) definition compared with that of Maikano.

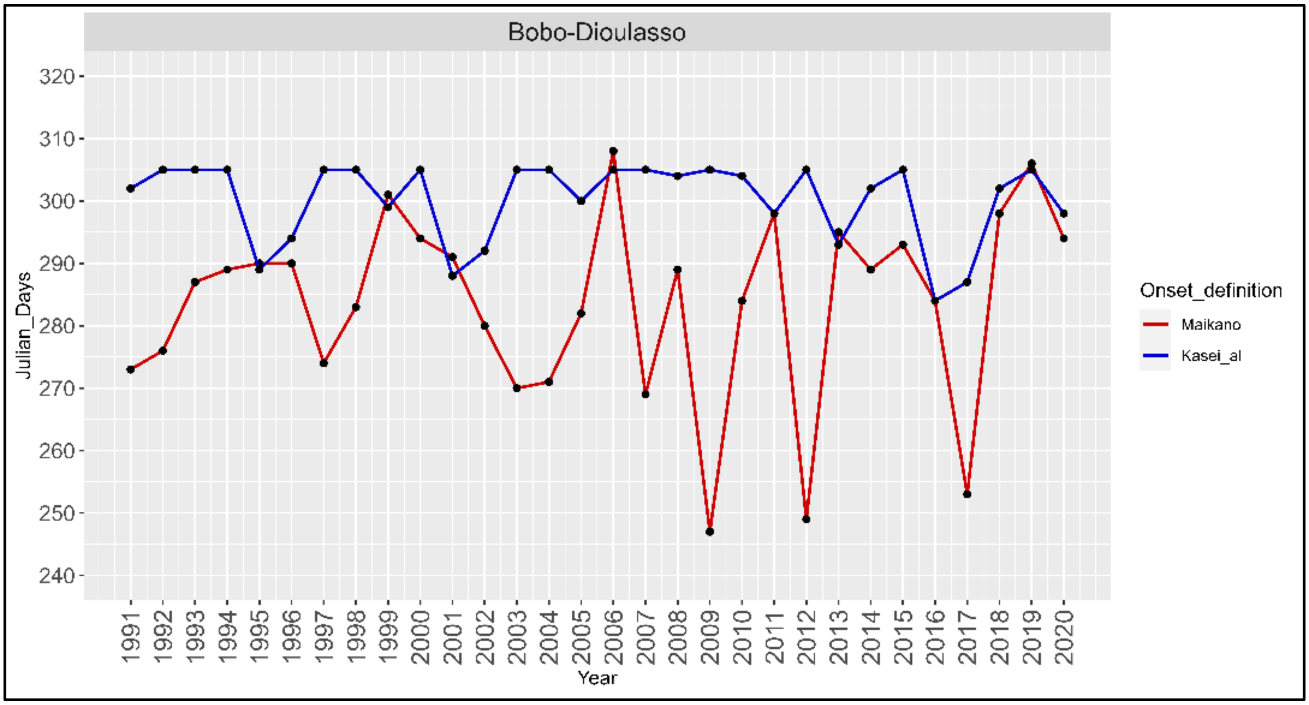


Figure 12: Cessation of season dates of the Bobo-Dioulasso station taking into account the two types of definitions

Table 4 : summary of the various statistics concerning the onset and cessation dates of the season at the Bobo-Dioulasso station

Stations	Sivakumar_mean	Kasei_al_mean	Sivakumar_std	Kasei_al_std	Sivakumar_P_value	Kasei_al_P.value	Sivakumar_slope	Kasei_al_slope
Bobo-Dioulasso	149	146	19.66	18.23	0.55	0.61	-0.32	-0.19
Bobo-Dioulasso	284	300	15.31	6.54	0.31	0.29	0.29	-0.13

Figure 13 shows the anomalies' curves for the two definitions based on the onset of season. The curve according to Sivakumar's definition shows a delay of 54 days compared with the average of the season onsets dates while that of (Kasei and Afuakwa) shows a delay of 36 days. Similarly, for the season onset dates, we observe 27 days earlier for the years 2010 and 2011 according to Sivakumar's definition, whereas for that of (Kasei and Afuakwa) we note 24 days earlier compare to the average.

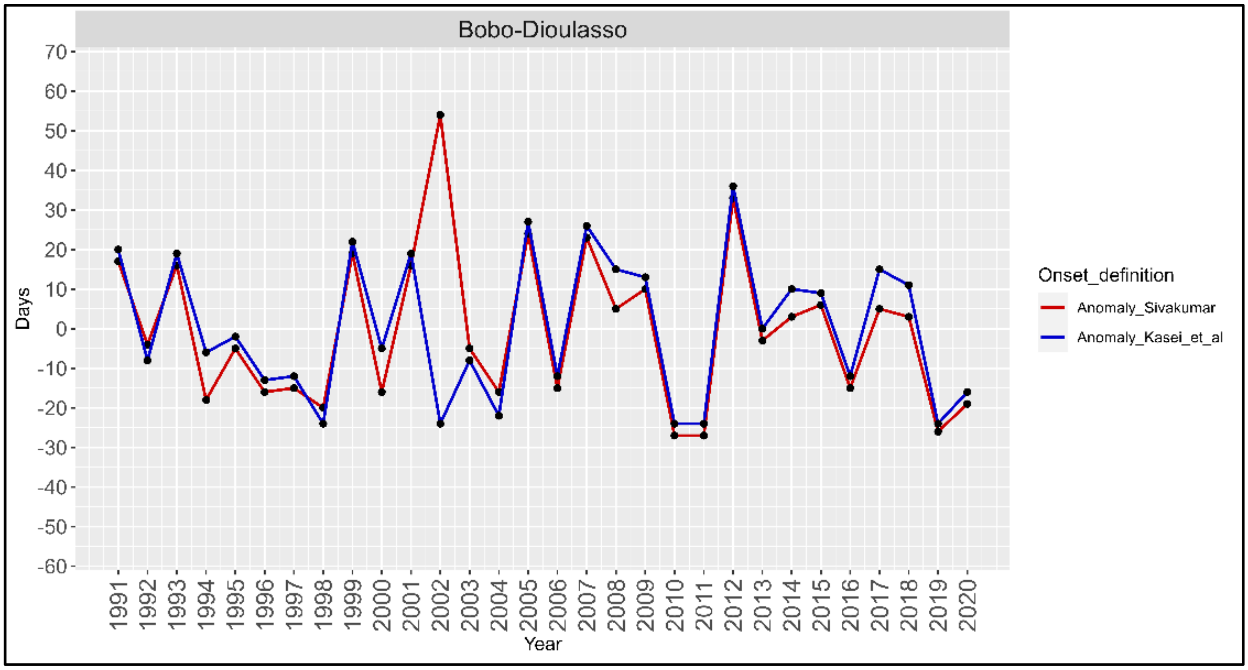


Figure 13: Anomalies of the 2 types of definitions on the onset dates of the seasons for the Bobo-Dioulasso station

We can see from figure 14 that the curves of the two definitions are compared with the anomalies associated with the cessation of the seasons, the Maikano curve shows increasingly pronounced variations. In particular, the Maikano curve shows anomalies of 37 to 24 days early around the mean, while the (Kasei & Afuakwa) definition shows anomalies of 16 to 5 days early. In 2009, 2012 and 2017, the Maikano curve experienced significant early day anomalies of 37, 35 and 31 days respectively, and late day anomalies of 24 and 22 days in 2006 and 2019 respectively. The (Kasei & Afuakwa) curve only had a 16-day early anomaly in 2016.

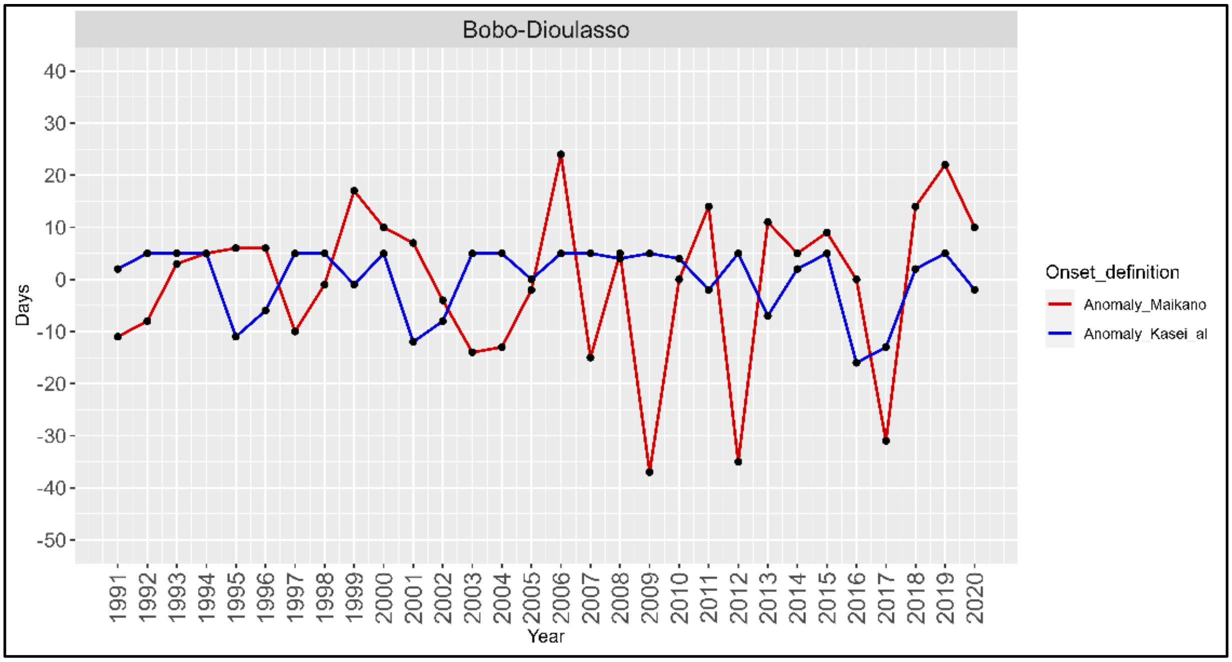


Figure 14: Anomalies of the 2 types of definitions on the cessation dates of the seasons for the Bobo-Dioulasso station

3.2. Dry spells analysis

3.2.1. Dry Spell Frequency analysis

- **Sahelian climatic zone: Dori synoptic station**

Figure 15's demonstrate that, in terms of DSF, the Kasei & Afuakwa curve is practically superior to the Sivakumar & Maikano curve for the Dori station, no DSF events happened between 1995 and 2012. Specifically, we observed that in the years 2017 and 1994, we had the most occurrences considering both 2 curves. In 2002, the frequencies are equal on both curves.

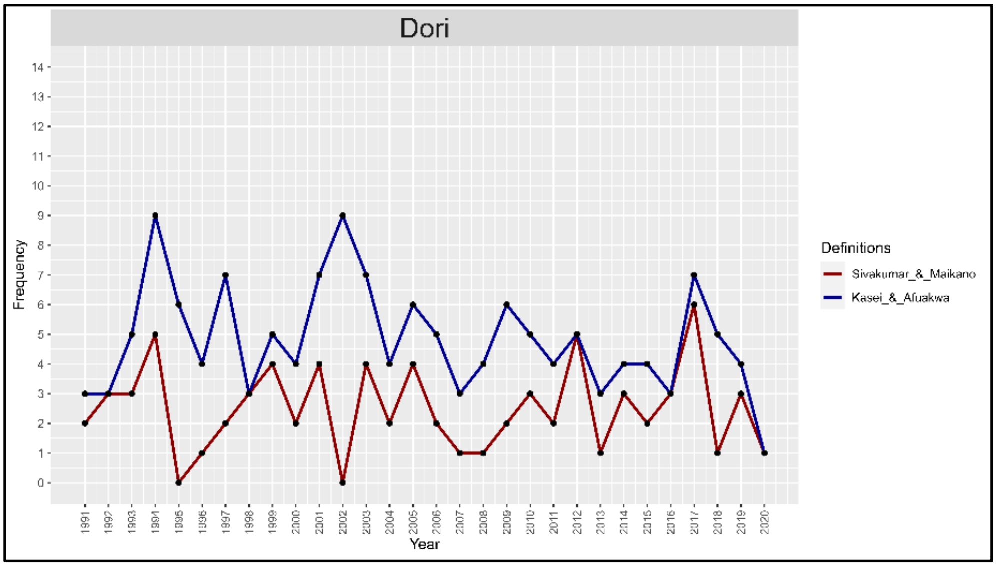


Figure 15: Dry Spells Frequency for the Dori synoptic station

- **Sudano-Sahelian climatic zone: Fada-N'Gourma synoptic station**

According to the analysis, the curve represented by (Kasei & Afuakwa) at the Fada-N'Gourma station slightly surpasses that of (Sivakumar & Maikano) as shown in figure 16. The years 1997, 2001, and 2011 showed the highest DSF occurrences on both curves. While the (Sivakumar & Maikano) curve reports a frequency of 8 as the highest recorded in 1997, the (Kasei & Afuakwa) curve records a frequency of 9 in 1997 and 2011.

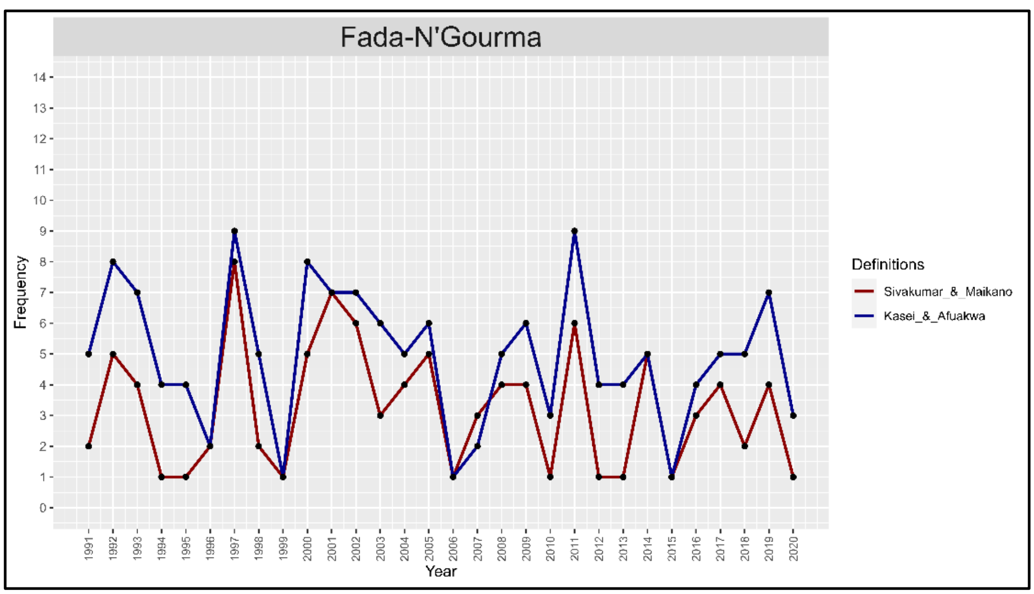


Figure 16: Dry Spells Frequency for the Fada-N'Gourma synoptic station

Additionally, the remaining stations in the Sudano-Sahelian zone (figure 17) show variations for both curves over a 30-year period. Comparatively fewer DSF occurrences are seen at the Boromo station than at the other stations. With 10 DSF for (Sivakumar & Maikano) and 12 DSF for (Kasei & Afuakwa) the Ouahigouya station stands out as having the highest frequency values in 2009.

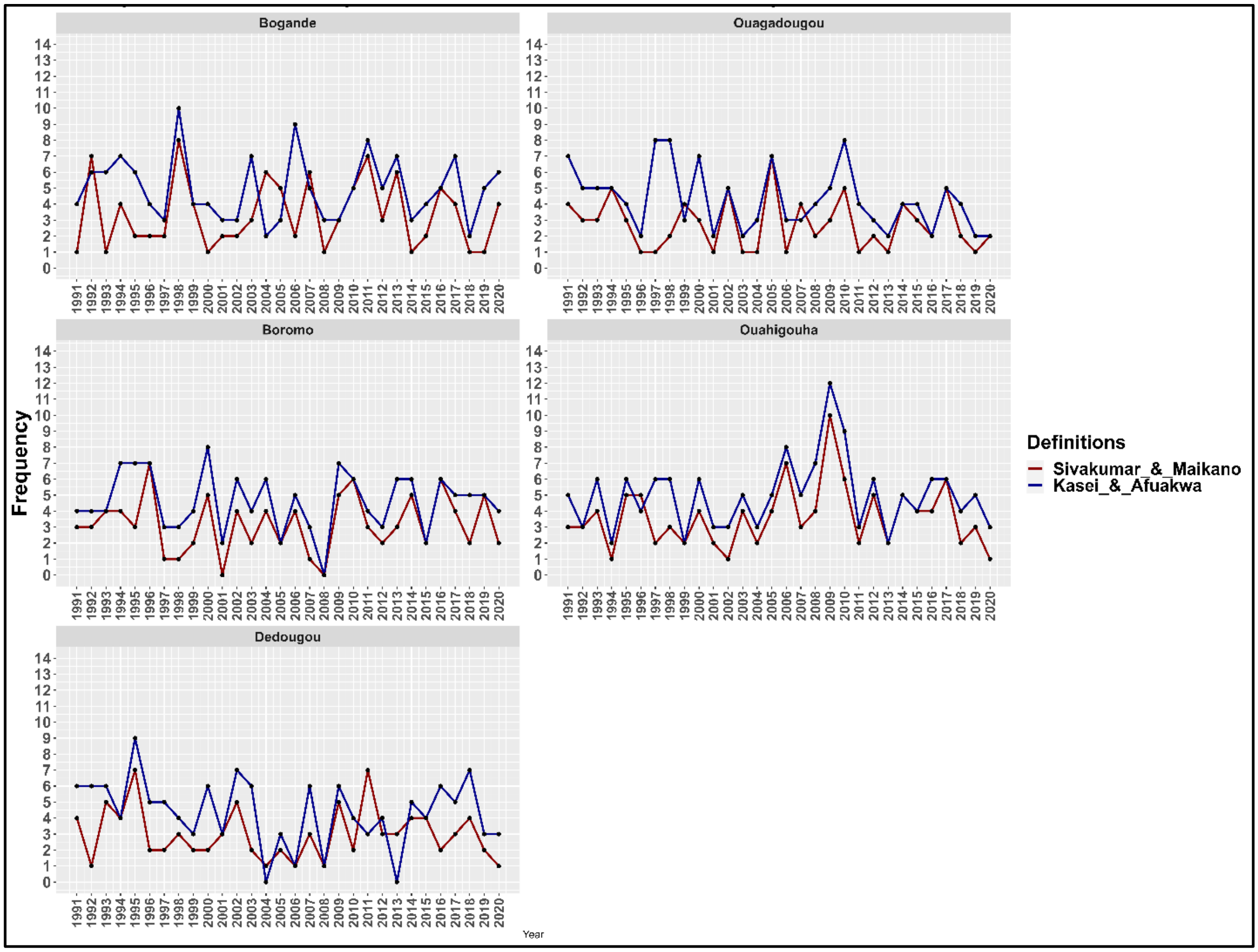


Figure 17: Dry Spells Frequency for the Sudano-Sahelian Zone synoptic stations

- **Sudanian climatic zone: synoptic station of Bobo-Dioulasso**

Remarkable changes are observed for both curves in the annual number of DSF recorded at the Bobo-Dioulasso synoptic station over a 30-year period as illustrated in figure 18. Compared with the definition of (Sivakumar & Maikano), the definition of (Kasei & Afuakwa) produces a significantly higher number of DSFs. While there is a noticeable difference in frequency between the two definitions from 2001 to 2011, for the majority of the years these two curves overlap. The years 1994 and 2011 stand out with the highest frequencies when looking at the (Sivakumar &

Maikano) curve, whereas 2012 recorded no DSFs. The (Kasei & Afuakwa) curve in contrast does not have any years with zero frequencies and most frequencies range from 4 to 7 from one year to the next.

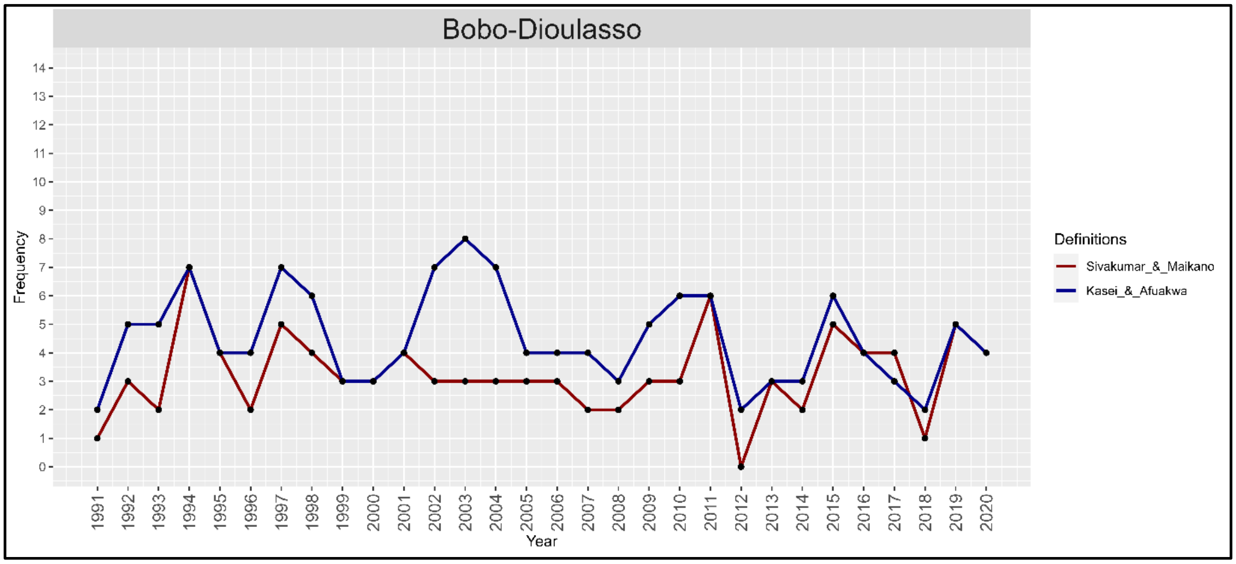


Figure 18: Dry Spells Frequency for the Bobo-Dioulasso synoptic station

Other stations in the Sudanian zone namely Po and Gaoua, show comparable patterns (figure 19). The (Kasei & Afuakwa) curve consistently overtakes the (Sivakumar & Maikano) curve over the 30-year period. These stations show progressively larger variations in the number of DSF compared to the Bobo station.

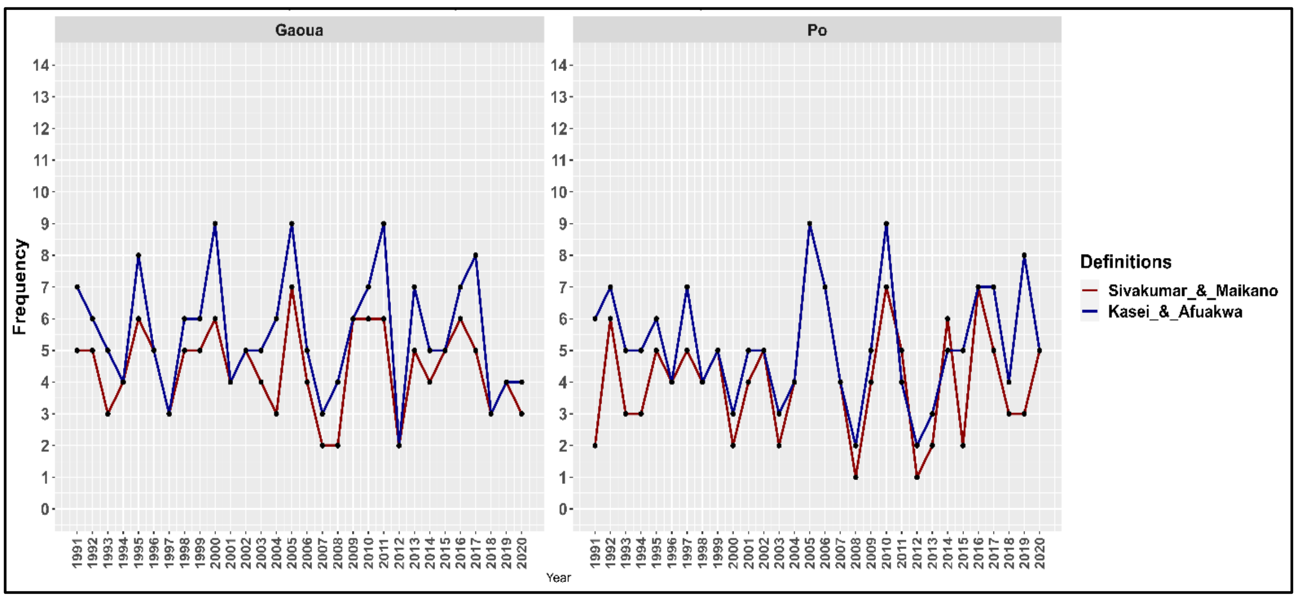


Figure 19: Dry Spells Frequency for the Sudanian zone synoptic stations

In the tables summarizing the time trends:

Df1= Sivakumar & Maikano

Df2 = Kasei & Afuakwa

In this table 5, we can see that most of the stations have downward trends, and the trends are not statistically significant based on the p_values with a confident interval of 90%.

Table 5 : Temporal Trend Analysis of dry spells frequency over the studied period

Stations	Trend_Def1	P_value_Def1	P_value_Def2	Trend_Def2
Bobo-Dioulasso	0.00	0.92	0.23	-0.04
Bogande	0.00	0.94	0.74	-0.01
Boromo	0.01	0.72	0.77	-0.01
Dedougou	-0.02	0.61	0.15	-0.06
Dori	0.00	0.94	0.16	-0.06
Fada-N'Gourma	-0.03	0.48	0.30	-0.05
Gaoua	-0.02	0.57	0.56	-0.02
Ouagadougou	-0.02	0.52	0.04	-0.09
Ouahigouha	0.03	0.51	0.59	0.03
Po	0.01	0.84	0.95	0.00

3.2.2. Longest Dry Spells Duration

- **Sahelian climatic zone: Dori synoptic station**

Between the two defined curves, the Dori station displays the highest Longest Dry Spell Duration (LDSD) values with 11 days for the (Sivakumar & Maikano) curve and 35 days for the (Kasei & Afuakwa) curve (figure 20). Noteworthy that no LDSD was detected in the (Sivakumar & Maikano) curve between 1995 and 2002. On the other hand, over the 30-year period the majority of LDSDs for the (Kasei & Afuakwa) curve occurred between 10 and 20 days. At this station, both curves show a slight upward trend.

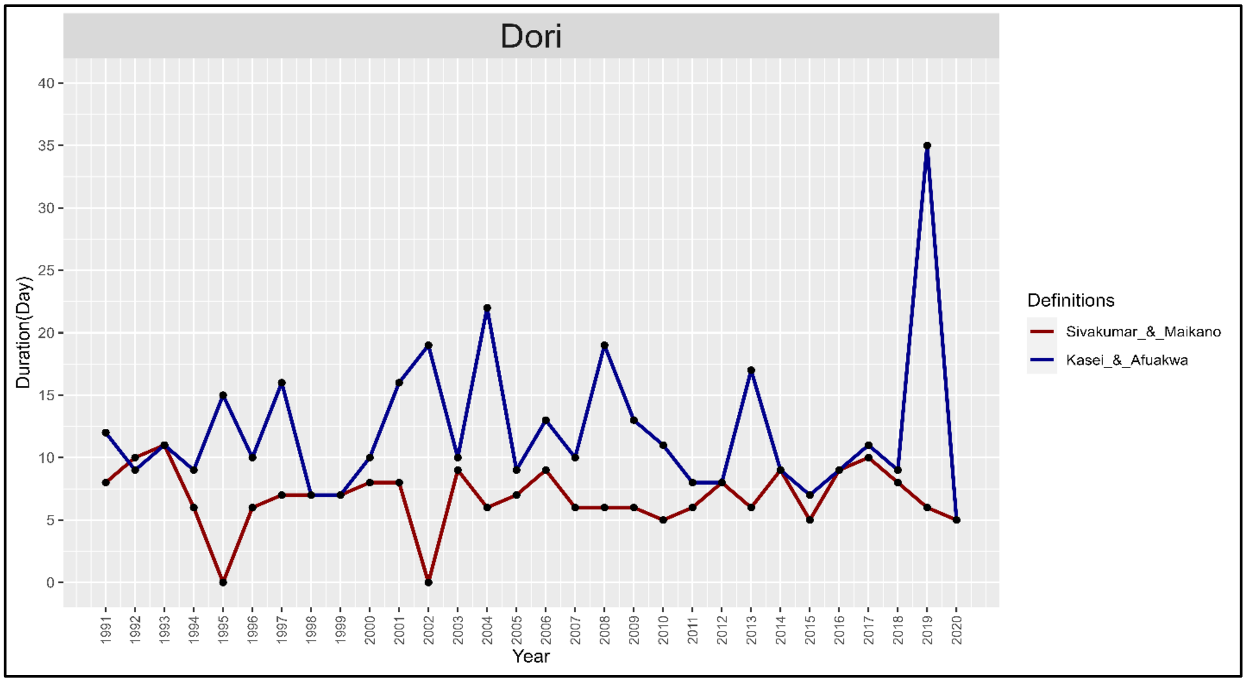


Figure 20: Longest Dry Spells Duration for the Dori synoptic station

❖ **Sudano-Sahelian climatic zone: Fada-N'Gourma synoptic station**

The two curves at the Fada-N'Gourma station display comparable and closely oscillating patterns, with a variation range spanning from 5 to 17 days over the entire 30-year period as can be seen in the figure 21. Compared to the (Kasei & Afuakwa) curve, the (Sivakumar & Maikano) curve has more occurrence of LDSDs lasting 5 days. Nevertheless, both curves experienced LDSDs lasting 17 days in 2012 and 2016 respectively for (Kasei & Afuakwa) curve and (Sivakumar & Maikano).

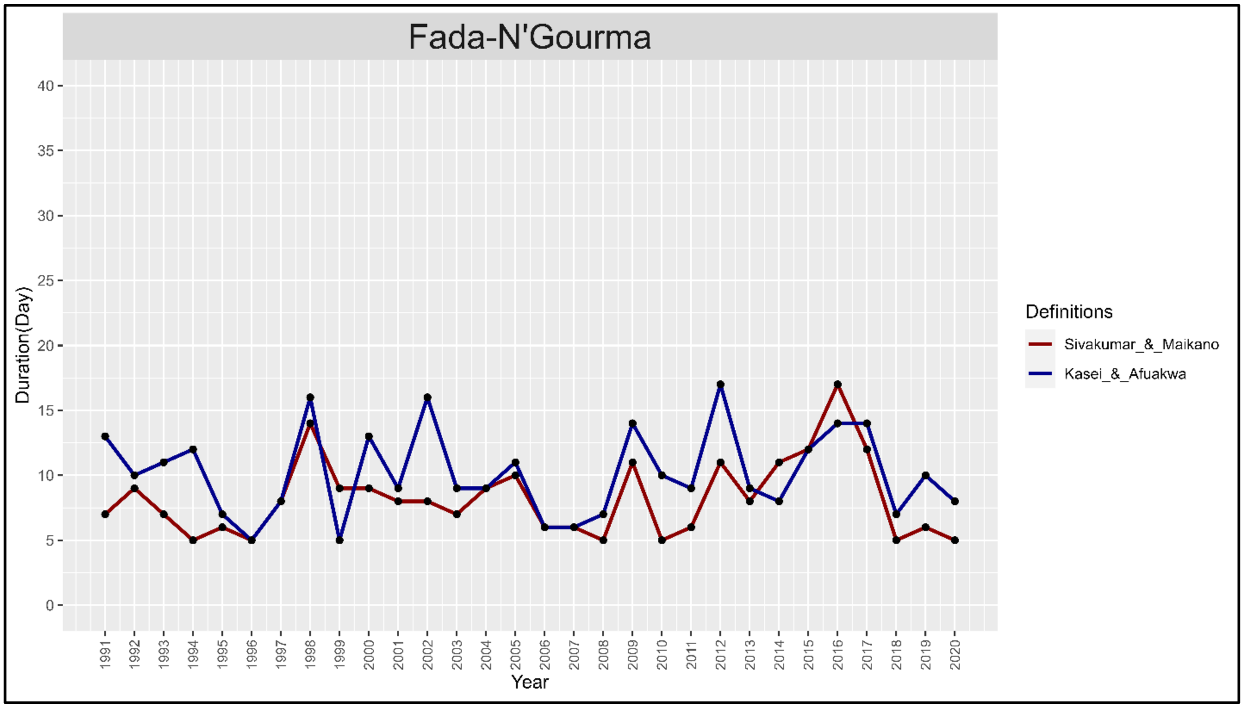


Figure 21: Longest Dry Spells Duration for the Fada-N'Gourma synoptic station

We find that over the 30 years, the LDSD values at the other five stations in the Sudano-Sahelian region vary from year to year (figure 22). LDSDs are on the decline at the Ouahigouya station, followed by Boromo which had no LDSDs between 2001 and 2008 during the 30-year period. When compared to the (Sivakumar & Maikano) curve, the Kasei & Afuakwa curve exhibits a significant difference in LDSDs of up to 38 days in the case of the Bogande station. Another side, the (Sivakumar & Maikano) curve at the Ouagadougou station indicates LDSDs lasting 34 days. Between the years of 2004 and 2013 there were no LDSDs for the (Kasei & Afuakwa) curve at the Dedougou station. (The Kasei & Afuakwa) curve, however, experienced an LDSD of 23 days in 2012 and for this station the two curves evolve simultaneously.

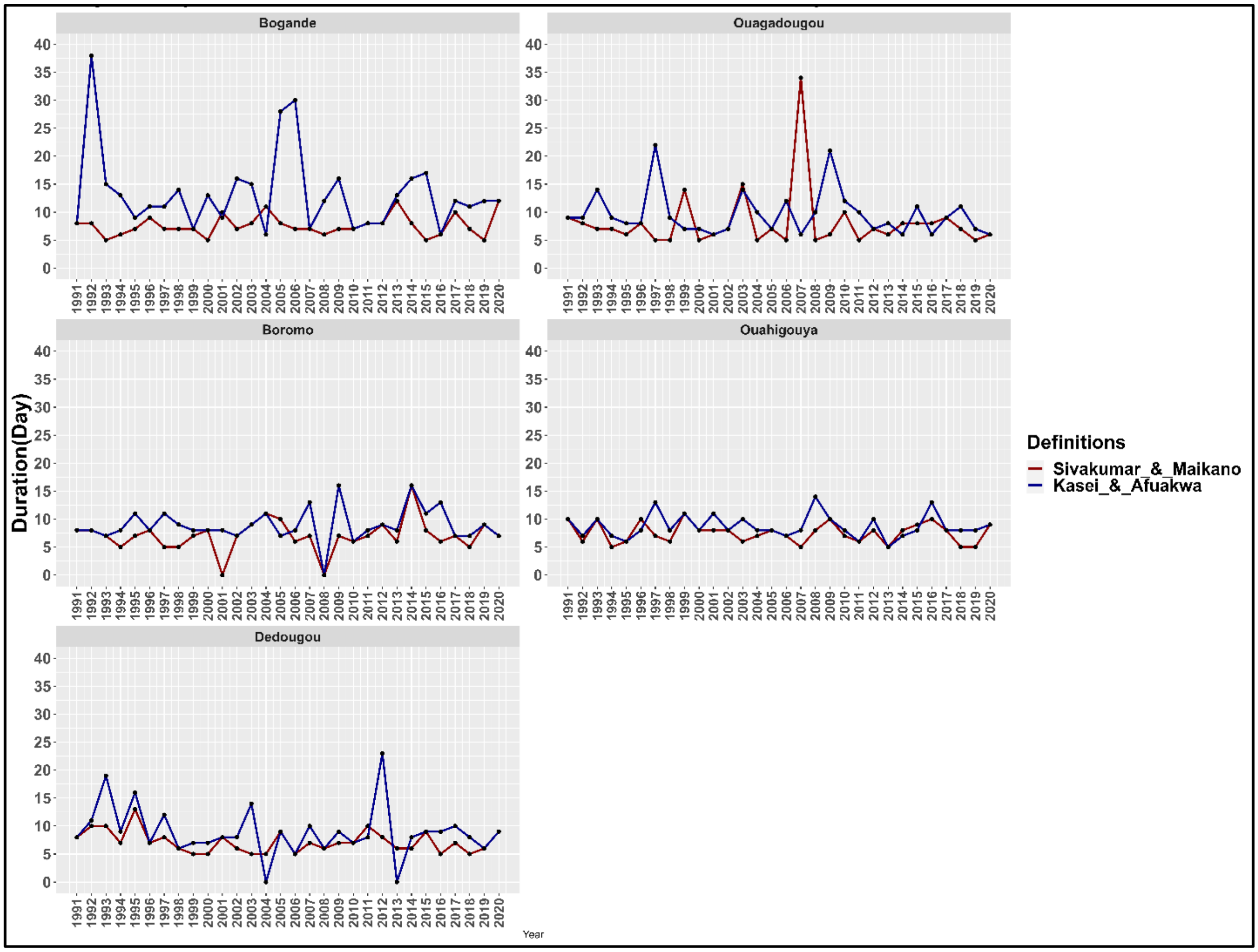
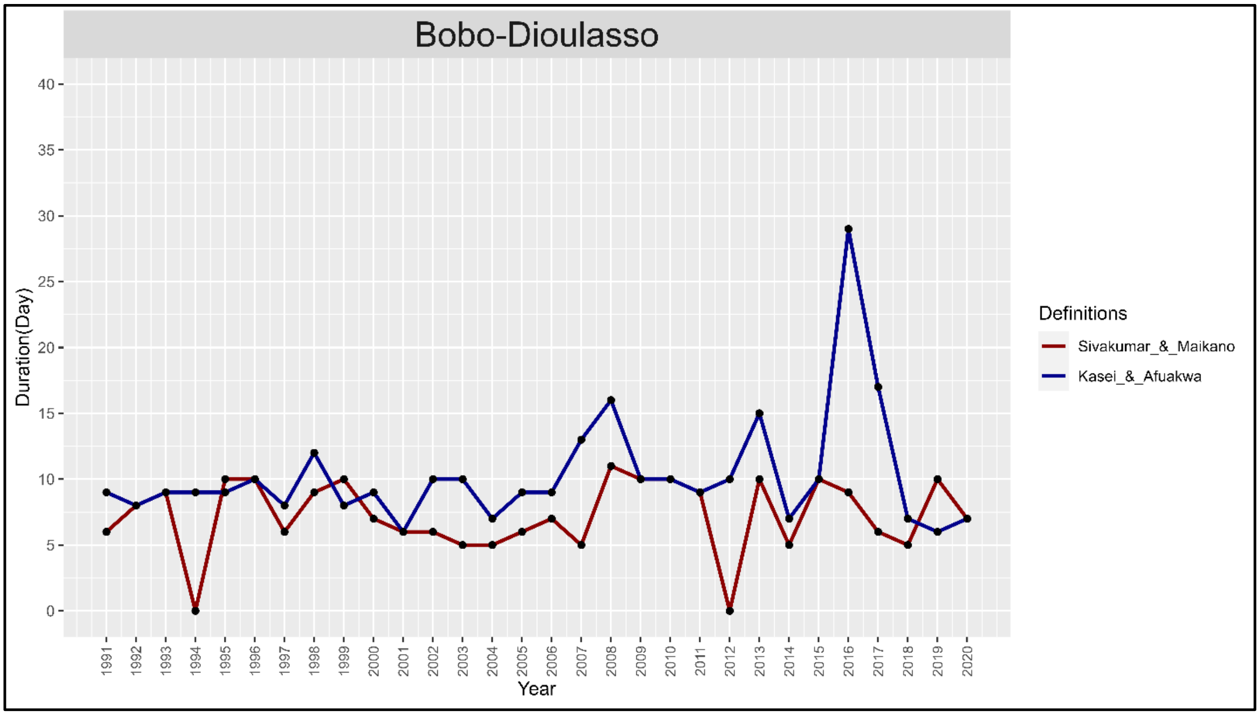


Figure 22: Longest Dry Spells Duration for the Sudano-Sahelian synoptic stations

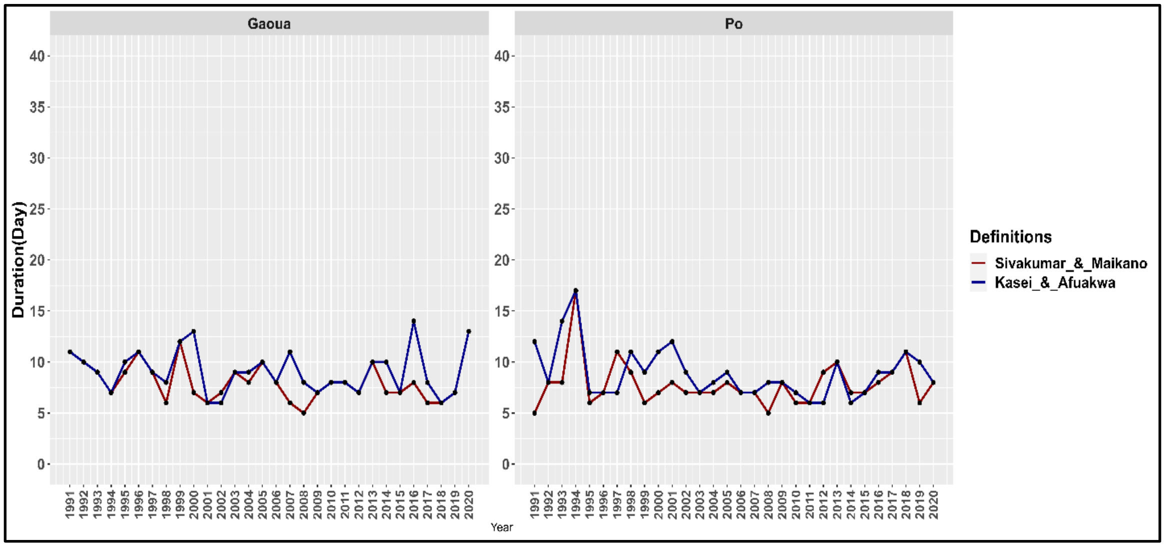
❖ **Sudanian climatic zone: Bobo-Dioulasso synoptic station**

The Bobo-Dioulasso station did not illustrate any LDSD between 1994 and 2012 according to Sivakumar and Maikano's analysis. LDSD at this station typically ranged from 0 to 10 days. The highest LDSD in 2016 was recorded on the Kasei and Afuakwa curve, giving rise to 29 days. Both definitions experienced LDSD variations ranging from 0 to 15 days over the 30-years period. These results offer a summary of the LDSD patterns seen annually at the Bobo-Dioulasso station. (see figure 23).



<u>Figure 23</u>: Longest Dry Spells Duration for the Bobo-Dioulasso synoptic station

When comparing the two definitions of the LDSD for the two other stations in the Sudanian zone, the Po station showed more variation than the Gaoua station. According to Kasei and Afuakwa 's curve, the highest LDSD at the Gaoua station was observed in 2016 totaling 14 days, while the Po station recorded 16 days of LDSD in 1994 as shown in the figure 24.



<u>Figure 24</u>: Longest Dry Spells Duration for the Sudanian zone synoptic station

According to Table 6, the Bobo-Dioulasso station exhibits the strongest upward trend, which results in an increase of 1.3 days in the LDSD every ten years considering the Df2. On the other hand, the LDSD decreases by 1.5 and 1 day respectively, every ten years at the Bogande and Po stations. There has been no significant change in Df1.

Table 6 : Temporal Trend Analysis of Longest Dry Spells Duration over the studied period

Stations	P_value_Def1	Trend_Def1	P_value_Def2	Trend_Def2
Bobo-Dioulasso	0.75	0.02	0.17	0.13
Bogande	0.36	0.04	0.35	-0.15
Boromo	0.51	0.04	0.58	0.04
Dedougou	0.15	-0.06	0.34	-0.09
Dori	0.99	0.00	0.65	0.06
Fada-N'Gourma	0.37	0.06	0.86	0.01
Gaoua	0.17	-0.06	0.58	-0.03
Ouagadougou	0.94	-0.01	0.39	-0.07
Ouahigouya	0.57	-0.02	0.78	-0.01
Po	0.72	-0.02	0.05	-0.10

3.2.3. Average Dry Spells Duration (ADSD)

- **Sahelian climatic zone: Dori synoptic station**

Comparing the curves represented by (Sivakumar and Maikano), Kasei and Afuakwa's curve displays higher averages in terms of ADSD (figure 25). It is noteworthy that the (Sivakumar & Maikano) curve did not present any ADSD between 1995 and 2002. Additionally, the (Kasei and Afuakwa) curve recorded an ADSD of 13 days in 2019.

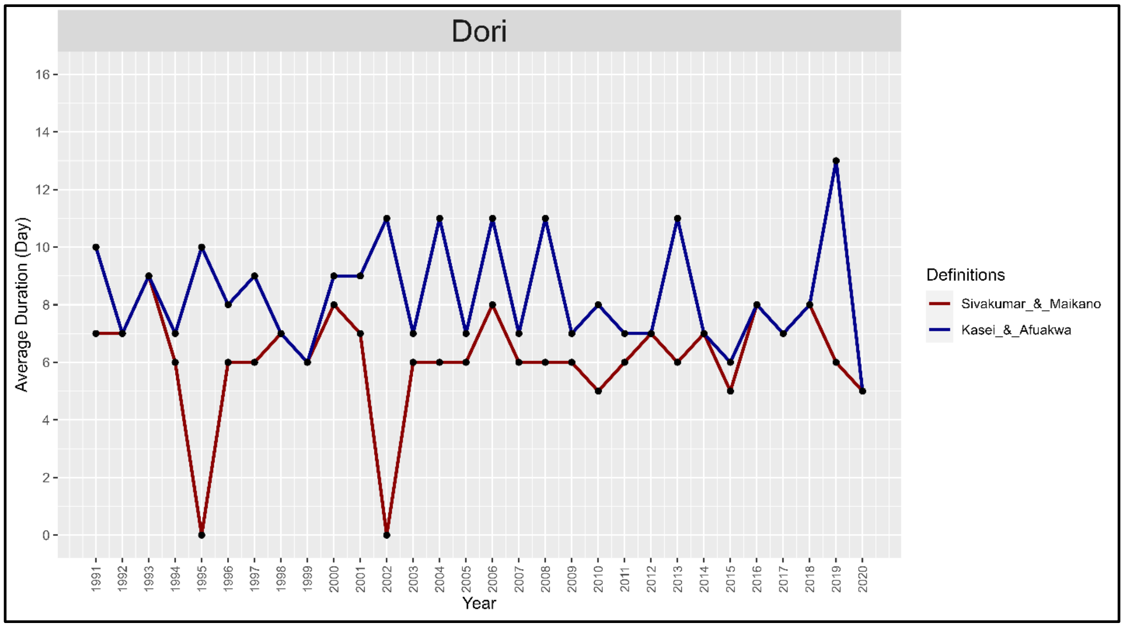


Figure 25: Average Dry Spells Duration for the Dori synoptic station

❖ **Sudano-Sahelian climatic zone: Fada-N'Gourma synoptic station**

In figure 25, the two curves merge approximately from 2012 to 2020 at Fada-N'Gourma station. The highest ADSD for both curves totaling 12 days happened in 2015. Furthermore, both curves show a 5-day lower ADSD

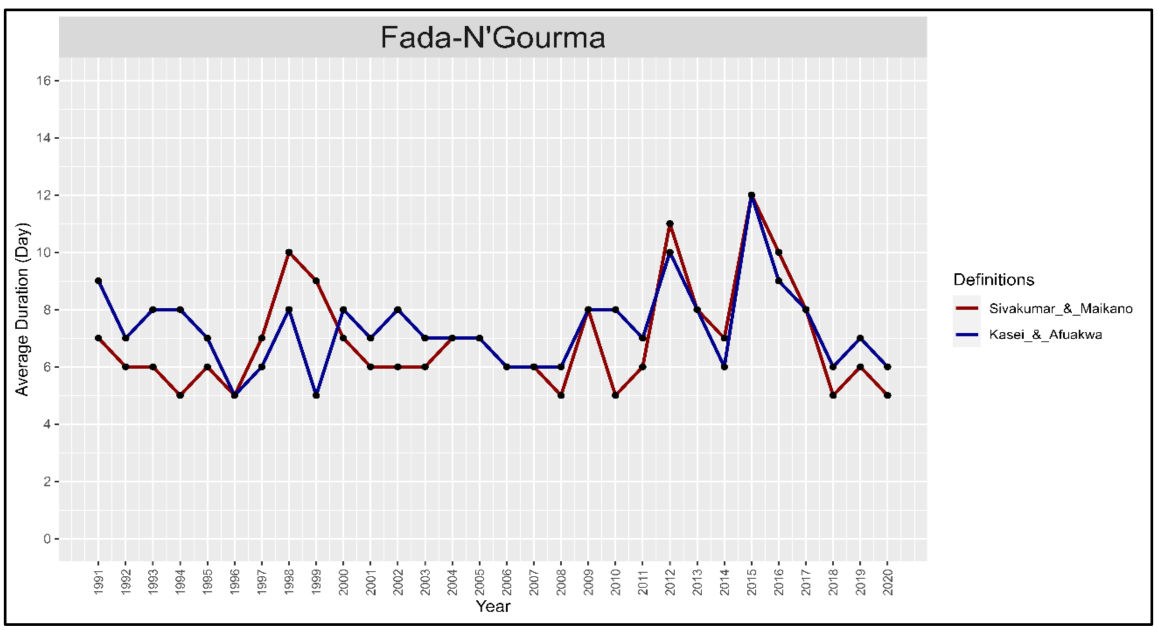


Figure 26: Average Dry Spells Duration for the Fada-N'Gourma synoptic station

The other five stations in the Sudan-Sahel zone, the Ouahigouya station shows relatively less variation. The stations in Bogande and Ouagadougou, on the other hand, present more variation over the 30-year period. The ADSD neutral years are indicated by the Boromo and Dedougou stations.

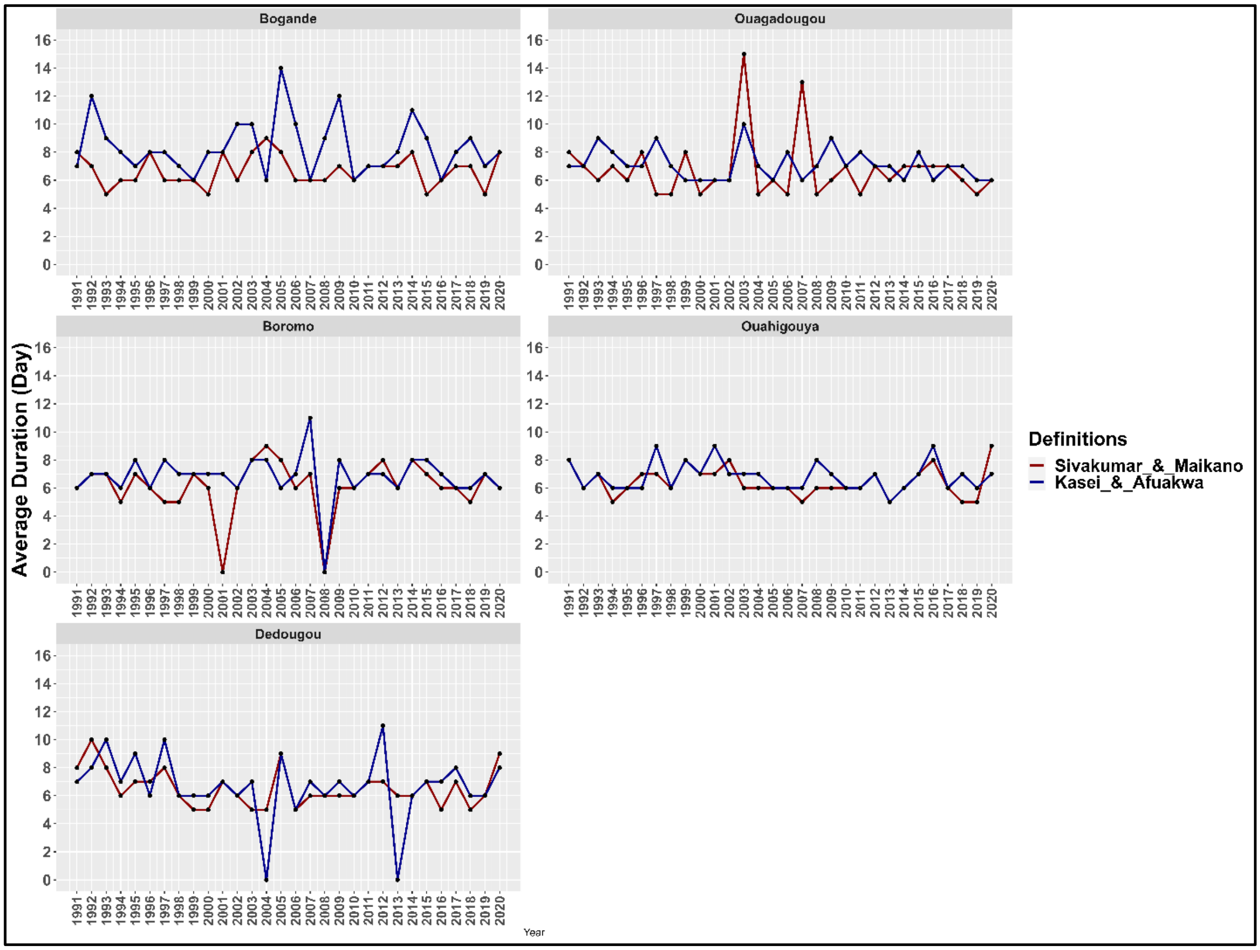


Figure 27: Average Dry Spells Duration for the Sudano-Sahelian zone synoptic stations

❖ **Sudanian climatic zone: Bobo-Dioulasso synoptic station**

The two definitions show that the Bobo-Dioulasso station reveals relatively small fluctuations over the studied period (figure 28). While the (Kasei & Afuakwa) curve records the highest ADSD of 12 days in 2016, the (Sivakumar & Maikano) curve displays a neutral ADSD in the year 2012. These two curves typically show variations between 5 and 10 days over most of the years.

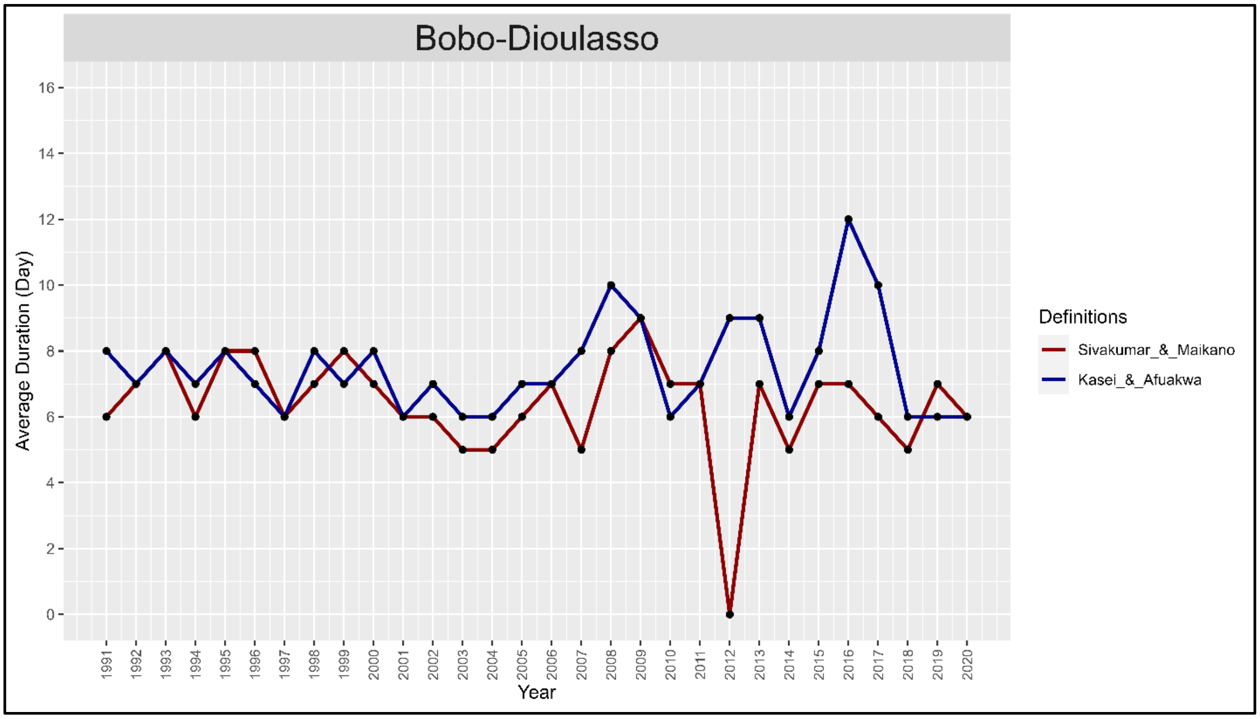


Figure 28: Average Dry Spells Duration for the Bobo-Dioulasso synoptic station

When com the Gaoua station in the Sudanian zone, the Po station shows noticeably more variation and figure 29 illustrate this analysis. For the same station from 1991 to 2000 and from 2011 to 2014 we have ADSDs of up to 10 days. The Gaoua station, on the other hand, has a relatively constant trend with fewer pronounced fluctuations.

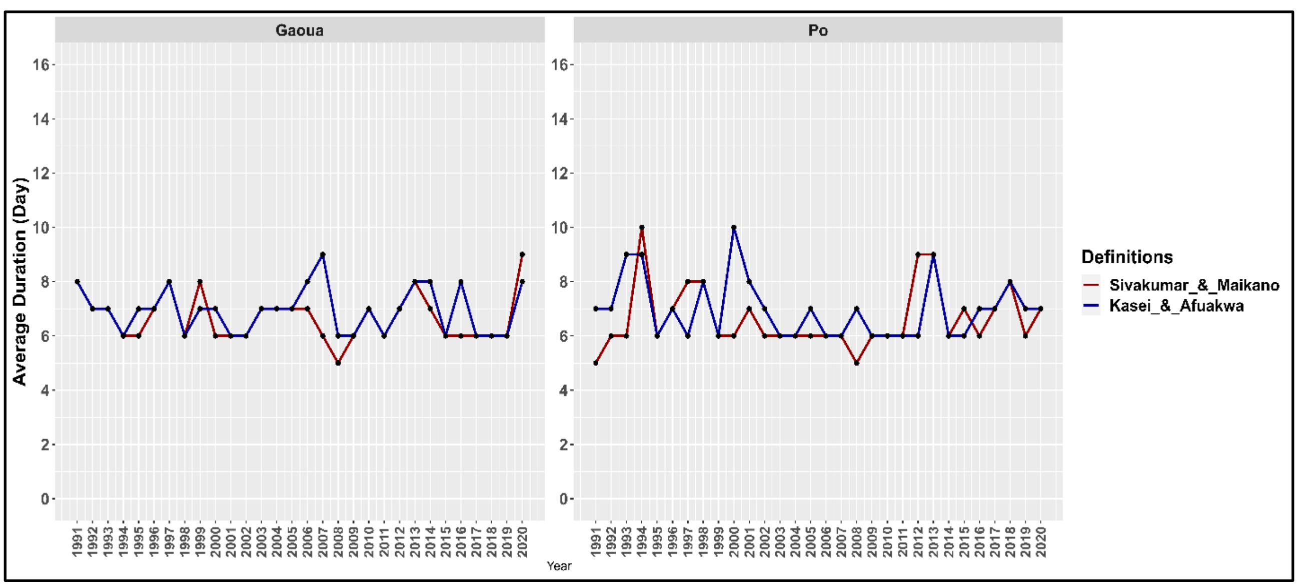


Figure 29: Average Dry Spells Duration for the Sudanian zone synoptic station

According to table 7, there are no discernible trends in the ADSD for all stations and both definitions, and the majority of the stations exhibit slightly declining trends.

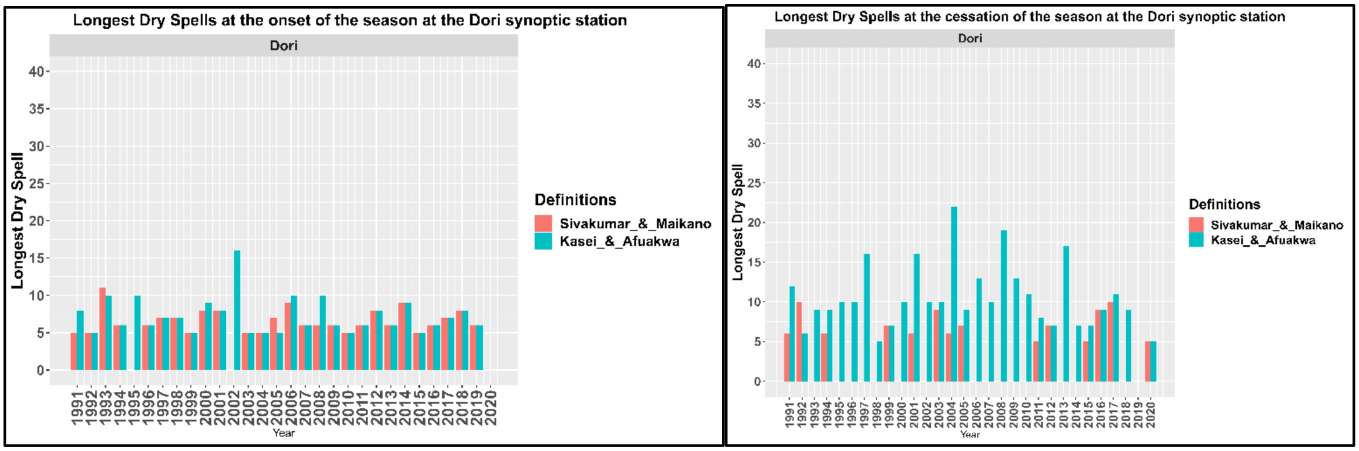
Table 7 : Temporal Trend Analysis of Average Dry Spells Duration over the studied period

Stations	P_value_Def1	Trend_Def1	P_value_Def2	Trend_Def2
Bobo-Dioulasso	0.17	-0.04	0.40	0.03
Bogande	0.75	0.01	0.72	-0.02
Boromo	0.83	0.01	0.87	-0.01
Dedougou	0.22	-0.03	0.41	-0.04
Dori	0.71	0.01	0.68	-0.02
Fada-N'Gourma	0.26	0.05	0.35	0.03
Gaoua	0.41	-0.01	0.48	-0.01
Ouagadougou	0.63	-0.02	0.33	-0.02
Ouahigouya	0.95	0.00	0.23	-0.02
Po	0.62	0.01	0.26	-0.03

3.2.4. Analysis of dry spell at the onset and the cessation of the season

- **Sahelian climatic zone: Dori synoptic station**

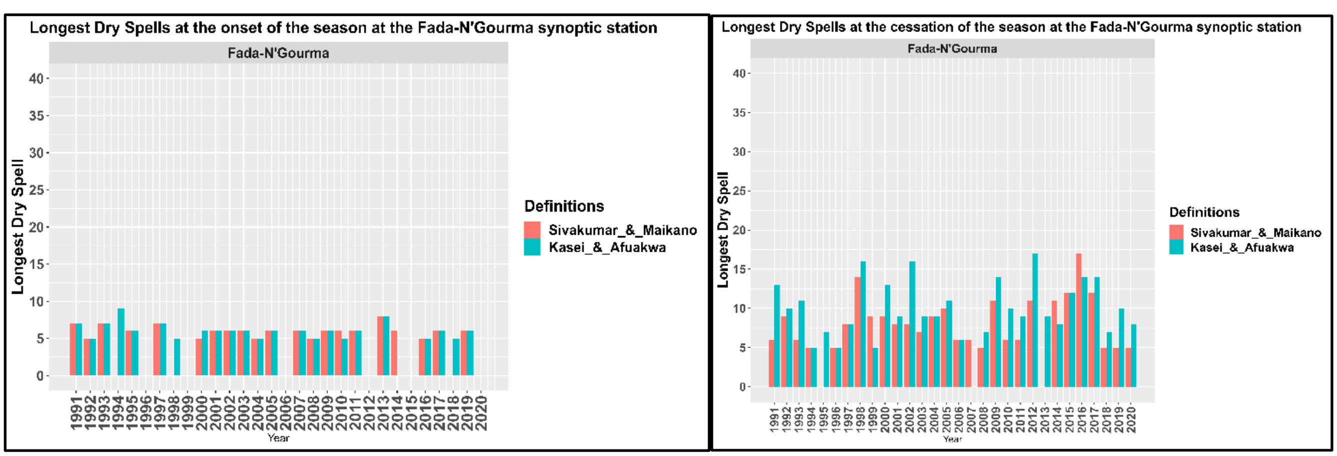
The LDS at the Dori station is depicted in the two graphs below between the onset and cessation of the season (figure 30) with the exception of 2012 when the LDS lasted 16 days. We observe that the LDS at the beginning of the season typically ranges between 0 and 10 days, it is important to note that no LDS as defined by (Sivakumar and Maikano) was reported between 1995 and 2012. The two definitions used in this study yielded identical LDS over a 21-year period. When compared to the definition proposed by (Sivakumar and Maikano), the definition by (Kasei and Afuakwa) presented the most LDS in terms of frequency and duration. The cessation of the season dates produced by the definition of (Kasei and Afuakwa) are significantly earlier than average, leading to LDS that have longer durations. In 1997, 2001, 2004, 2008, and 2013 the LDS for this station were extended.



<u>Figure 30</u>: LDS between the onset and the cessation of the season for Dori synoptic station

❖ Sudanian-Sahelian climatic zone: Fada-N'Gourma synoptic station

In the case of Fada-N'Gourma station, it is noted that neither of the two definitions detected any LDS at the onset of the season for the years 1996, 1999, 2006, 2012, 2015, and 2020 (figure 31). It should be noted that the definition proposed by Sivakumar and Maikano did not detect a LDS at the onset of the season for the years 1994 and 1998, additionally the LDS detected by both methods do not last longer than 10 days at the onset of the season. For the years 1995 and 2013, the method (Sivakumar & Maikano) did not detect any LDS at the cessation of the season and similar to this, the method of (Kasei & Afuakwa) did not capture any LDS for the year 2007. At the cessation of the season, the longest dry periods were recorded in 1998, 2002, 2009, 2012, 2016 and 2017. Overall, Kasei and Afuakwa's definition tends to produce more LDS at the end of the season than Sivakumar and Maikano's definition (see figure 30).



<u>Figure 31</u>: LDS between the onset and the cessation of the season for Fada-N'Gourma synoptic station

The other stations in the Sudano-Sahelian Zone namely Boromo, Dedougou, Ouagadougou, and Ouahigouya show LDS at the onset of the season, but these do not last longer than 10 days over the 30-year period. The Bogande station occasionally experiences extended LDS that last longer than 10 days. Furthermore, some stations show years without any early-season LDS. Only the Bogande station consistently presents an increasing number of LDS at the onset of the season according to the definition suggested by (Kasei and Afuakwa) when looking into the LDS at the cessation of the season. The other stations, however have a fluctuation range that generally lasts between 5 and 15 days (see figure 32).

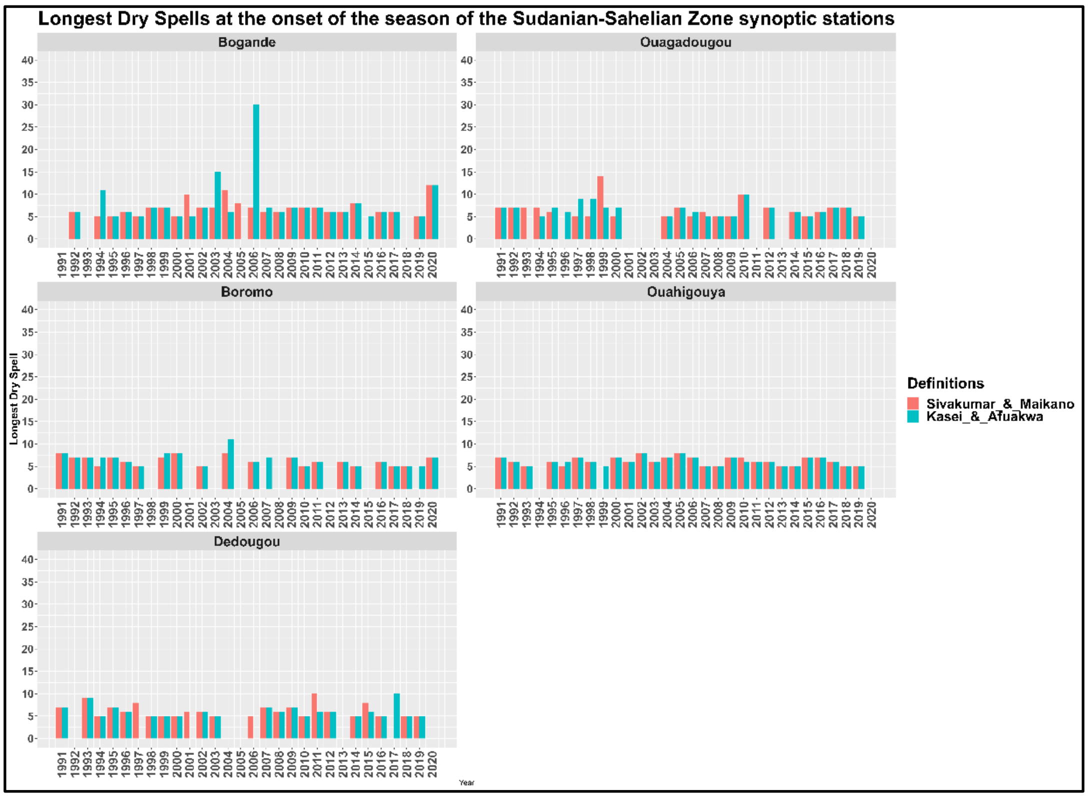


Figure 32: LDS between the onset and the cessation of the season for the five other synoptic station of Sudano-Sahelian zone

❖ Sudanian climatic zone: Bobo-Dioulasso synoptic station

The SDL at the onset of the season at the Bobo-Dioulasso station lasted 10 days as shown in figure 33. It is important to note that neither method detected LDS for the years 2005 and 2012. With the exception of the years 1992, 1996, 2003 and 2006, the LDS calculated for the 30-year period are similar between the two definitions. In particular, the LDSs produced by the definition of (Kasei and Afuakwa) increase over time as shown in 2016.

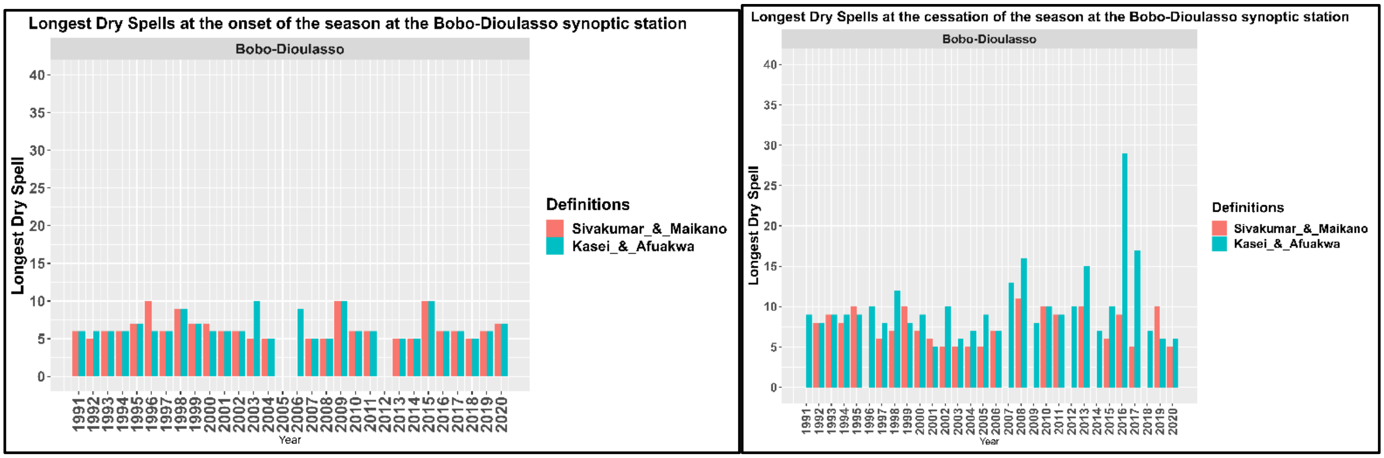
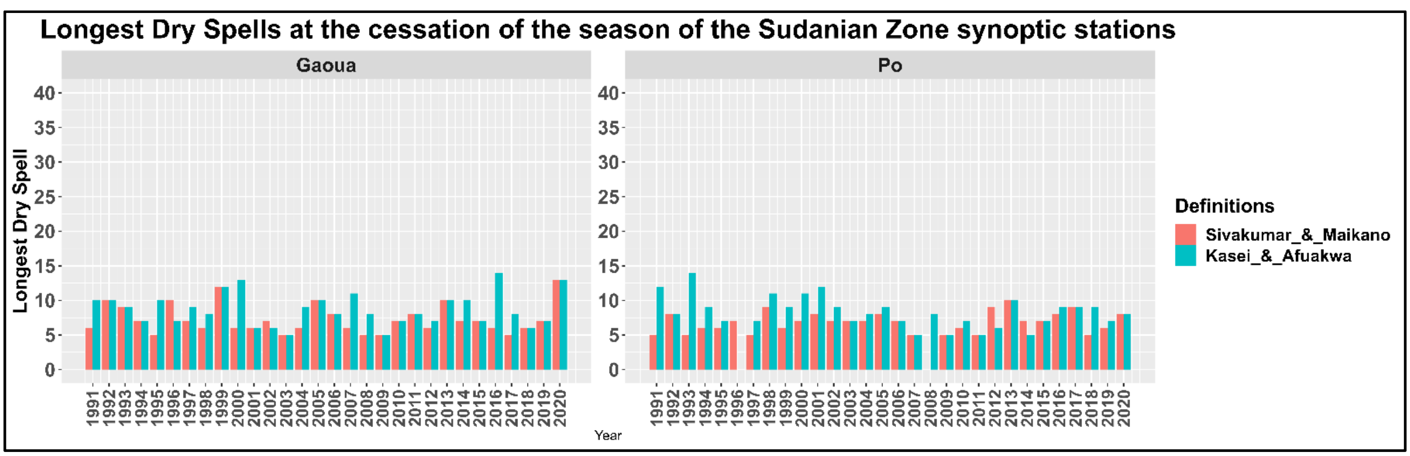


Figure 33: LDS between the onset and the cessation of the season for Bobo-Dioulasso synoptic station

The analysis shows that the Gaoua station has no LDS exceeding 10 days using either method, unlike the other 2 stations in the Sudan zone. The Po station, however, displays dry spellss longer than 10 days, as seen in the years 1994, 1997, and 2018. Given the definition of (Sivakumar & Maikano), it is noteworthy that the Po station shows no evidence of LDS in the years 2000, 2003 and 2012, no LDS were found from 2019 to 2020. Both stations do not have LDS that last longer than 15 days when the season ends. Given both definitions the majority of observed LDS last 5 to 10 days (figure 34).



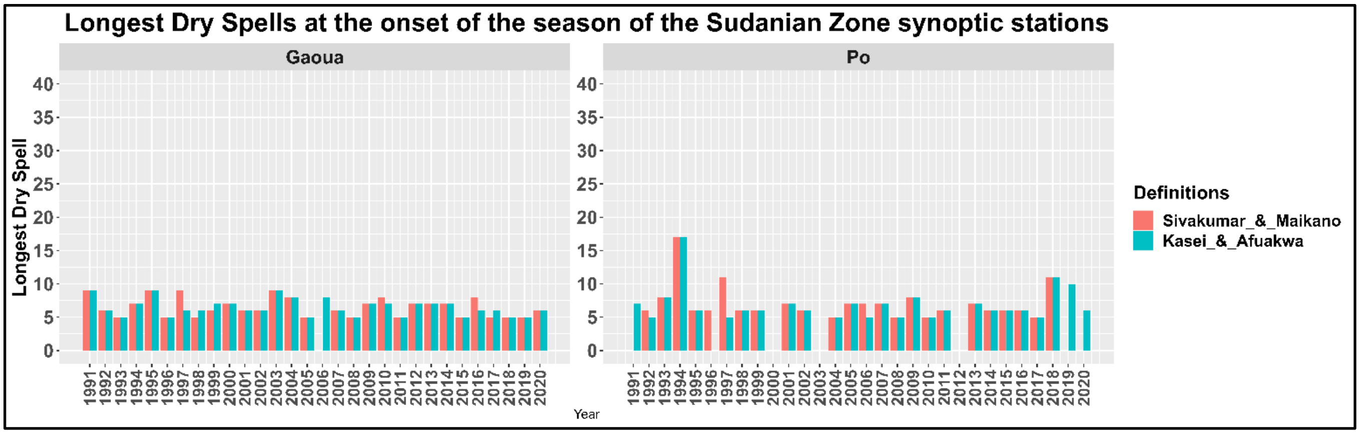


Figure 34: LDS between the onset and the cessation of the season for the five other synoptic stations of Sudanian zone

3.3. The association between Dry Spells and large-scale drivers

3.3.1. Intraseasonal variability: The MJO mode

❖ **Sudanian-Sahelian climatic zone synoptic stations**

The likelihood of Madden-Julian Oscillation (MJO) modulation in the occurrence of DS is shown in figure 35. There are noticeable differences found among the six stations studied. Phase 7 of the MJO gives a probability of 85% for the Bogande station and 35% for the Boromo station. These 2 stations have the highest probability of MJO modulation in the occurrence of DS. For both stations, phases 1 and 2 show increasingly low probabilities. However, phases 3 and 4 for the Bogande station show a non-negligible probability of between 30% and 40%. Across the three stations like Dedougou, Fada-N'Gourma and Gaoua show an increase of the probability of the modulation. Particularly at the Fada-N'Gourma station, the variability is quite remarkable in the modulation of the MJO in relation to the occurrence of DS, as phases 3 and 4 also have a high probability. The other phases of these three stations, on the other hand, show a lower incidence of modulation probabilities, and it should be noted that phase 3 of the Ouahigouya station is distinguished by a high probability of occurrence of DSs of MJO modulation, reaching 75%, whereas the other stations show relatively low probabilities.

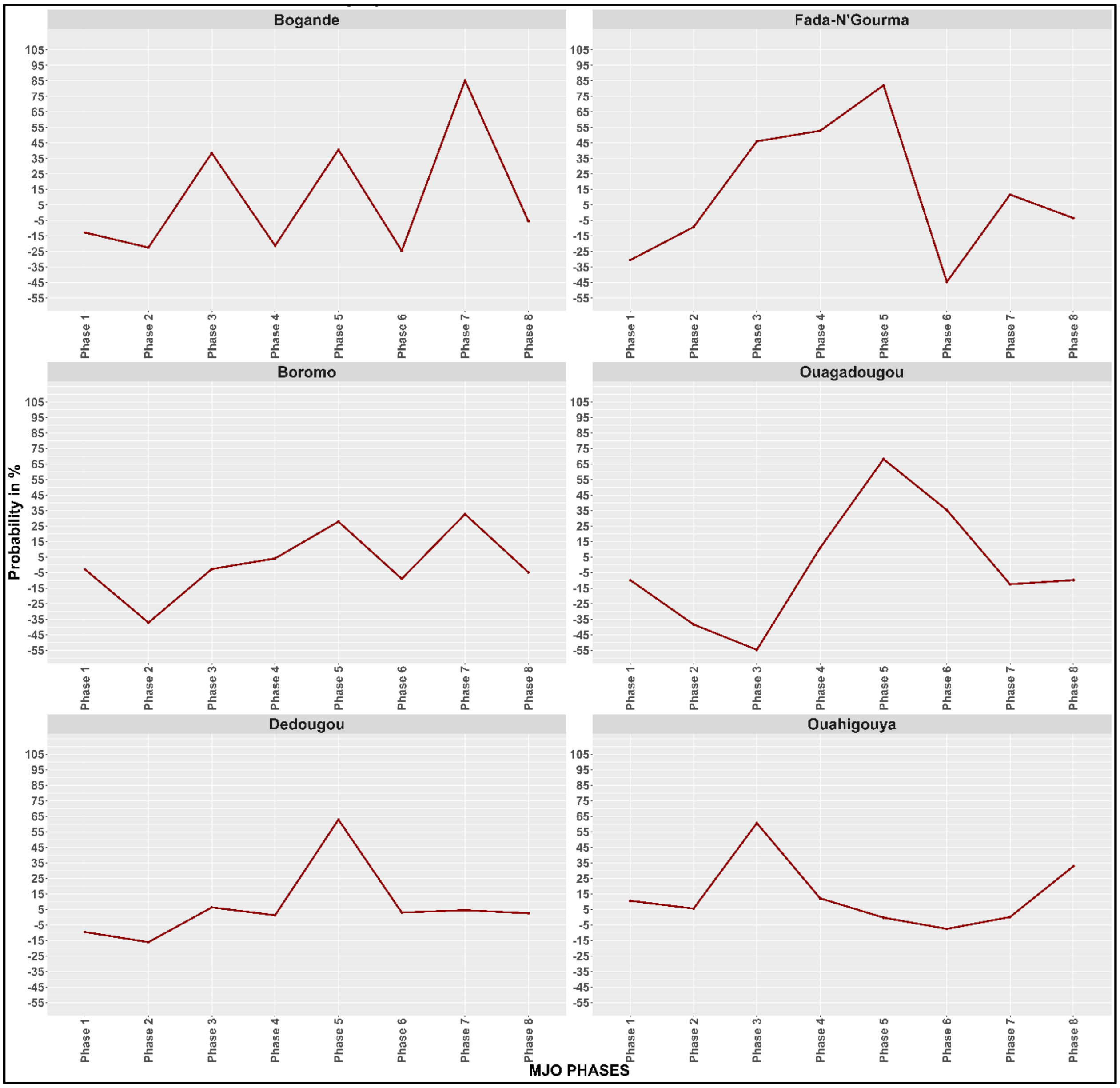


Figure 35: Modulation of the MJO in the occurrence of DS of the Sudano-Sahelian zone synoptic stations

- **Sudanian climatic zone synoptic stations**

The Bobo-Dooulasso station had the highest probability of modulating the MJO in the development of the DS in phases 4 and 7, compared with the Po and Gaoua stations (see figure 36). On the other hand, phases 5 and 7 for the Gaoua station show an increase in the probability of this modulation and as for the Po station, phase 5 shows the highest probability. Phases 1 and 2 for most of these three stations show a low probability of modulation, and phase 8 for the Bobo-Dioulasso and Po stations shows a low probability of DS occurrence.

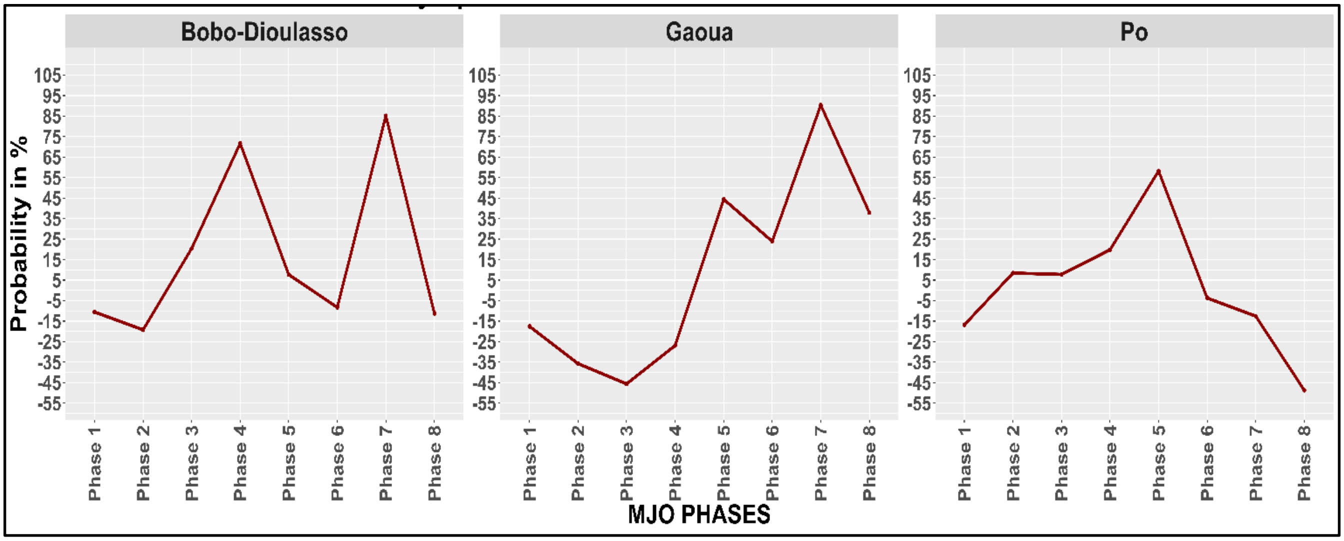


Figure 36: Modulation of the MJO in the occurrence of DS of the Sudanian zone synoptic stations

Phase 7 is where the Dori station is observed to have the highest probability of DS modulation, while phases 1, 2, and 8 have comparably lower probabilities as shown in figure 37.

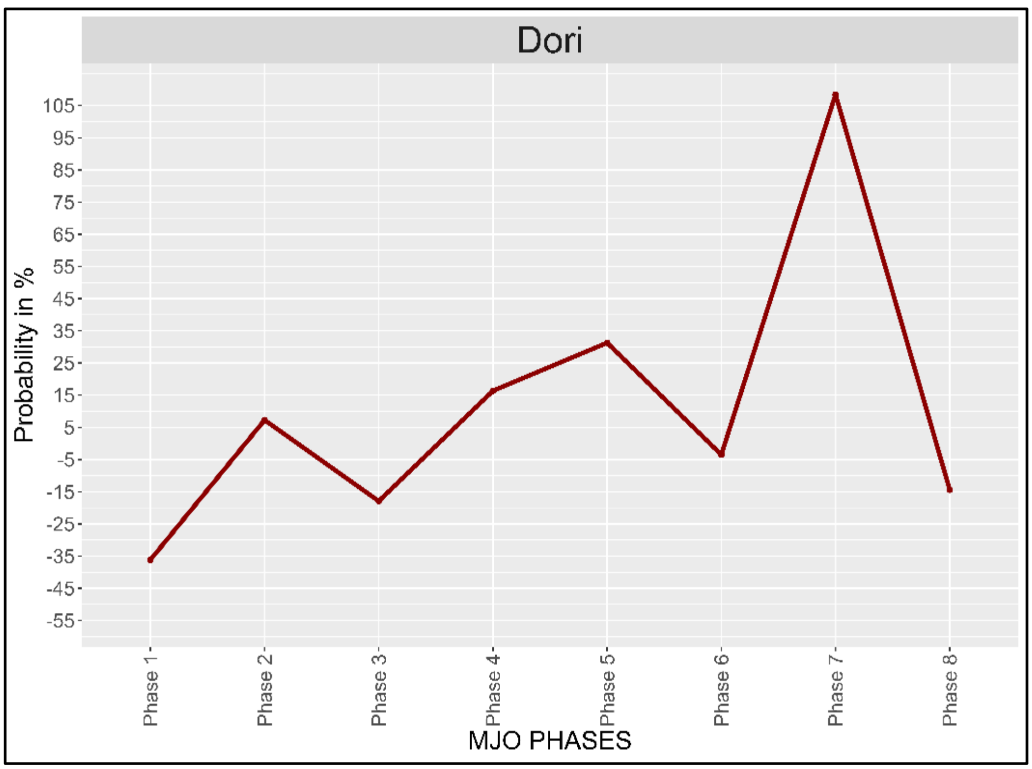


Figure 37: Modulation of the MJO in the occurrence of DS of the Sahelian zone synoptic station

If therefore the rainfall analysis corroborates the modulation of DSs by the MJO that we showed above, we conducted a composite analysis study to see if there is a relationship between the average rainfall totals by phase and the various phases observed in which we found the highest probability of modulation in order to further support the findings of this analysis. Phases 5 and 7 show the most variation in the occurrence of DS for all the stations studied and following the composite analysis, we noticed that the average rainfall totals in these phases are lower and decreasing, in contrast to phases 1, 2, 3, 4, and 8 where the average rainfall totals are higher, i.e., increasing. It should be noted that phase 4 shows a relatively low average cumulative rainfall for some stations like Bobo-Dioulasso as is the case for the Ouahigouya station in phase 3. This analysis is of crucial importance because it has enabled us to demonstrate the robustness of our results (appendix V, VI, VII).

3.3.2. Intraseasonal variability: The ENSO mode

The three tables show how various states of ENSO affect DS interannual variability (occurrence). Table 5 shows how El Niño impacts DSs. at the Bobo-Dioulasso station is the one that is the most impacted by the El Niño phenomenon when it comes to the occurrence of the DS, followed by the Boromo and Gaoua stations. The neutral phase greatly impacts the Ouahigouya station with a 110% change in the DS occurrence, according to table 7. La Niña state doesn't have strong changes like the other states. It usually causes wet weather, which could explain the low changes shown in table 6. In other words, La Nina years are associated with less dry spells.

Table 8 : Modulation of the El Nino in the occurrence of DS

Enso_state	Stations	spell	Total number years	Mean	Px	Pa	MP
El Nino	Bobo-Dioulasso	123	6	20.3	20.5	0.2	101.5
El Nino	Bogande	110	6	21.56667	18.33333	-3.23333	-6.6701
El Nino	Boromo	121	6	19.4	20.16667	0.766667	25.30435
El Nino	Dedougou	134	6	18.76667	22.33333	3.566667	5.261682
El Nino	Dori	58	6	15.66667	9.666667	-6	-2.61111
El Nino	Fada-N'Gourma	165	6	20.66667	27.5	6.833333	3.02439
El Nino	Gaoua	173	6	27.9	28.83333	0.933333	29.89286
El Nino	Ouagadougou	104	6	18.03333	17.33333	-0.7	-25.7619
El Nino	Ouahigouya	144	6	22	24	2	11
El Nino	Po	135	6	25.66667	22.5	-3.16667	-8.10526

Table 9 : Modulation of the La Nina in the occurrence of DS

Enso_state	Stations	spell	Total number	Mean	Px	Pa	MP

			years				
La Nina	Bobo-Dioulasso	216	9	20.3	24	3.7	5.486486
La Nina	Bogande	254	9	21.56667	28.22222	6.655556	3.240401
La Nina	Boromo	170	9	19.4	18.88889	-0.51111	-37.9565
La Nina	Dedougou	180	9	18.76667	20	1.233333	15.21622
La Nina	Dori	116	9	15.66667	12.88889	-2.77778	-5.64
La Nina	Fada-N'Gourma	159	9	20.66667	17.66667	-3	-6.88889
La Nina	Gaoua	281	9	27.9	31.22222	3.322222	8.397993
La Nina	Ouagadougou	188	9	18.03333	20.88889	2.855556	6.315175
La Nina	Ouahigouya	183	9	22	20.33333	-1.66667	-13.2
La Nina	Po	257	9	25.66667	28.55556	2.888889	8.884615

Table 10 : Modulation of the Neutral state in the occurrence of DS

Enso_state	Stations	spell	Total number years	Mean	Px	Pa	MP
Neutral	Bobo-Dioulasso	270	15	20.3	18	-2.3	-8.82609
Neutral	Bogande	283	15	21.56667	18.86667	-2.7	-7.98765
Neutral	Boromo	291	15	19.4	19.4	0	0
Neutral	Dedougou	249	15	18.76667	16.6	-2.16667	-8.66154
Neutral	Dori	296	15	15.66667	19.73333	4.066667	3.852459
Neutral	Fada-N'Gourma	296	15	20.66667	19.73333	-0.93333	-22.1429
Neutral	Gaoua	383	15	27.9	25.53333	-2.36667	-11.7887
Neutral	Ouagadougou	249	15	18.03333	16.6	-1.43333	-12.5814
Neutral	Ouahigouya	333	15	22	22.2	0.2	110
Neutral	Po	378	15	25.66667	25.2	-0.46667	-55

3.4. Discussion

The first objective of our study was to determine the characteristics and different patterns DS in Burkina Faso. To achieve this goal, two essential points were carefully examined: the onset and cessation dates of the season, as well as the analysis of the characteristics of DS within these specified periods. The two definitions used to determine the onset dates of the season yield minor differences across the three studied climatic zones, whereas significant variations are observed in the cessation dates. Generally, the definition proposed by (Kasei and Afuakwa) consistently precedes the definition by (Sivakumar and Makaino) indicating progressively later cessation dates. On average, the onset dates of the seasons exhibit a high temporal variability compared to the cessation dates, suggesting that it is easier to forecast the cessation dates of the season than the onset dates. Across all three climatic zones, the onset dates of the season are on average the first decade of July for the Sahelian zone, the second decade of June for the Sudano-Sahelian zone, and the third decade of May for the Sudanian zone according to both definitions. A study conducted by Akinseye et al., (2016) in Mali focusing on the same three climatic zones and using the same definitions yielded similar results to those found in this study. Furthermore, to further support the finding that there is greater variation in determining the onset dates of the season compared to the cessation dates, Recha et al., (2012) demonstrated in the Tharaka district in Kenya that the cessation dates of rainfall show less variability compared to the onset of rainfall. Referring to the ANAM report on seasonal forecasts of agro-hydro-climatic characteristics for the rainy season of 2023, the different onset and cessation dates of the season determined by ANAM further support the results of our research. For the Sahelian zone, the normal onset dates of the season fall between the last decade of June and the first decade of July, In the Sudan-Sahelian zone the onset dates range from the last decade of May to the last decade of June, while in the Sudanese zone they occur between the first and last decades of May. It is prudent to employ the definition provided by (Sivakumar and Maikano) for determining the onset and cessation dates of the season as well as the determination of Dry Spells (DS). As for Kasei and Afuakwa's definition, it is suitable for determining the onset dates of seasons. Regarding the extracted DS, we observe that DS ranging from 5 to 10 days are most frequent during the rainy season. Furthermore, the DS become longer towards the cessation of the season compared to the beginning which aligns with ANAM's findings. Generally, we find more DS using Kasei and Afuakwa's definition than with Sivakumar and Maikano's. The link we can establish between observed LDS at the cessation of the season and the cessation of the rainy season is that the cessation of rainfall is not as critical for plant growth since most plants can survive for several days with little or no rain given that the soil moisture content remains high. However, an LDS of two weeks can be detrimental to plants leading to reduced yields. The most critical period for seed germination and crop establishment is the first four weeks when favorable precipitation conditions are crucial. Therefore, carefully defining the onset of the rainy season is necessary to enhance agricultural activities and water resource management. In addition, information about the continuity of DS within a season is essential for deciding on a specific crop or crop variety and selecting varieties with different growth durations for a specific location (Sivakumar, 1992). It also aids in determining adaptation strategies such as additional irrigation and on-field operations in agriculture (Taley and Dalvi, 1991; Sandeep et al., 2018). Prior knowledge of drought periods can facilitate the generation of synthetic precipitation sequences and the estimation of irrigation water demand.

Across all the stations studied, phases 5 and 7 exhibit the highest probabilities of MJO modulation during the occurrence of dry spells. While phases 3 and 4 should not be overlooked their probability levels are relatively low. Due to the division of DS between ENSO states, we can say that an ENSO state is not a reliable indicator of DS occurrences. The El Niño state demonstrates the most significant modulation compared to La Niña and Neutral states as stated in the literature review. On the other hand, most extreme wet events occur during Neutral or La Niña years. To further illustrate these findings, Shimizu, M.H. et al., (2017) conducted a study in northern South America where convection suppression was observed during phases 3, 4, and 5 of the MJO. Extreme wet events are more frequent when tropical convection is localized in the Indian Ocean during phases 1 and 2 of the MJO, and when there is no convection over Australia during phases 7 and 8 of the MJO. Additionally, according to Ajay Raghavendra et al. (2020), moderately negative OLR anomalies (indicating increased convection) are present in phases 8, 1, and to a lesser extent phase 2, while positive OLR anomalies (indicating suppressed precipitation) are present in phases 4 and 5. However, JAS (July-August-September) only exhibits marginal anomalies. Weakly positive OLR anomalies are observed in West Africa during JAS but negative during MAM (March-April-May) in phase 7. Indeed, our results confirm reliable probabilities of MJO modulation during the occurrence of DS in phases 1 and 2 and we can also mention phase 8 although it occasionally shows relatively high probabilities in certain areas. This information is valuable for services such as ANAM in improving their seasonal forecasts and enhancing local and regional decision-making for farmers.

4. Conclusion and recommendations

4.1. Conclusion

Due to seasonal rainfall variability in Burkina Faso, analysis of intra-seasonal rainfall variability and its trend were found to be crucial for agricultural planning and water management practices. In response to this, the present study aimed at determining intra-seasonal rainfall variability such as; rainfall onset, cessation, dry spell analysis, and its drivers such as the MJO and the ENSO, and examine their impact on agriculture sector. The onset and cessation dates were identified for 10 stations spatially distributed in the three climatic zones. This information is very important to farmers of these climatic zones in deciding on crop types to be cultivated and on planning sowing dates as a function of observed onset dates. The onset of rainfall is strongly variable, with a mean standard deviation of 19 across the studied areas taking into account the two definitions used in this study. The cessation of rainfall has low variation having a mean standard deviation range from 9 to 11. Also, Results from dry spell analysis show that the possibility of getting dry spells ranging from 5 and 15 days during the onset of the rainy season is high compared to those of the cessation of season where dry spells range from 5 to 25 days. Certain phases of the MJO, such as phases 5 and 7, have been found to increase the likelihood of dry spells. These phases are associated with suppressed rainfall in certain regions, leading to a higher probability of extended dry periods. On the other hand, ENSO refers to the fluctuation of sea surface temperatures in the tropical Pacific Ocean. During El Niño events, characterized by warmer-than-average sea surface temperatures, there is a higher likelihood of dry spells occurring and this study revealed the impact of these two modes on the occurrence of DS. The hypothesis that the analysis of the observed changes in the onset and cessation dates of seasons over the past three decades will reveal significant temporal shifts and patterns is verified on the basis of the variability observed in the dates of the onset and cessation of the seasons; Similarly, the hypothesis that In Burkina Faso, variations in rainfall patterns have a significant impact on the characteristics and evolution of dry spells is verified because the pluviometry variability influences in much in the behavior and the occurrence of the DS. With regard to the third hypothesis, states that there is a significant association between dry spells and the drivers of the Madden-Julian Oscillation (MJO) and the El Niño-Southern Oscillation (ENSO). H3 is partially verified because only a few phases of the MJO and a few states of ENSO reveal high probabilities in the modulation of these modes in relation to the occurrence of DS. A deeper understanding of the role of the MJO and ENSO in shaping dry spells can be gained, enabling better prediction, mitigation, and adaptation strategies for the impacts of these climate phenomena on various sectors and regions.

4.2. Recommendations

Information of onset of rain, cessation of the rain and dry spells analysis and their trend is important for appropriate agricultural decision making so that reduction in yield of the crops is avoided by taking appropriate action.

Since the study is situated in the three climatic zones of Burkina Faso, the findings of this study can contribute much to the future planning and management of water resources. Depending on the result obtained in this work, the following useful points are recommended:

- ❖ This research project may serve as a guiding tool for weather forecasters, risk managers and decision makers in providing the time of onset, cessation and length of growing period of the studied area so as to select the suitable crop varieties;
- ❖ The rainfall onset-cession can be used as the base for different rainfed-based production analysis and system development;
- ❖ The planning for small scale irrigation a rainwater harvesting can be informed by the results of this study;
- ❖ The National Meteorological Agency can use these results to further improve their sub-seasonal and seasonal forecasting of dry spells occurrence;

5. Developing and disseminating tailored dry spell information for the farmers will be of great value and this study can support such initiatives,
6. Beyond the climate science, recommendation is made to conduct more research on adaptation options for smallholder’s farmers facing dry spells.

- ❖ The inclusion of modes of variability such as the ENSO and the MJO as predictors in predicting dry spells, further studies are appreciable.

- ❖ Further studies are needed on the modeling aspect of the dry spells variability and change in the study area in the different should be encouraged to project the future of crop yield.

In general, for sustainable management of agricultural water (through proper planning of rain-fed agriculture) in the area and in order to reduce impacts related to droughts, future research directions should be geared to investigating impacts of climate change on future characteristics of dry spells in the areas.

Then, what do climate models and projections suggest about the potential trajectory of dry spells in Burkina Faso? How might these patterns evolve in the coming years, and what are the potential scenarios?

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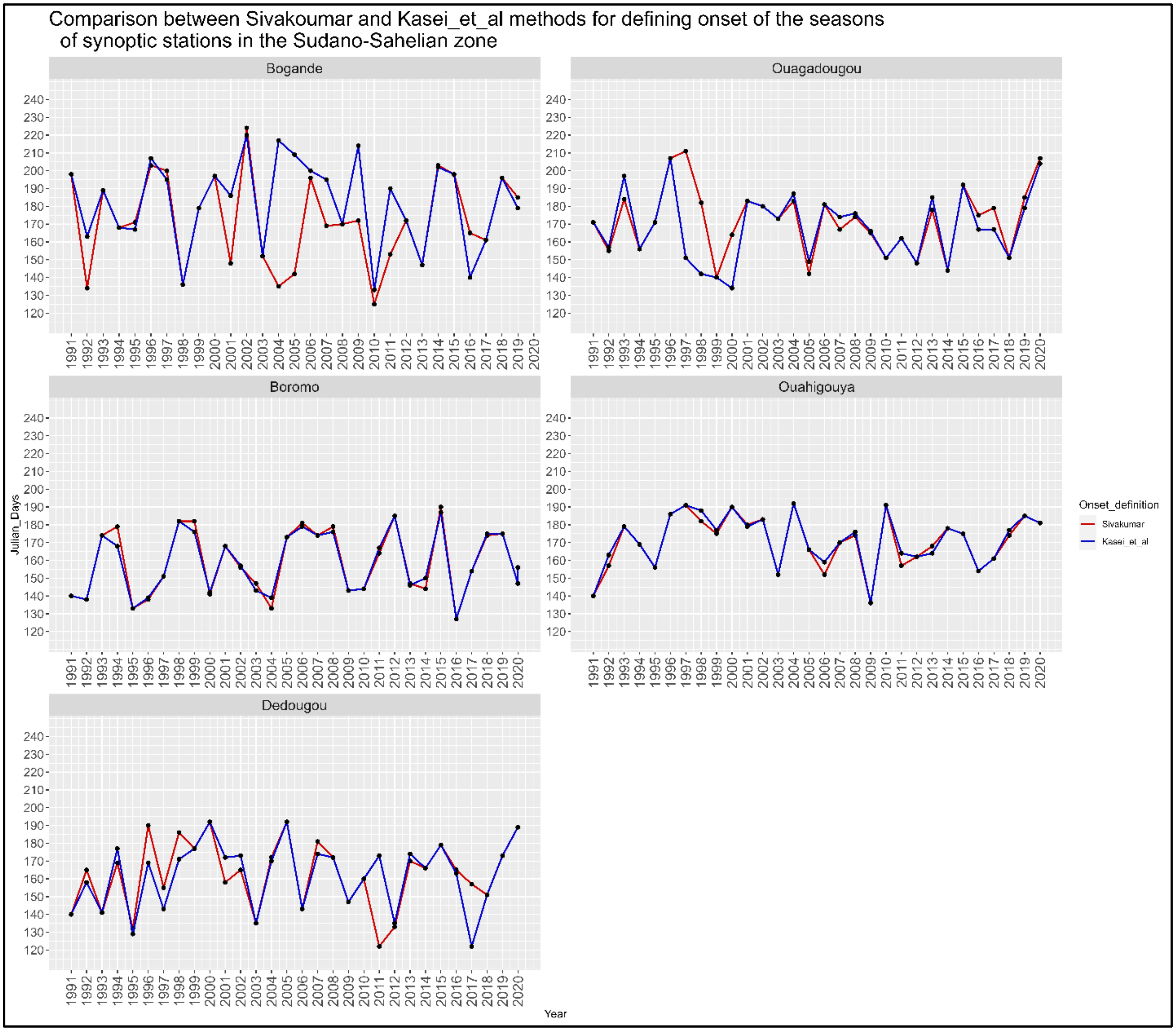
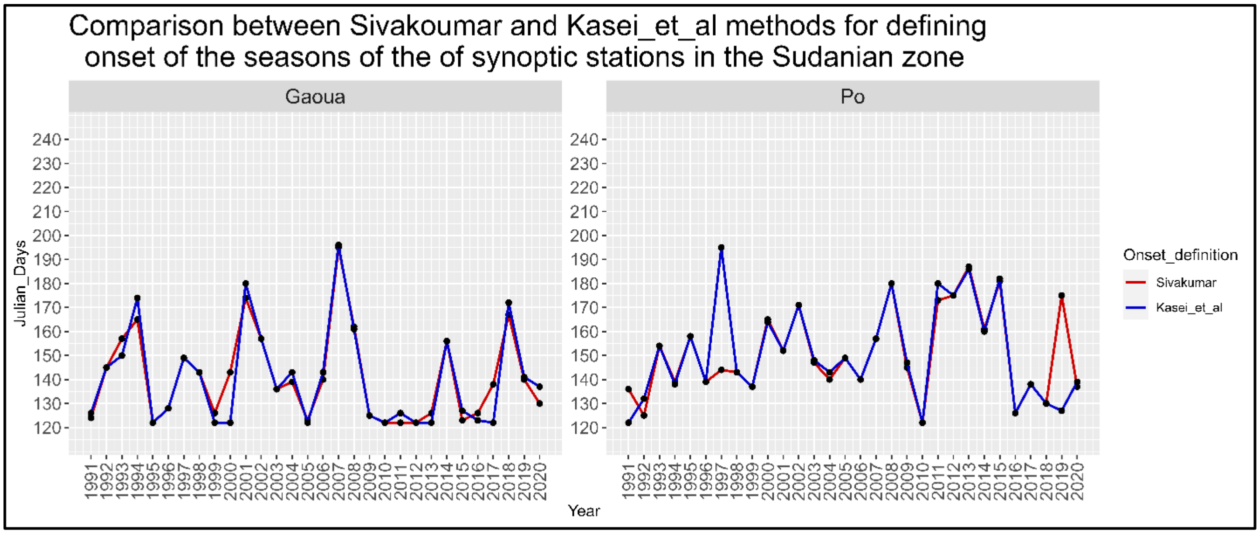
Appendix

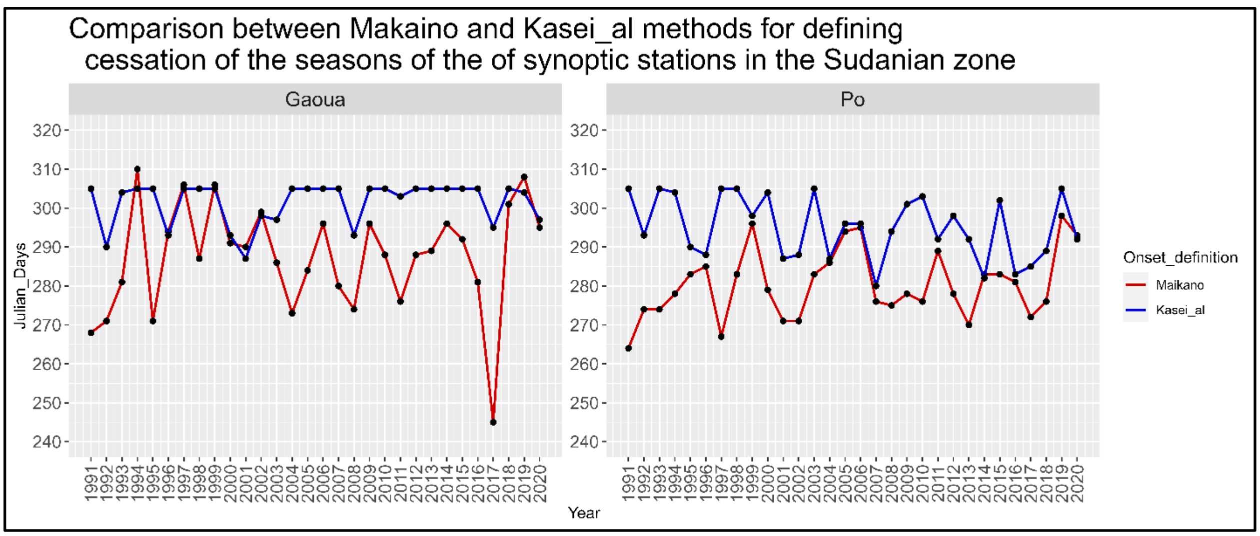
Appendix I : Cessation dates for the five synoptic stations in the Sudano-Sahelian climate zone



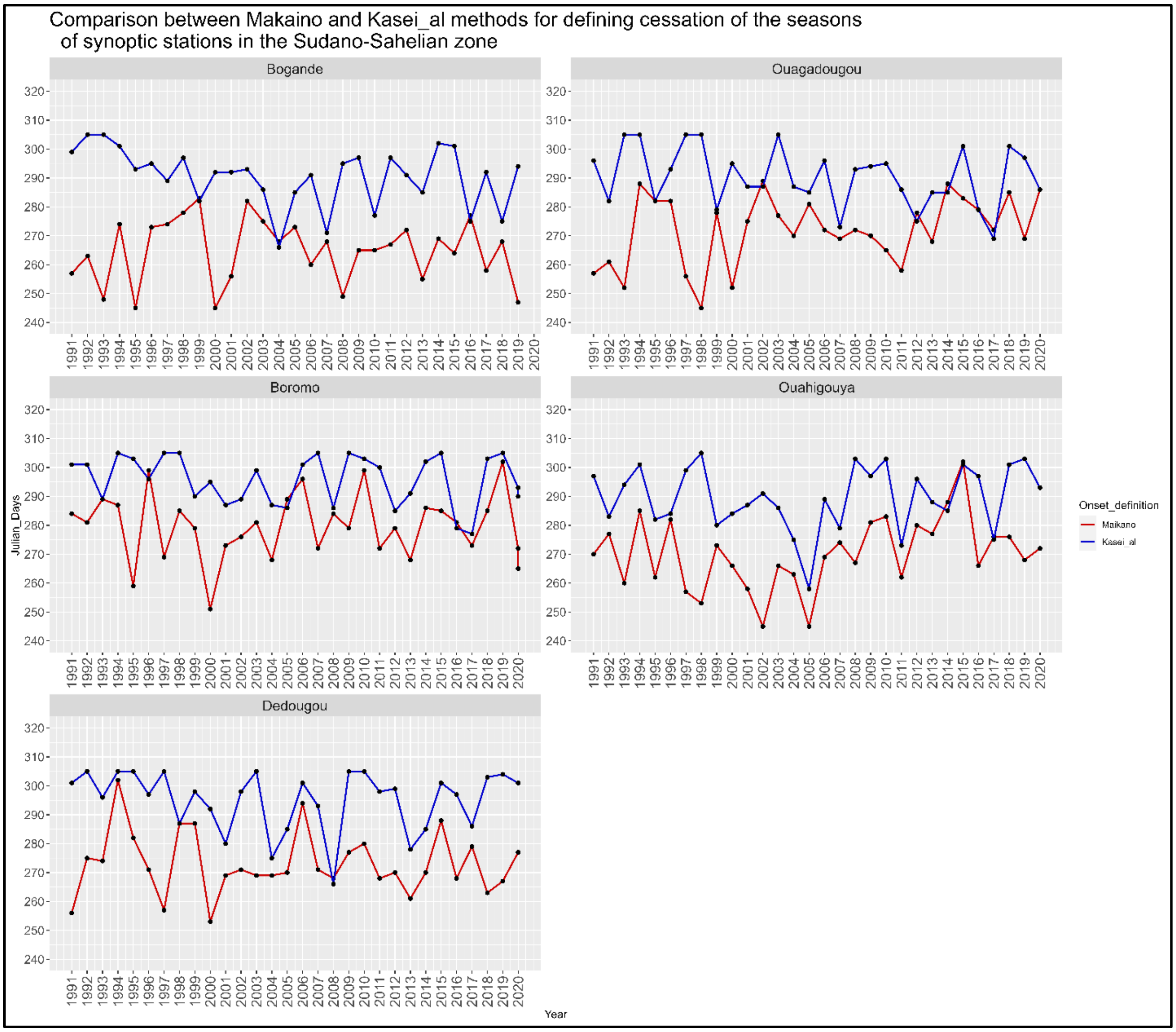
Appendix II : Onset dates for the five synoptic stations in the Sudanian climate zone



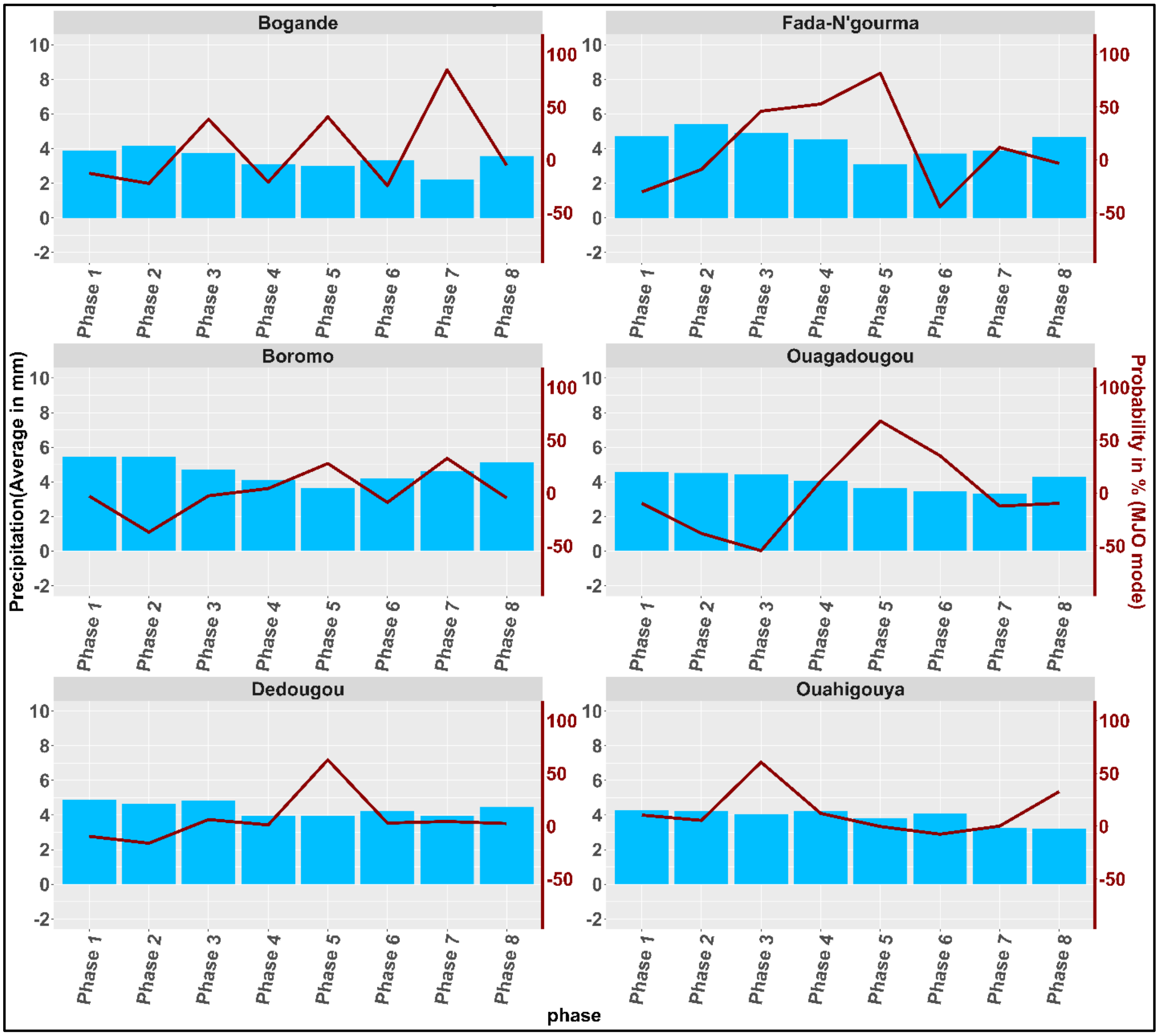
Appendix III : Cessation dates for the five synoptic stations in the Sudanian climate zone



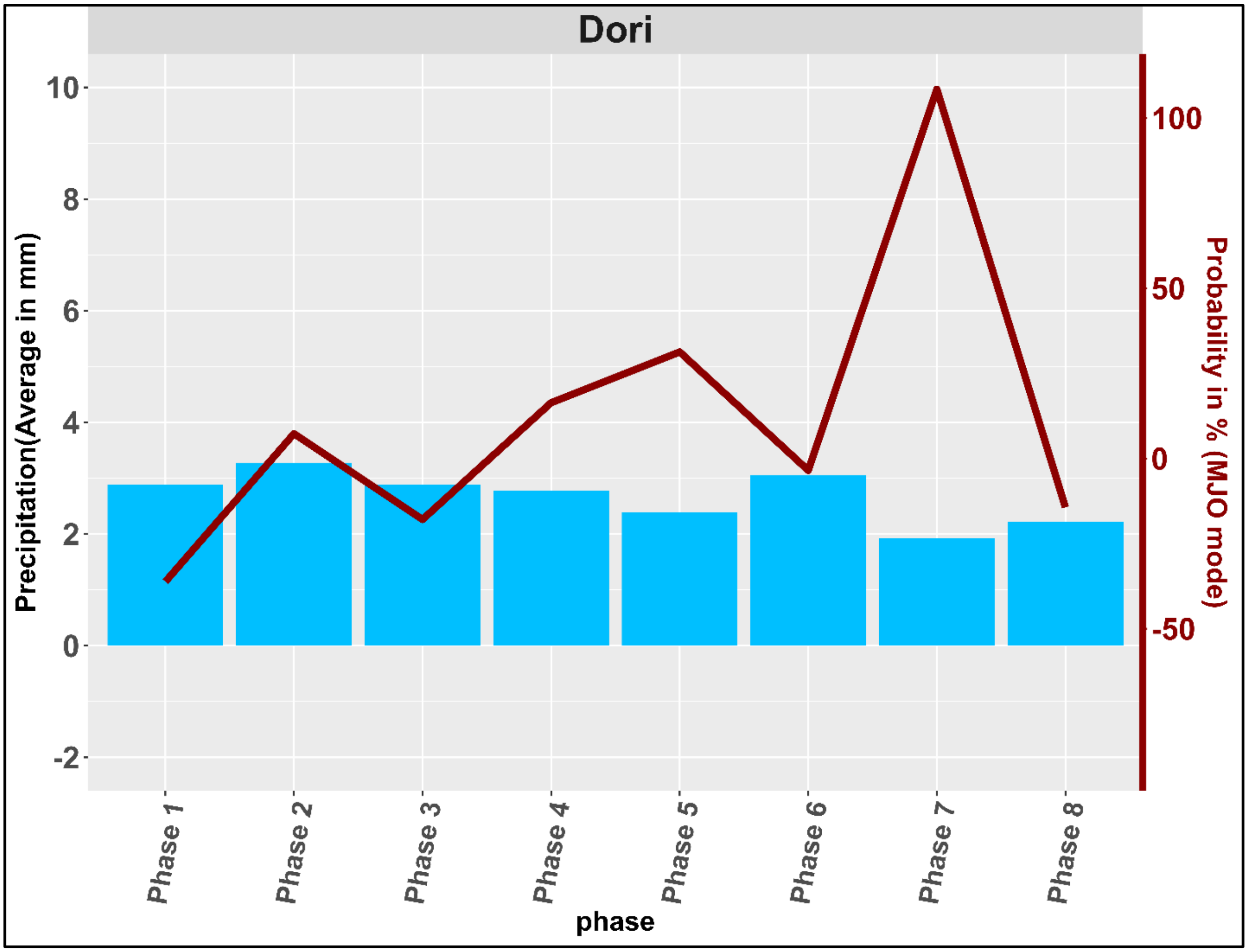
Appendix IV : Cessation dates for the five synoptic stations in the Sudanian climate zone



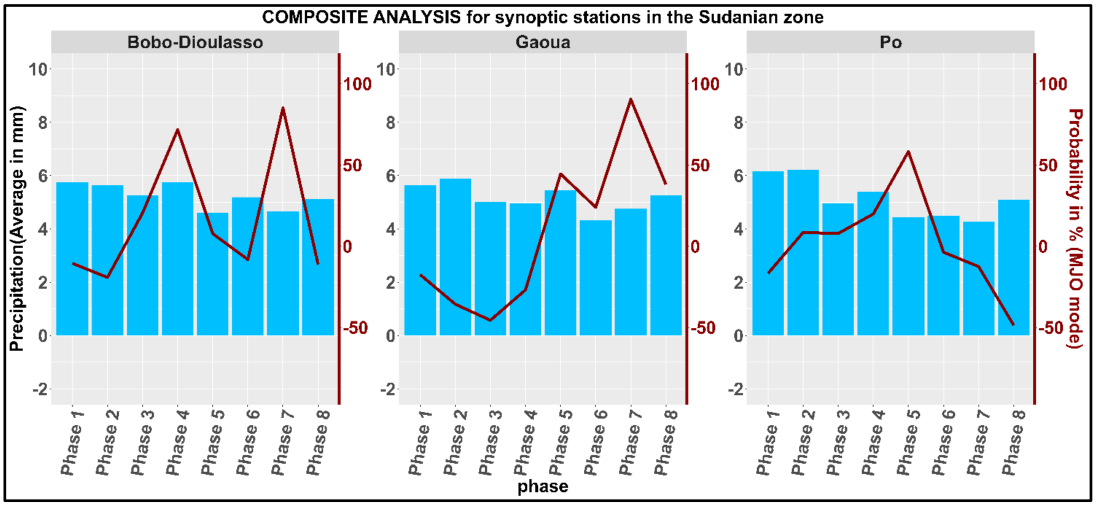
Appendix V : Composite analysis of the MJO of synoptic stations in the Sudano-Sahelian zone



Appendix VI : Composite analysis of the MJO of Dori synoptic station



Appendix VII : Composite analysis of the MJO of synoptic stations in the Sudanian



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