UNIVERSIDADE ESTADUAL PAULISTA
“JÚLIO DE MESQUITA FILHO”
Campus de São José dos Campos
Instituto de Ciência e Tecnologia

Cemaden
Centro Nacional de Monitoramento
e Alertas de Desastres Naturais

UNIDADE DE PESQUISA DO
MINISTÉRIO DA
CIÊNCIA, TECNOLOGIA,
INOVAÇÕES E COMUNICAÇÕES

PÁTRIA AMADA
BRASIL
GOVERNO FEDERAL

Nelson Pedro António Mateus

ASSESSMENT OF THE IMPACTS OF NATURAL DISASTERS RELATED TO DROUGHT IN ANGOLA

São José dos Campos
2022

Nelson Pedro António Mateus

ASSESSMENT OF THE IMPACTS OF NATURAL DISASTERS RELATED TO DROUGHT IN ANGOLA

Dissertation presented to the Institute of Science and Technology, Paulista State University (Unesp), São José dos Campos Campus; National Center for Monitoring and Alerts of Natural Disasters (Cemaden), as part of the requirements for obtaining the title of MASTER by the Graduate Program in natural disasters.
Area: Natural Disasters. Line of research: disasters associated with extreme events, drought, fires and water scarcity.

Advisors: Dr. José Marengo
Dra. Ana Paula Cunha

São José dos Campos
2022

Instituto de Ciência e Tecnologia [internet]. Normalização de tese e dissertação [acesso em 2022]. Disponível em http://www.ict.unesp.br/biblioteca/normalizacao

Apresentação gráfica e normalização de acordo com as normas estabelecidas pelo Serviço de Normalização de Documentos da Seção Técnica de Referência e Atendimento ao Usuário e Documentação (STRAUD).

Mateus, Nelson Pedro António
Assessment of the impacts of natural disasters related to drought in Angola / Nelson Pedro António Mateus. - São José dos Campos : [s.n.], 2022.
64 f. : il.

Dissertação (Mestrado em Desastres Naturais) - Pós-graduação em Desastres Naturais - Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), São José dos Campos, 2022.
Orientador: José Marengo
Coorientadora: Ana Paula Cunha

1. Seca. 2. Impactos. 3. Clima. I. Marengo, José, orient. II. Cunha, Ana Paula, coorient. III. Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia, São José dos Campos. IV. Universidade Estadual Paulista 'Júlio de Mesquita Filho' - Unesp. V. Universidade Estadual Paulista (Unesp). VI. Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden). VII. Título.

Ficha catalográfica elaborada pela Biblioteca Prof. Achille Bassi e Seção Técnica de Informática, ICMC/USP
com adaptações - STATI, STRAUD e DTI do ICT/UNESP.
Renata Aparecida Couto Martins CRB-8/8376

EXAMINING BOARD

José A. Marengo
Universidade Estadual Paulista, UNESP
Campus de São José dos Campos
CEMADEN

Member of the Board
Adriana Cuartas
Universidade Estadual Paulista, UNESP
Campus de São José dos Campos
CEMADEN

Member of the Committee
Ricardo Ferreira Carlos de Amorim
Universidade Federal de Alagoas, UFAL
UFAL

São José dos Campos
23/02/2022.

THANKS

I first thank God for the capacity and grace granted. To my family members; especially my parents, Pedro Eduardo Mateus and Madalena Domingos António for their support and teachings throughout their lives. To my advisors Pof. Dr. José A. Marengo and Prof. Dra. Ana Paula Cunha for the opportunity and patience in the orientation during my master's degree. To the members of the board for the suggestions and criticisms made. To my friends, Jaime Fernando António and Anacleto Marito Diogo.

"Whatever your hand finds to do, do it with all your heart."

Solomon

Sumário

MATEUS, Nelson Pedro António. **Avaliação dos impactos dos desastres naturais relacionados à seca em Angola.** 2022. Dissertação (Mestrado em Desastres Naturais) - Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), São José dos Campos, 2022.

RESUMO

Angola é um país localizado na África Austral e é frequentemente afetado por desastres naturais de natureza hidrometeorológicos. A agricultura é um dos principais meios de sustento e parte da base econômica do país. Entretanto, esse meio é frequentemente afetado pelas condições climáticas, como por exemplo, pelo prolongado déficit de chuva que desencadeia episódios extremos de seca e as condições climáticas associadas. Os resultados mostraram que 7.9 milhões de pessoas em Angola estão expostas a seca, totalizando cerca de 30.8 % da população. Desse registro, cerca de 1,9 milhões de pessoas anualmente sofrem devido aos impactos da seca. Da população afetada, 0,93 milhões são crianças com idade compreendida entre 0-14 anos, e cerca de 1,01 milhões são adolescentes, jovens, adultos e idosos com idade compreendida entre 15 e superior a 65 anos. Dentre as principais lacunas que contribuem para que as ações ao combate à seca continuem ineficientes, destaca-se primeiro a necessidade do monitoramento da seca, conhecimento do risco de desastres relacionado a seca no país, educação, comunicação e capacidade de resposta aos impactos da seca. Dessa forma, esse estudo mostrou que o preenchimento dessas lacunas, auxiliam na mitigação aos impactos da seca e facilita com que os órgãos governamentais, comunidades e indivíduos, tomem decisões em tempo hábil para reduzir os impactos da seca, antes de causar expressivos danos para sociedade angolana. Do ponto de vista climático, grande parte dos eventos de seca estão relacionados com a variação da SST no atlântico norte e sul. Os casos analisados entre os períodos de 1989/90, 1994/95, 2014/15 e 2018/19 na análise climática da seca, mostraram que cerca de 29% do total da extensão territorial do país, estava exposta a seca na categoria de extrema a excepcional. Os casos estudados apresentaram anomalias negativas de chuva e estavam relacionadas a atuação de uma anomalia anticíclica.

Palavras-chave: seca, impactos, clima.

MATEUS, Nelson Pedro António. ***Assessment of the impacts of natural disasters related to drought in Angola**.* *2022. Dissertation (Master in Natural Disasters) - Paulista State University (Unesp), Institute of Science and Technology; National Center for Monitoring and Alerts of Natural Disasters (Cemaden), São José dos Campos, 2022.*

ABSTRACT

Angola is a country located in Southern Africa and is often affected by natural disasters of a hydrometeorological nature. Agriculture is one of the main means of sustenance and part of the country's economic base. However, this medium is often affected by weather conditions, such as the prolonged rain deficit that triggers extreme episodes of drought and the associated weather conditions. The results showed that 7.9 million people in Angola are exposed to drought, totaling about 30.8% of the population. Of this record, about 1.9 million people annually suffer due to the impacts of drought. Of the affected population, 0.93 million are children aged 0-14 years, and about 1.01 million are adolescents, young people, adults and the elderly aged between 15 and over 65 years. Among the main gaps that contribute to the actions to combat drought remain inefficient, we highlight first the need for drought monitoring, knowledge of the risk of drought-related disasters in the country, education, communication and capacity to respond to the impacts of drought. Thus, this study showed that filling these gaps, help mitigate the impacts of drought and facilitates government agencies, communities and individuals to make timely decisions to reduce the impacts of drought, before causing significant damage to Angolan society. From a climatic point of view, most drought events are related to the variation of SST in the North and South Atlantic. The cases analyzed between the periods of 1989/90, 1994/95, 2014/15 and 2018/19 in the climate analysis of drought, showed that about 29% of the total territorial extension of the country was exposed to drought in the category of extreme to exceptional. The cases studied presented negative rainfall anomalies and were related to the performance of an anticyclic anomaly.

Keywords: drought, impacts, climate.

1 INTRODUCTION

Natural disasters are defined by the World Health Organization (WHO) as situations or events caused by nature which overload society's local capacity to overcome the impacts caused. It is estimated that globally more than 100,000 lives are lost because of natural disasters. Since the 1970s, the African continent has suffered more than 2,000 disasters, with just under half occurring in the last decade (GFDRR and World Bank, 2018: 5). The most common disasters are those of hydrometeorological origin, especially floods and droughts.

Examples of economic impacts include farmers who lose money because drought destroyed their crops or ranchers who may have to spend more money to feed and water their animals. In addition to the economy, drought also affects the environment and society. Plants and animals depend on water, just as people do. Drought can shrink their food supplies and damage their habitats. Sometimes this damage is only temporary, and other times it is irreversible. Drought can also affect people’s health and safety. Examples of drought impacts on society include anxiety or depression about economic losses, conflicts when there is not enough water, reduced incomes, fewer recreational activities, higher incidents of heat stroke, and even loss of human life. Drought conditions can also provide a substantial increase in wildfire risk. As plants and trees wither and die from a lack of precipitation, increased insect infestations, and diseases associated with drought, they become fuel for wildfires. Long periods of drought can equate to more wildfires and more intense wildfires, which affect the economy, the environment, and society in many ways such as by destroying neighborhoods, crops, and habitats (NCDC 2022- https://www.ncdc.noaa.gov/news/drought-monitoring-economic-environmental-and-social-impacts). Drought and its impacts are really two sides of the same coin. We cannot fully understand drought without understanding its impacts, which can affect all parts of our environment and communities. Understanding drought conditions, societal vulnerability, and their related effects on one another provide us with historical lessons that can aid in dealing with future drought conditions.

Drought impacts have been documented in other regions of Africa as well as in other continents. In Brazil, the drought that occurred in 2014/2015 in southeast Brazil generated a great growth in the demand for water, the inefficiency of the management of this resource and generated an intense water crisis (Marengo et al., 2015). In the US, the 2021 water year was California's driest in a century, and more than half of the state's water years since 2000 have been dry or drought years. The California Department of Water Resources reports that 2021 is the second driest year in state history. The driest year happened all the way back in 1924. The report detailed rising temperatures and lack of rainfall as key factors (NCDC 2022-https://www.ncdc.noaa.gov/sotc/drought/202113). The recurrence of drought spells over the years in Australia has become a frequent phenomenon with significant impacts on agricultural output and productivity. Protracted drought events impacted crop physiology with adverse impact on grain development, hampered chlorophyll production, fruit bearing, number of grains/spikes, ovule fertility, pollen vitality, nodule performance, flowering period, cell growth, photosynthesis and transpiration, seed set and standard seed size. In 1990, 2002─10, 2003─07, 2006, 2006─07, and 2018─19, drought reduced various crops production in Australia by 51%, 18%, 32%, 58%-56%-50%, and 53%, respectively (Roy et al. 2021).

In Africa, Richard et al (2001) documented 1950–1988 period and on late summer season (January–March) in Southern Africa, where the 1970–1988 period had more variable rainfall, and more widespread and intense droughts than the 1950–1969 period. The drought was re-declared as a national emergency in South Africa on 4 March 2020. This is the third time the government has declared a state of emergency in six years. The drought of 2019 has been described as the worst in the last 90 years in the country, with the lowest recorded rainfall in Windhoek since 1891. The 2018–2021 Southern Africa drought is an ongoing period of drought in Southern Africa. The drought began in late October 2018 and negatively affects food security in the region. The regular drought episodes in South Africa highlight the need to reduce drought risk by both policy and local community actions. In the past, environmental and socioeconomic factors in South Africa's agricultural system have been affected by drought, creating cascading pressures on the nation's agro-economic and water supply systems. Therefore, understanding the key drivers of all risk components through a comprehensive risk assessment must be undertaken to inform proactive drought risk management (Meza et al 2021). During Kenya's 2008-2011 drought, losses totaled around $12.1 billion, and the economy slowed by about 2.8 percent. In Malawi, drought is estimated to have affected about 1.7% of GDP (Piters, 2018).

The problems caused by natural disasters in sub-Saharan Africa have increasingly become a challenge for all African rulers. However, this reality is significantly reflected in Angola. Angola is a country located in sub-Saharan Africa on the western coast of the continent geographically the country is divided into three regions; north, center and south (Fig1a and 1b). Angola is prone to natural disasters such as epidemics, floods and drought-related disasters in vulnerable regions. The natural phenomenon of drought alone does not cause disaster, but disasters occur when there are preexisting conditions of social vulnerability (Kelman, 2018; Mattedi; Butzke, 2001). Thus, natural disasters related to droughts hinder the supply of food and water in much of southern Angola, which leads to human losses due to form and lack of water and triggers numerous pathologies (VOA, 2019; Aja et al., 2017, 2016).

The context of impacts related to natural disasters caused by drought in Angola is not recent. For example, in the 1830s, the gradual decline of the slave trade abroad and the increased trade in raw materials brought significant demographic changes, contributing to the increase in hunger and epidemic crises in the 19th century (Dias, 1981). In the 1980s, the number of people affected by the impacts of the drought increased. In 1981, 1985 and 1989 the drought affected 580,000 people. In the 1990s, between 1992 and 1998, the number of affected rose to 2,005,000. In 2001, 2004, 2005, 2012 and 2013, drought conditions affected 1,858,900 people, and the drought in 2001 caused the deaths of 58 people due to hunger, lack of water and malnutrition (Nnopuechi, 2021). However, it is important to remember that while the impacts of drought plagued the population, the country was going through a tragic period of civil war, which began in 1975 and lasted until the year 2002. According to Peters (2018), the civil war falls into one of the conflicts affecting low-income countries in Africa, hinders resilience to natural disasters, and significantly increases vulnerability, which was the case of the 27 years of war in Angola.

In 2012/2016, according to the civil protection report, the country experienced four successive years of drought and estimated that a total of one million and six hundred thousand people were victims of drought (Aja et al., 2017). The impact of this event was also pointed out as one of the factors that caused great losses in agriculture and the increasing number of family abandonment due to hunger and an increase in the number of deaths from malnutrition due to low food availability (Aja et al., 2017). Moreover, it is estimated that in the provinces of Cuanza Sul, Benguela, Lunda Sul and Bié, the number of hospitalizations and deaths from malnutrition increased during these prolonged years of drought. In Huila and Cunene, hospitalizations increased from 1357 to 8092 and 3031 to 6044, respectively. On the other hand, a loss estimated at around US$ 2,297 to US$ 452.4 million was estimated in the agricultural sector, food security, water supply and basic sanitation (Aja et al., 2017).

After two years in the summer of 2019 the country faced one of the most extreme episodes of drought. The drought affected more than 2.3 million people, and this number was much higher than that recorded in 2012/2016, and may be evidence of the failure of the measures adopted or suggested in Angola's civil protection report but not implemented. According to the journal e-GLOBAL (2020), in the first six months of 2020, 46 deaths were recorded in Angola due to hunger.

According to the International_Recovery_Platform (DW, https://www.dw.com/pt-002/sul-de-angola-continua-a-sofrer-com-a-seca-e-a-fome/a-46270279), the impact of the drought was so profound that it led to deaths due to hunger in surprising numbers in some locations of the provinces in southern Angola. Still, about 10,982 head of cattle died, 52,119 agricultural fields were destroyed in those provinces.

The United Nations has made available US$465 million to create strategies to combat the impacts of drought, and the Angolan government has made about US$200 million available for the same purpose (VATICANNEWS, 2020, RFI, 2019, UNICEF, 2019). However, the strategy policies, projects and measures taken so far have not shown plausible results.

Measures to mitigate the impacts of drought in Angola should not simply be focused on the distribution of food baskets or on the declaration of a post-disaster alarm, as suggested in the latest civil protection report (Mateus e António, 2020).

The official report published by civil protection in 2016 proposed some actions to mitigate the impact of drought, but there was no in-depth analysis of regions vulnerable to drought impacts. In addition, the report was restricted to an evaluation only for the southern region during the years 2012/2016. After the great damage caused by the drought in the summer of 2019, a news article published by the new newspaper advanced information that the ministry of telecommunications intended to study the feasibility of using satellite images for drought monitoring; however, to date, this news remained only on the theoretical stages (NOVO JORNAL, 2019).

In 2021, drought conditions affected a total of 1.3 million people in Cunene, Huíla and Namibe, the population of these regions facing severe hunger (Fig.1c). The agricultural fields were sterile, pastures and food reserves exhausted. The impact of the drought in 2021 caused the provinces mentioned to be on food insecurity alert. That same year, a mass migration of families to Namibia was recorded, searching for water, food, cattle grazing. Still, under the impact in 2021, the drought affected 114,000 children under five years of age, presenting acute malnutrition cases (relief pool, 2021; RFI, 2021).

Currently, the country has bet on projects related to the creation of dams for water supply and projects related to water distribution training (Angop, 2021).

The impacts of drought are highly varied depending on the socioeconomic environment of the affected community in Angola. Therefore, indicating the types of impacts to which a region is vulnerable or exposed to drought is essential for decision-making and for defining appropriate indicators for drought monitoring (UNDRR, 2017; BLAUHUT, 2020). However, a detailed study involving major regions vulnerable and exposed to drought could help catalyze competent bodies to create actions aimed at reducing drought damage in the country and provide the basis for monitoring drought in the future. In addition to this detail, a study was not made that indicates the main gaps that exist in the implementation of actions that work to combat drought or proposed and unimplemented actions. On the other hand, the climate is one of the main factors for understanding drought dynamics and drought monitoring.

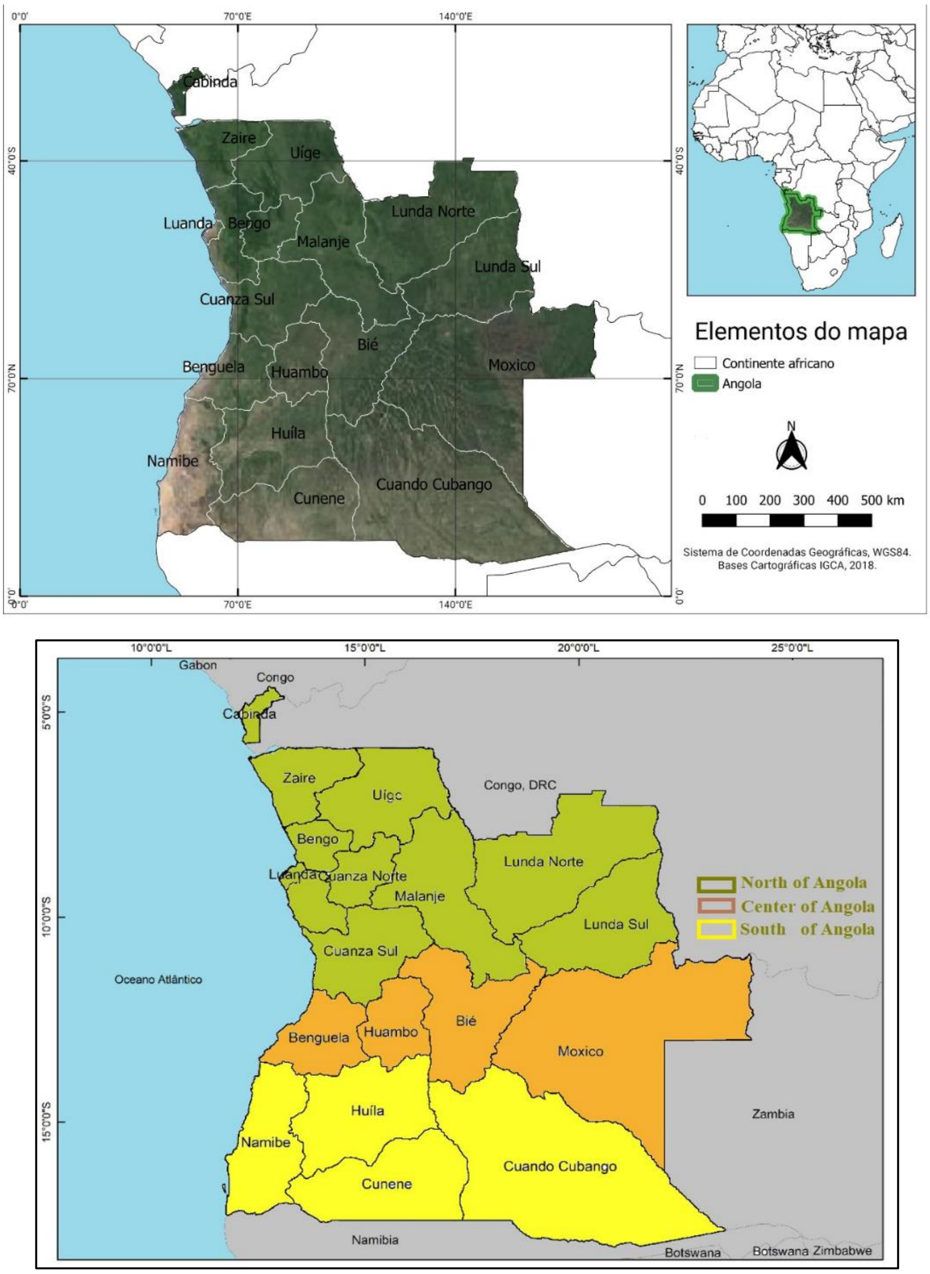
In the face of the above, one may ask: Do we understand how climate variations affect the rest of the country in terms of the occurrence of drought? Do we know what weather systems are associated with these events? What are the current trends of drought occurring in different regions? How is it possible to identify regions most affected by drought? Moreover, we do not know to what extent the bodies responsible for proposing actions have failed or continue to fail and what gaps must be filled in so that drought-fighting actions are effective in Angola.

In the context of the interdisciplinarity of the management of disaster risk reduction related to drought and the understanding of the main climatic factors involved, this dissertation should aim to: 1) Evaluate the main climatic conditions associated with drought, 2) to evaluate the impacts, vulnerability and adaptation of the population in relation to the impact of natural disasters related to drought.

The dissertation was structured in two articles: the first addresses the spatial-temporal characteristics of droughts in Angola, and the second article addresses the impacts, vulnerability and adaptation of the population to the impacts caused by drought.

Finally, based on this evaluation, we propose and reinforce strategies to combat drought by analyzing drought risks, monitoring, communication, and capacity. These are important axes for a future proposal of a monitoring system; however, it is not our focus to propose the implementation of a monitoring system in this study, although its advantages are addressed.

Figure 1: a) representative map of Angola, b) map of the regions of Angola, c) Impact of drought in Cunene province in the year 2021.



Source: UNICEF-ANGOLA, 2022.

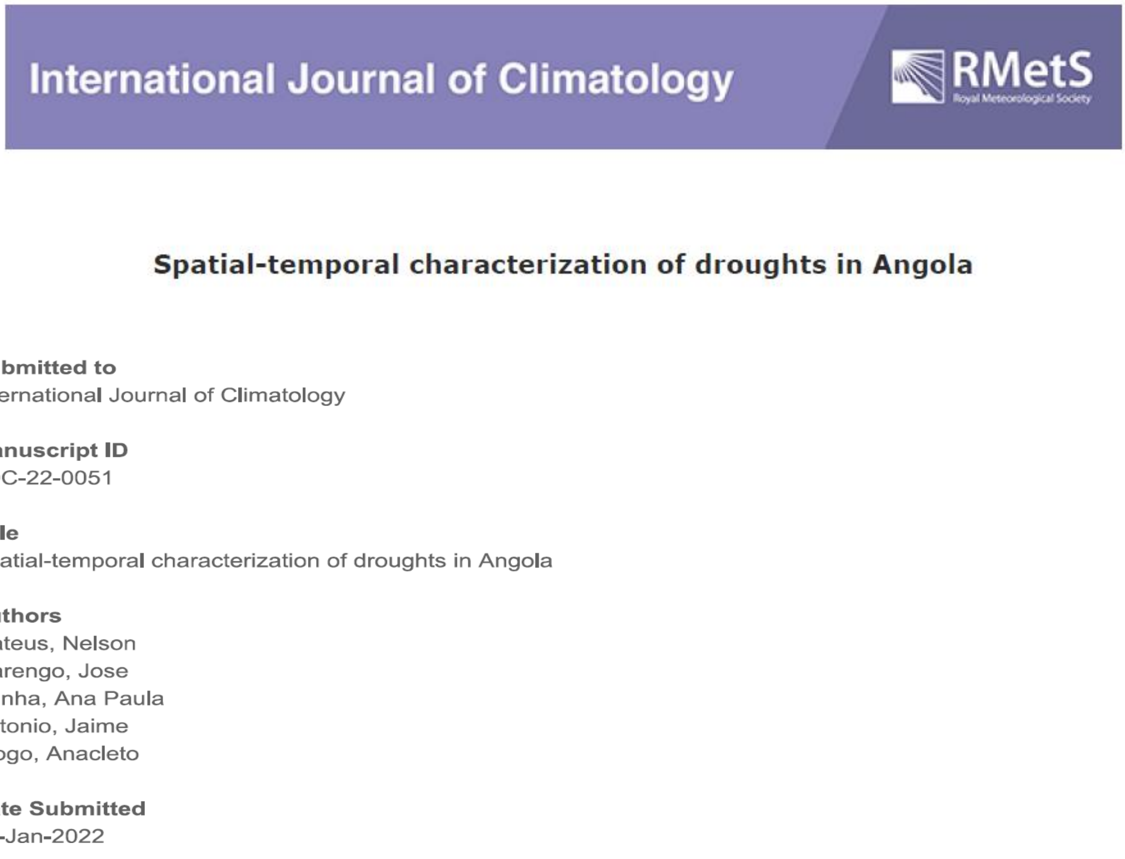
2 ARTIGO

Nelson P. A. Mateus[1], José A. Marengo[2], Ana P. M.A. Cunha[2], Anacleto Marito Diogo[3],
Jaime Fernando António[4].

Journal title: International Journal of Climatology

Data de submissão: 15/01/2022

MATEUS, NELSON PEDRO ANTÓNIO.**Spatial-temporal characterization of droughts in Angola**. 2022. Dissertação (Mestrado em Desastres Naturais) - Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), São José dos Campos, 2022.



International Journal of Climatology

RMetS
Royal Meteorological Society

Spatial-temporal characterization of droughts in Angola

Submitted to
International Journal of Climatology

Manuscript ID
JOC-22-0051

Title
Spatial-temporal characterization of droughts in Angola

Authors
Mateus, Nelson
Marengo, Jose
Cunha, Ana Paula
Antonio, Jaime
Diogo, Anacleto

Date Submitted
15-Jan-2022

SPATIAL-TEMPORAL CHARACTERIZATION OF DROUGHTS IN ANGOLA

Nelson P. A. Mateus[1], José A. Marengo[2], Ana P. M.A. Cunha[2], Anacleto Marito Diogo[3],
Jaime Fernando António[4].

[1]Graduate Program in Natural Disasters, UNESP/CEMADEN, State University of São Paulo, São José dos Campos, Brazil.

[2]National Center for Monitoring and Early Warning of Natural Disasters, São José dos Campos, Brazil.

[3]Graduate program in analysis and modeling of environmental systems, UFMG.

[4]Doctoral program of the National Institute for Space Research, INPE.

ABSTRACT

Angola is located in southern Africa and is frequently affected by natural disasters of a hydrometeorological nature. Among them, drought is one of the most impactful phenomena that plays a significant role in water resources, food and energy insecurity. Monitoring the risk of drought events at various levels of intensity is extremely important and represents a gap to be filled in terms of knowledge of drought in Angola. This approach includes understanding the variation in key climate variables in relation to drought in Angola. The present study evaluated the main climatic conditions associated with drought events in the country, including understanding the spatiotemporal patterns of droughts. For this, the frequency, duration and intensity of drought events are evaluated using the Standardized Precipitation Index (SPI). The assessment of the affected areas was carried out using the Integrated Drought Index (IDI). The results showed that Angola was repeatedly affected by drought events. The longest drought events were identified in the South and Center regions of the country. In the South region, the longest drought occurred from 1992 to 1997, totaling 83 consecutive months of drought in the region, in the Center the longest event occurred during the years 1994 to 1997, and in the North region between 2003 and 2005, totaling 46 and 23 months, respectively. The climatic conditions evaluated for the drought events studied (1989/1990, 1994/1995, 2014/2015 and 2018/2019) showed that most drought events in the country are associated with the variation of sea surface temperatures in the South Atlantic Ocean. The analysis of the drought category showed that during the years analyzed, about 29.7% of the territorial extension of Angola is affected by drought events in the severe to exceptional category.

Key Words: Drought, Climate, Angola.

1 INTRODUCTION

Drought is defined as a natural phenomenon that occurs slowly and intensifies over time. Over the years, droughts have occurred on a large scale globally, causing different impacts. It is said that about 135 billion dollars and 12 million victims were affected by droughts between 1900 and 2013 (Nnopuechi, 2021). This reality is no different when approached about Southern Africa, known for housing arid and semi-arid regions where drought has been recurrent. However, in Africa, drought is caused by several factors ranging from physical to oceanic influences with El Niño and La Niña, variations in sea surface temperature (SST), influences on atmospheric waves, among other factors that influence the spatial distribution of rainfall (Austin, 2008)**.**

Weather and climate hazards are among the environmental, social and economic determinants of the geographical distribution of natural disasters that occur in much of Africa. The availability of food can be threatened through extreme climate impacts on crops, livestock due to increased or deficient rainfall, triggering flood events, landslides and drought, as well as heat waves (IPCC - AR5, 2014). Furthermore, access to food in Africa has been severely affected by variations in weather and climate due to drastic changes in climatic variables such as rainfall, temperature, humidity, among others (IPCC - AR5, 2014). Drought is one of the most disastrous natural phenomena that cause scarcity and lack of water in hydrological basins and severely affect the majority of the population in various forms, both in socioeconomic and environmental aspects. In this context, drought risk plays a significant role in water management, economic development, agricultural production, and other factors (Nnopuechi, 2021).

Angola is located in sub-Saharan Africa, on the west coast of the continent (Fig.1a, b and c). The country is prone to natural disasters such as epidemics, floods and drought-related disasters in vulnerable regions. For example, agriculture, which was the main base of sustenance mainly in the South and Central regions of Angola, depends significantly on climate and climate variations. Thus, most of the agricultural production of family farmers is affected by climatic variations since these farmers depend mainly on agriculture for their subsistence, such as the cultivation of cassava, corn, massambala, among others (Gautam *et al.*, 2006; Cooper and Coe, 2011; Karpouzoglou and Barron, 2014; Lottering, Mafongoya and Lottering, 2020).

In Angola, climate and political instability contribute to a decrease in food supply to the population long before the 19th century. For example, in the 1830s, the gradual decline of the slave trade abroad and the increased trade in raw materials brought important demographic changes, that contributed to the increase in hunger and epidemic crises in the 19th century (Dias, 1981). Since the 1980s, there has been a considerable increase in the number of people affected by drought in Angola. For example, the drought conditions in the 1980s (1981, 1985 and 1989) affected 580,000 people. In the 1990s, between 1992 and 1998, the number of affected roses to 2,005,000. In 2001, 2004, 2005, 2012 and 2013, the drought conditions affected 1,858,900 people, and the drought in 2001 caused the death of 58 people due to hunger, lack of water and malnutrition (Nnopuechi, 2021).

Some studies have shown that droughts in sub-Saharan Africa are not perceived as an isolated event, but are linked to changes in seasonal rainfall patterns, which is a consequence of climate variations that are pointed out as a result of future climate change (Dai, 2011; IPCC - AR5, 2014). The southern region of Angola experienced four successive years of severe drought in 2012/2016 when most of its impacts began immediately after the emergence of negative rainfall anomalies. From a climatic point of view, according to the report presented by the Civil Defense of Angola, the beginning of this drought could be associated with an episode of El Niño in 2012/2013 (Aja *et al.*, 2017). The economic impacts of this drought in the Namibe, Huíla, and Cunene provinces, alone were estimated to be around US$749 million, and the agricultural and fishing sector was by far the most impaired (Limones *et al.*, 2020; RFI, 2019; Novo Jornal, 2019).

Among the regions most affected in 2012/2016, Namibe, Cunene, and Huíla stood out. These three provinces of Angola are characterized by being arid and semi-arid agro-ecological zones (Fig.1b, Fig.1c) containing deserts and savannas with an annual rainfall average of 200-400 mm per year, with the rainfall season beginning in mid-October and ending in the first half of March (Xavier, 2013; Diogo, 2020)

The regions mentioned above are also characterized mainly by agropastoral activities and livestock, thus being an important asset for the sustenance of cattle, goats, pigs and poultry. During the drought of 2012/2016, it was estimated that a total of one million and six hundred thousand people were victims of drought; in these years, there was a significant increase in cases of malnutrition, family abandonment, and also a worsening of deforestation and the continuous degradation of water resources (Aja *et al.*, 2017).

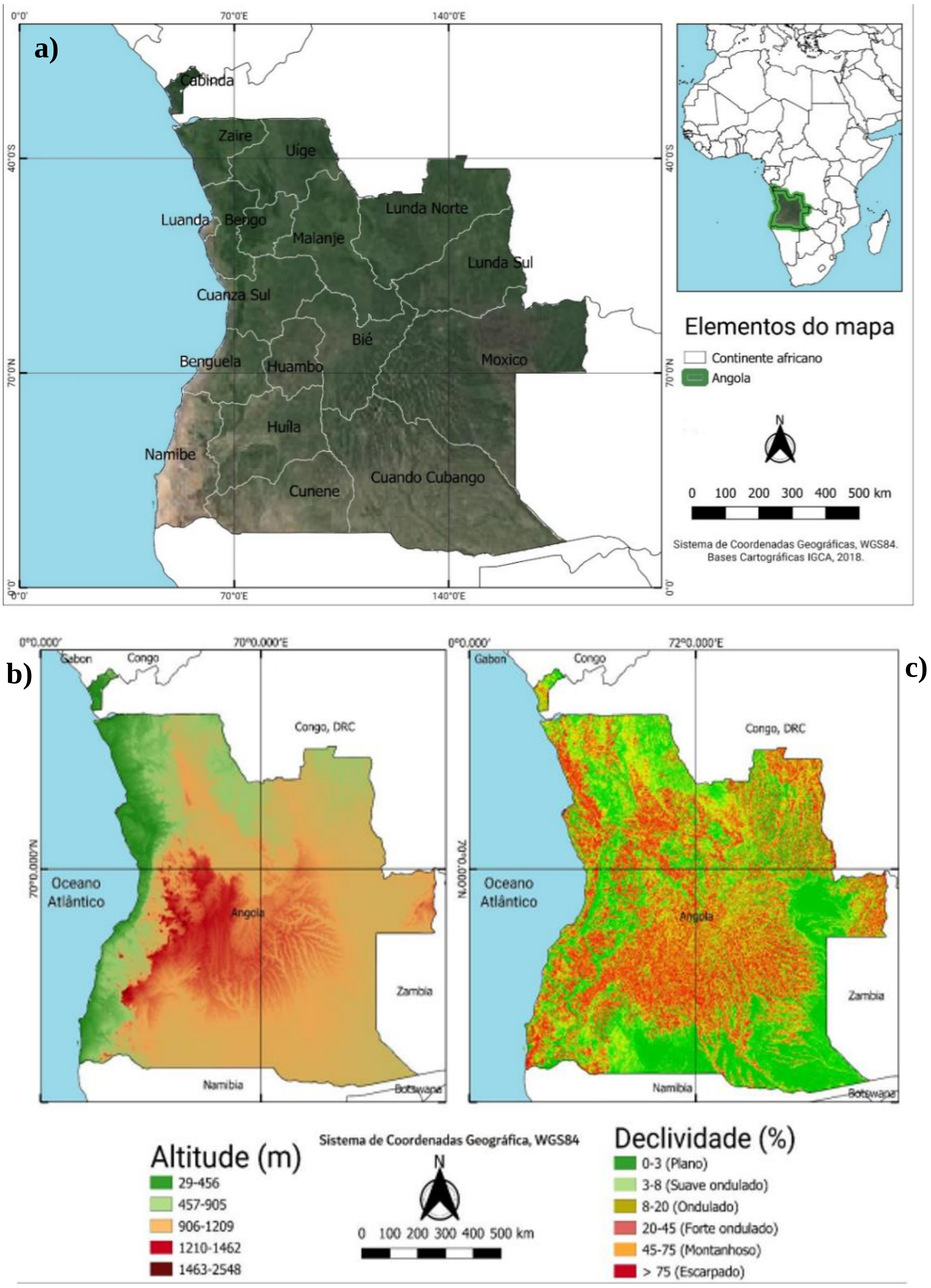
Two years later, after the drought episode in 2012/2016, Angola experienced again between 2018/2019, one of the most extreme episodes of drought affecting around 2.3 million people (DW, 2019b). The drought of 2018/2019, resulted from a large center of anticyclonic circulation established in the region. The action of the anomalous anticyclone caused deficit and rainfall in much of the Southern region; that is, this system inhibited convection and consequently the formation of clouds, allowing the transport of drier air at high levels of the atmosphere to the surface, persisting every summer of 2019 (Mateus & António, 2020).

In 2021, the drought conditions affected a total of 1.3 million people in Cunene, Huíla and Namibe, the population of these regions faced severe hunger. The agricultural fields have been barren, pastures and food reserves exhausted. The impact of the drought in 2021 caused the aforementioned provinces to go on food insecurity alert, and in that same year, a mass migration of families to Namibia was recorded in search of water, food, for cattle grazing. Still, under the impact in 2021, the drought affected 114,000 children under five years age, presenting acute malnutrition cases (reliefweb, 2021; RFI, 2021).

Given this broad approach, it is essential that researchers, scientists and competent agencies, understand and communicate the probability of drought events at various levels of intensity, as well the evaluation of the most impacted areas. This knowledge involves understanding the main climatic variables, and this understanding so far is a gap to be filled in terms of knowledge of drought in Angola. Thus, aspects such as understanding drought variability in relation to climatic conditions are scarce in the literature when it comes to Angola. Furthermore, this understanding helps create various integrated strategies necessary to carry out drought risk assessments to find technological and institutional solutions adapted to ensure water and food security for the population (VOA, 2019; Luetkemeier, Mbidzo and Liehr, 2021). In addition, detailed studies on the assessment of drought impacts and analyzes the climatic aspects associated with the occurrence of drought for the entire territory of Angola are currently very scarce.

Therefore, one may ask: Do we understand how climate variations affect the rest of country in terms of the occurrence of drought? Do we know what weather systems are associated with these events? What are the current trends of drought occurring in different regions? How is it possible to identify regions most affected by drought? To answer these questions, the aim of this study is to evaluate the spatial-temporal characteristics of drought and its relationship with the main associated climatic conditions, as well the characterization of drought categories and trends analysis of climate conditions leading to droughts.

Figure 1: Map of Angola and its main provinces. Source: a) Author b), c) Diogo (2020)



2 MATERIALS AND METHODS

The study area comprises all territorial extension of the country (latitude -11.2 and longitude 17.87). The country is divided by an arid coastal strip composed of the provinces of Namibe and Luanda. The dry season period in these regions takes place from June to August. In the central, south and eastern regions of the country, the semi-humid tropical climate predominates, comprising the province of Cuanza-Sul, Moxico, Huíla, with annual rainfall s between 750 mm and 1250 mm, with March being the least rainfall y month.

The dry tropical climate occurs in the coastal strip from Quelo to Benguela, with rainfall between 500 and 700 mm, with the monthly maximum in April of 130 mm (Figure 1b, 1c). The tropical desert climate also predominates in the region, on the southwest coast comprising the province of Namibe. In addition to these factors, Angla shows high-altitude reliefs in the center of the country, the cold currents of Benguela further south over the Atlantic Ocean, and the Namibian desert (CIMA, 2019; Diogo, 2020).

2.1 DATA

According to Mateus and António (2020), hydrometeorological measurements throughout the country is scarce, making it difficult to carry out several studies in the region. Angola also suffered 27 years of civil war, making it impossible to grow a consistent climate and hydrological database. In addition, the country has so far seen political crises that make it impossible for some scientific sectors to grow and develop.

The National Institute of Meteorology of Angola (INAMET, http://www.inamet.gov.ao/ao/) suffers from a strict bureaucracy for data acquisition, so climate data is not made publicly available. For this reason, this study proposed using satellite data, reanalysis and gridded rainfall datasets that are freely available and that have been proved to be useful in climate studies around the world. Rainfall data were obtained from the Climate Hazards Group InfraRed Rainfall with Station data (CHIRPS, (Funk *et al.*, 2015)) and are used to determine the Standardized Precipitation Index (SPI, (MCKEE, 1995) and are available in https://www.chc.ucsb.edu/data/chirps. CHIRPS dataset has been widely used in East and West Africa to determine drought events. In addition, studies indicate that this dataset has a good spatial representation and is reliable in climate studies in these regions of Africa (Dinku *et al.*, 2018; Muthoni *et al.*, 2019).

Satellite-derived Vegetation Health Index (VHI) data, has also been used and is available on the http://www.star.nesdis.noaa.gov. The SPI and VHI indices were combined to calculate the integrated drought index to characterize drought intensity and spatial variability in Angola (IDI, Cunha et al., 2019).

The zonal and meridional wind components and relative humidity data, are derived from the National Centers for Environmental Prediction –National Center for Atmosphere Research (NCEP-NCAR) reanalysis between 1981 and 2020, in spaced grid points of 2.5°x2.5. This data set, is used to evaluate as main climate variabilities, such as specific humidity, zonal and meridional wind components, related to drought events and are available on the website: https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html (Kalnay *et al.*, 1996).

2.2. METHODS

2.2.1. Drought Indicators

The SPI is an index used to characterize drought events and is useful for assessing the spatial variation of severity (Mckee, Doesken & Kleist, 1993; MCKEE, 1995). In this study, the SPI was used to evaluate the space-time characteristics of drought in Angola and to calculate the integrated drought index (IDI). SPI is computed on several time scales, consisting of a period of accumulated rainfall (Barker *et al.*, 2016). In this study, a 12-month scale was calculated using monthly rainfall of 1984-2020. The 12-month scale shows long-term rainfall patterns associated with water levels in reservoirs, flows, and groundwater levels. However, this scale has been recommended to evaluate drought events since the smaller scales may present characteristics similar to rainfall (Fechine, 2015; Cunha et al., 2019).

Monthly rainfall time series from the CHIRPS dataset were adjusted to a gamma probability density function defined according to the following equation:

$$g(x) = \frac{1}{\beta^{\alpha} T(\alpha)} X^{\alpha-1} e^{-x/\beta} \qquad [1]$$

where α> 0 represents the shape parameter, β> 0 is a scalar parameter, x>0 corresponds to the amount of rainfall, and Γ (α) is the gamma function defined as,

$$T(\alpha) = \int_0^{\infty} y^{a-1}\, e^{-y} dy \qquad [2]$$

where the parameters α and β of the gamma distribution are based on the approximation of:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad [3]$$

$$\beta = \frac{\bar{x}}{\alpha}, com\ A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad [4]$$

where n is the number of observations. By integrating the Equation [1] in relation to x leads to the calculation of the cumulative probability function of the gamma distribution, expressed as in Equation (5),

$$G(x) = \int_0^x g(x)dx = \int_0^x \frac{1}{\beta^{\alpha} T(\alpha)} x^{\alpha-1} e^{-x/\beta} dx = \frac{1}{T(a)} \int_0^x t^{a-1} e^{-1} dt \qquad [5]$$

The values that result from this function are adjusted to the inverse of the normal distribution with zero mean and standard deviation equal to one. Thus, this standardized normal distribution results in the SPI values, which can be represented by the equation [5]. After this step, we evaluate the frequency, intensity, and duration of drought, through the equations of [6], [7], and [8], respectively. For this, it was considered the beginning of the drought when the SPI-12 reached a value equal or less than -1 for two consecutive months (Haile *et al.*, 2020).

$$F = \frac{n_m}{N_m} X100 \qquad [6]$$

$$I = \left| \frac{1}{n} \sum_{i=1}^{n} SPI_i \right| \qquad [7]$$

$$D = \frac{\sum_{i=1}^{n} d_i}{n} \qquad [8]$$

Where F - frequency of drought, n_m – number of months of drought, N_m – total number of months, n - number of occurrencesn_m of drought with SPI <= -1, D- Duration of drought, d - duration of all drought events.

2.2.2. Integrated Drought Index (IDI)

After calculating the SPI indices and obtaining the VHI data (Kogan, 1995), both were combined to estimate the IDI. VHI is a combination of vegetation condition (VCI) obtained by the NDVI difference by its minimum and maximum values during the analyzed period and the Temperature Condition Index (TCI), obtained by the difference in brightness temperature and its minimum and maximum values. These maximum and minimum values, are related to the weekly VCI and TCI time series from 1986 to 2021 and are standardized for each pixel, available on the website: www.star.nesdis. noaa.gov.

Although SPI is recommended due to its simplicity and multiscale characteristic in quantifying humidity and abnormal dryness, negative SPI does not always correspond to the reality of drought. This is because it does not consider the impact of water deficit on vegetation. On the other hand, VHI typically presents a much more general picture of the impact drought and can even capture space details for monitoring and identifying drought-affected areas. Thus, we generate the IDI from combining these two indices. The methodology is detailed in Cunha *et al.* (2019), the VHI data were made to evaluate the most critical years (1989/1990, 1994/95, 2014/15, 2018/19) of drought, for November, December, January, February, March, April (NDJFMA) and combined with the different SPI scales for the IDI generation. The IDI was calculated considering the time scales of 3, 6 and 12 months, and used to evaluate drought trends. In addition, IDI was used to categorize the most critical drought events in Angola. The drought categories estimated in SPI, VHI and IDI are duly detailed in table 1. During the most critical years of drought, a monthly minimum map was constructed to identify drought-affected areas in the category of severe to exceptional with IDI on the 12-month scale.

Table 1: Representation of SPI, VHI, IDI and drought classification values by category (Cunha et al., 2019).

SPI	**VHI**	**Drought Classification**	IDI
>0,5	>40	Normal	Normal
-0.5 a -0.8	30 a 40	Abnormally Drought	Weak drought
-0.8 a -1.3	20 a 30	Moderate drought	Moderate Drought
-1.3 a -1.6	12 a 20	Severe Drought	Moderate Drought
-1.6 a -2.0	6 a 12	Extreme Drought	Weak Drought
<-2.0	<6	Exceptional Drought	Exceptional Drought

2.2.3. Mann-Kendall Trend Test

The trend of rainfall anomalies is evaluated using the Mann-Kendall test to identify an increase or decrease in rainfall. Thus, we filter only the negative anomalies of the rainfall evaluation.

According to Kendall (1948), the test is calculated using the following equations:

$$S = \sum_{I=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_i - y_i) \qquad [8]$$

where n is the number of data points, xi and xj are the data of the values in time series i and j (j> i), respectively. After some mathematical procedures, the expression that shows the statistics of the Mann - Kendall test (Z) is obtained:

$$z = \begin{cases} \frac{S-1}{\sqrt{\partial^2 S}} & se\ S > 0 \\ 0, & se\ S = 0 \\ \frac{S+1}{\sqrt{\partial^2 S}}, & se\ S < 0 \end{cases} \qquad [9]$$

Positive Z values indicate increasing trends, while negative Z shows decreasing trends. The trend test is done at a specific significance α level. In this study, the significance level α = 0.05, at the significance level of 5%, the null hypothesis of no trend is rejected if | Z | > 1.96.

2.2.4. Ocean-atmospheric index analysis

SST based ocean-atmospheric indices were used to evaluate the correlation between rainfall patterns and the drought years. In this study, we considered the Tropical Northern Atlantic Index (TNA), an indicator of surface temperatures in the eastern North Atlantic Ocean, and the Tropical Southern Atlantic Index (TSA), an indicator of surface temperatures in the western South Atlantic Ocean (https://psl.noaa.gov/data/climateindices/list/).

3 RESULTS

3.1 Temporal characterization of drought during the period from 1984 to 2020

This section presents the main drought events in South, North, and Central Angola from 1984 to 2020, totaling 36 years of analysis. These events are identified through the SPI evaluated on the 12-month scale. The results show that the main drought events in the South region occurred in 1985/1986, 1987/1988, 1989/1990, 1991/1992,1992/1997,2002/2003, 2005/2006, 2012/2014, 2014/2016, 2017/2018 and 2019/2020. The events in this region varied their intensity from weak to exceptional drought and duration of 11 to 83 months (table 2 and Fig.2). Thus, the most intense events occurred in 2014/2016 and 2019/2020. In those years, the El Niño event with the intensity very strong (VS**) to weak (W**) predominated, respectively (table 1). The longest-running event in 1992/1997 and 2014/2015, where SPI negative values persisted from 22 to 83 consecutive months, respectively, in both years, was also a strong El Niño event. According to Preethi et al. (2015), the occurrence of El-Niño events has a substantial impact on the rainfall regime in Angola, increasing rainfall in the north of the country and Decreases in much of the South.

In the Central region, drought intensity ranged from weak to severe, and drought occurrence was recorded in 24 years (1985/1986, 1987/1988, 1989/1990, 1992/1993, 1994/1997, 2000/2001, 2005/2006, 2007/2008, 2012/2013, 2014/2016, 2017, 2019/2020). The most prolonged duration was 46 months, observed in 1994/1997 and 22 months in 2000/2001. In terms of intensity, the years 1994/1997 and 2014/2016 showed higher intensity in the severe drought category (Fig.2 and Table 2). In addition, the intensity ranged from weak to moderate drought lasting between 4 and 17 months. In the Central region, most years with the occurrence of drought were associated with the El-Niño and La-Niña events varying their intensity from weak, moderate and strong, except in 1992/93, 2017, 2019/2020.

In the North, the intensity also varied from weak to severe, and events took place in 1984/1985, 1992, 1993/1994, 1996/1997, 2000/2002, 2003/2005, 2006, 2012/2013, 2014/2015, 2016/2018, 2020. The maximum intensity was observed in the events that occurred in 1984/1985 and 1993/1994, lasting 16 and 12 months, respectively. However, in this region, the most prolonged event occurred in 2003/2005. In general, except the event that occurred in 1992/1993, most of the events in the Central region occurred in periods that predominated the occurrence of La Niña and El Niño events, varying their intensity from weak to strong (table

1). However, for the central region, events are mostly associated with La Niña events than El Niño.

Figure 2: Temporal representation of drought through the SPI-12 in the South(a), Center(b) and North(c) regions.

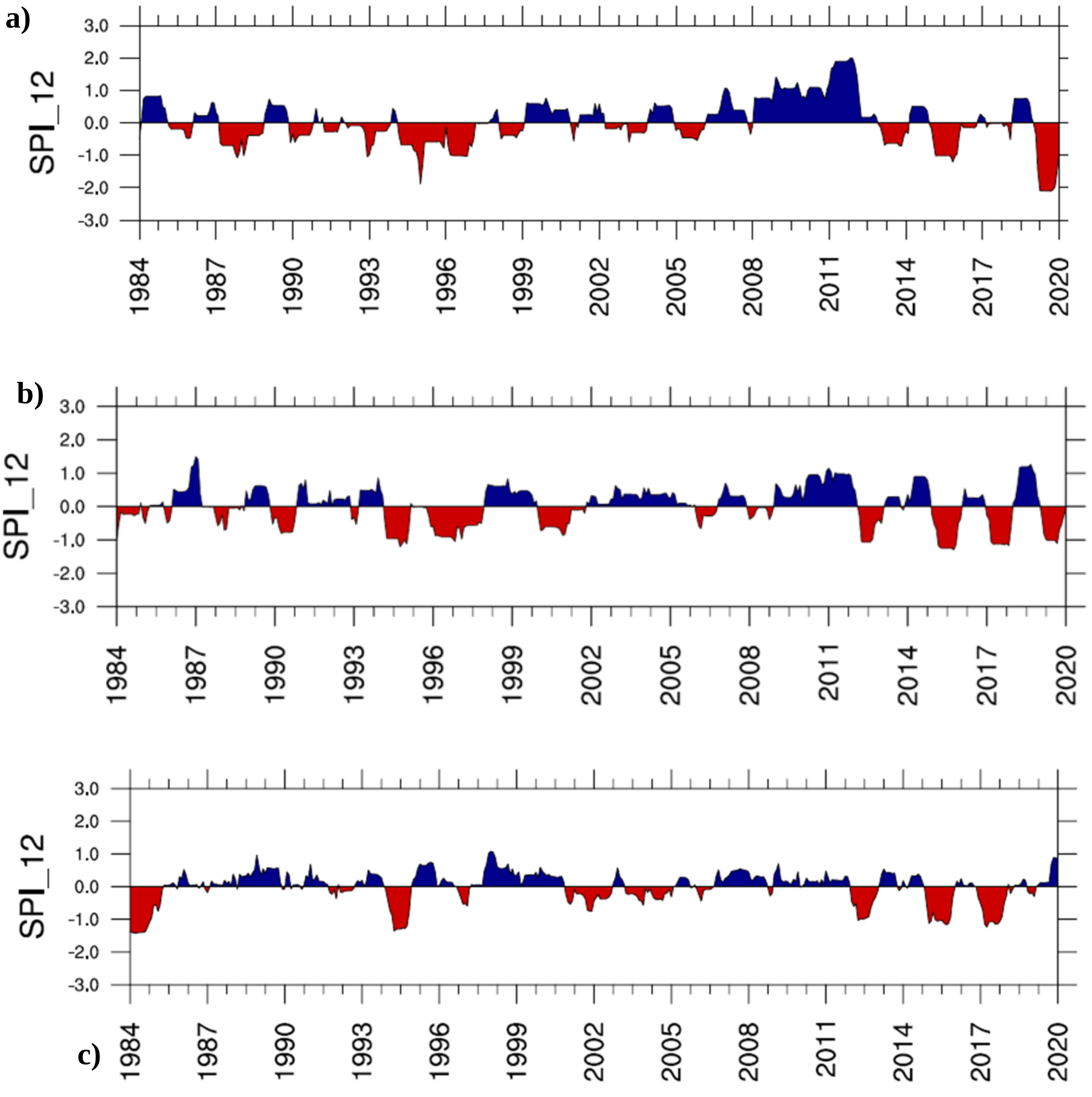


Table 2: Duration and intensity of drought in the South, Center (, and North. (**)- El Niño, (*) La Niña, (W)-Weak, M-Moderate, S-Strong, VS-Very Strong.

SOUTH		
Year	Duration (months)	Intensity (SPI_12)
1985/1986 (S*)	12	Moderate Drought
1987/1988 (S*)	20	Moderate Drought
1989/1990	11	Weak Drought
1991/1992	9	Weak Drought
1992/1997 (M, S**, VS**)**	83	Extreme Drought
2002/2003 (M)**	20	Weak Drought
2005/2006	13	Weak Drought
2012/2014 (W)**	14	Weak Drought
2014/2016 (VS)**	22	Weak Drought
2017/2018 (W*)	11	Weak Drought
2019/2020 (W)**	13	Exceptional Drought
CENTER		
Year	Duration (months)	Intensity (SPI_12)
1985/1986 (W*)	4	Weak Drought
1987/1988 (S)**	17	Moderate Drought
1989/1990 (S*)	10	Moderate Drought
1992/1993	4	Weak Drought
1994/1997 (M*, M)**	46	Severe Drought
2000/2001 (W*)	22	Moderate Drought
2005/2006 (W*)	12	Weak Drought
2007/2008 (S*)	13	Weak Drought
2012/2013 (M*)	12	Moderate Drought
2014/2016 (W)**	13	Severe Drought
2017	11	Moderate Drought
2019/2020	11	Moderate Drought
NORTH		
Year	Duration (months)	Intensity (SPI_12)
1984/1985 (W*)	16	Extreme Drought
1992 (S)**	7	Weak Drought
1993/1994	12	Severe Drought
1996/1997 (M*)	6	Weak Drought
2000/2002 (M)**	22	Moderate Drought
2003/2005 (W)**	23	Weak Drought
2006 (W)**	7	Weak Drought
2012/2013 (M*)	13	Moderate Drought
2014/2015 (W)**	14	Moderate Drought
2016/2018 (W*)	14	Moderate Drought
2020 (M*)	3	Weak Drought

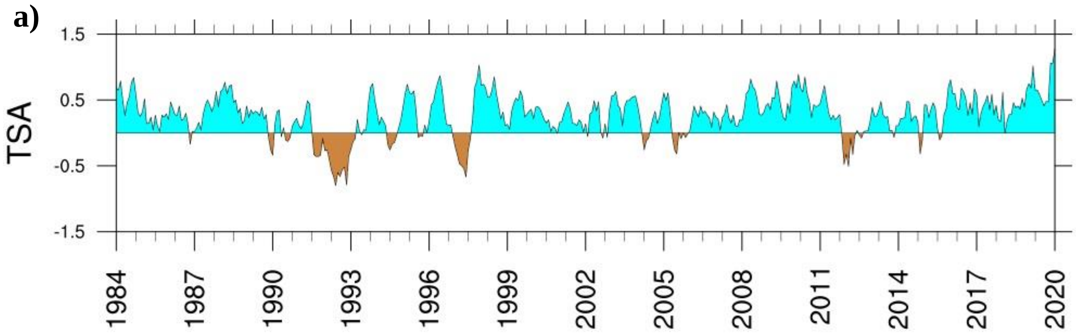
In the dry years that occurred in the North region, it was observed that the drought events with the highest intensity (1985/1986, 1993/1994, 2012/2014, 2014/2016 and 2019/2020) occurred when SST in the Atlantic Ocean was hot. However, some events also occurred with anomalously cold SST (Fig.3a, Fig3b).

In the Central region, it is observed that during the events of 1992/93, 2017, 2019/2020 (no occurrence of El Niño and La Niña), an anomalous cooling of SST in the South Atlantic, which may have contributed to rainfall deficit and triggered in drought events (Fig 3a).

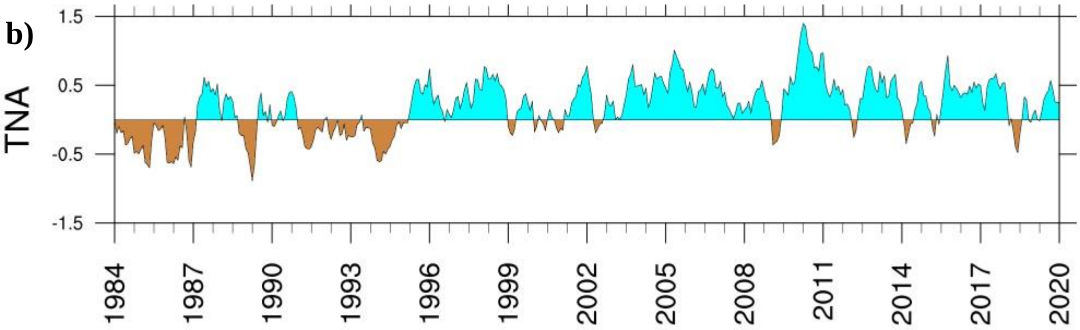
In the South region, most of the events were also associated with cooling waters of the South Atlantic (Fig.3a). In the Center, most of the events occurred when in the North Atlantic there were negative anomalies of SST (Fig 3b). So, according to the most recent studies of Kim *et al.* (2021), Xavier (2013), Giannini (2010) and Li, Y. *et al.* (2021) the cooling waters in South and North Atlantic change rainfall distribution in Angola. Thus, cooling in the South Atlantic is associated with decreased rainfall on much of country's coast. Concerning the North Atlantic, when the SST is anomalously cold, the rainfall decreased in some provinces of the Center, such as Cunene, Cuando Cubango and some parts of Moxico. However, as long as SST in the North Atlantic is anomalously hot, there is rainfall deficit in much of the North and South region, mainly in the provinces of Malanje, Uíge, Zaire, Huíla, Cuanza Sul, Bengo and in the north of Luanda.

Figure 3: SST anomalies in the South Atlantic (TSA, (a)) and North (TNA,(b)) in the years of drought.

a)



b)



3.2 Spatial Analysis of Intensity and Frequency

Figures 4 and 5 show the intensity and Frequency drought events identified by the SPI-12 for the north, central and south regions. In the Northern region, the provinces of Malange, north of Lunda Norte and Lunda Sul, presented maximum drought intensity, the provinces located in the east and west of the region presented lower intensity events. The maximum intensity in these provinces may be related to variations in SST in the South and North Atlantic oceans.

In the Central region, most provinces had intense drought events, mainly in the north-central region of Huambo, Bié and in the west of Moxico (Fig.4a and Fig4b). However, the less intense events in these provinces are located between the north-northeast parts. as expected, in the Southern region, the events with greater intensity occur in much of the province of Cunene, Cuando Cubango, and in the extreme southwest of Huíla. According to Diogo (2020), this region has the smallest rainfall season and the shortest period of return of rainfall, in addition to the strong influence on the variations in SST of the North and South Atlantic, which considerably alter the rainfall regime (Kim *et al.*, 2021).

Figure 4: a) representation areas in Angola (North, Central and South), b) Spatial representation of drought intensity based on SPI-12, in the North, Central, South of Angola, for 1984-2020, respectively. SPI-12 values lower than -1 were considered.

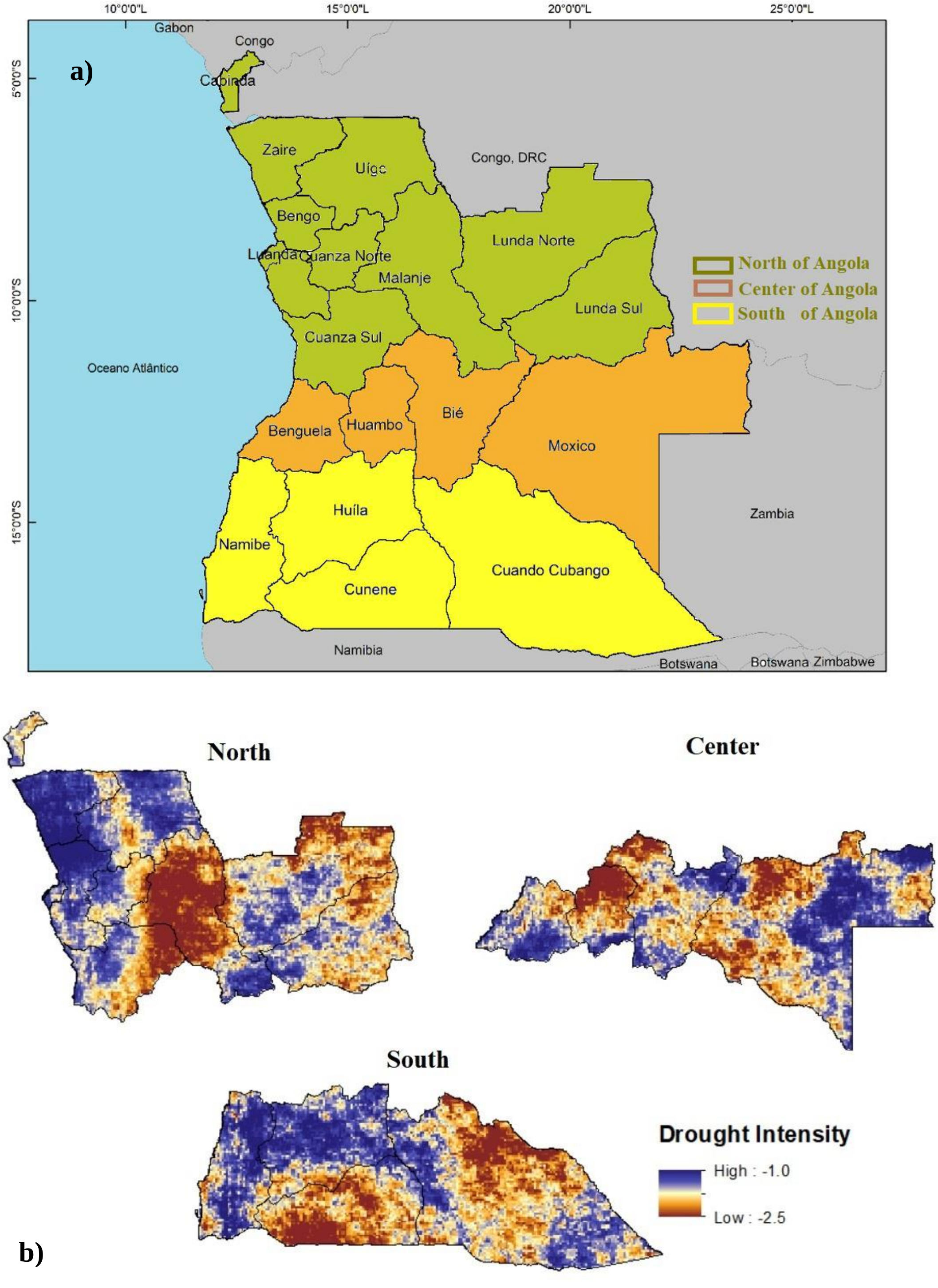
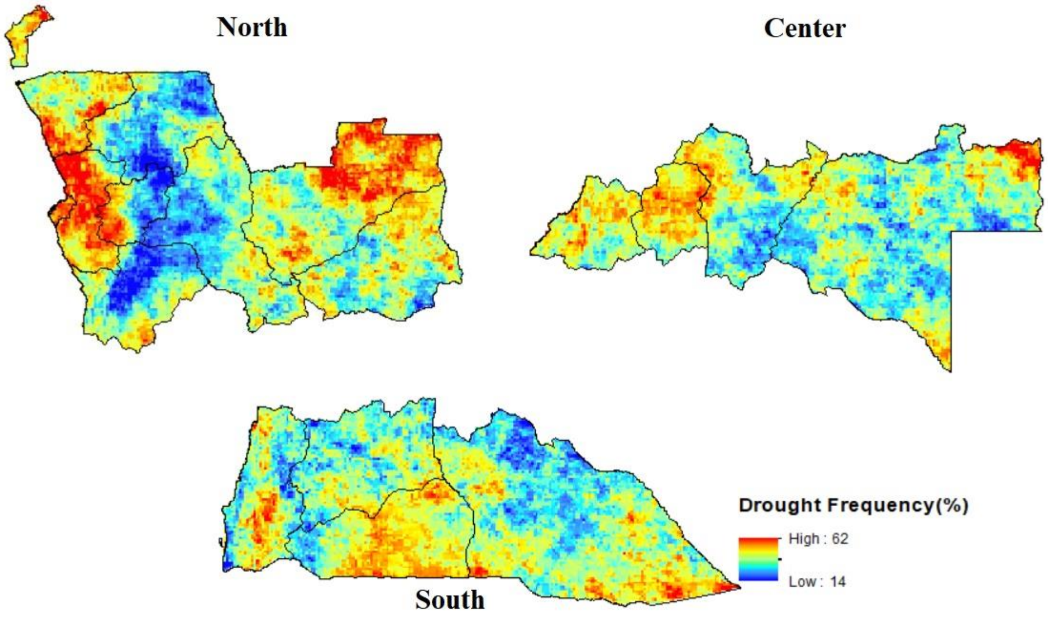

a)
10°0'0"L
15°0'0"L
20°0'0"L
25°0'0"L
5°0'0"S
10°0'0"S
15°0'0"S
Gabon
Congo
Cabinda
Zaire
Uíge
Congo, DRC
Bengo
Luanda
Cuanza Norte
Malanje
Lunda Norte
Lunda Sul
Cuanza Sul
Oceano Atlântico
Benguela
Huambo
Bié
Moxico
Huíla
Namibe
Cunene
Cuando Cubango
Zambia
Namibia
Botswana
Botswana Zimbabwe
North of Angola
Center of Angola
South of Angola
North
Center
South
Drought Intensity
High : -1.0
Low : -2.5
b)

Figure 5 shows the frequency of droughts in all regions of Angola. In the Northern region, the provinces near the coast and part of the northeast have a high frequency of drought events (62%). Among these provinces, high frequencies occurred in Luanda, Bengo, northern Luanda Norte, Zaire, and northeastern Lunda Sul. However, the lowest frequencies occurred in Malanje, north of Cuanza Norte and Uíge. In the Center and South, the provinces of Huambo, Bié, west, and east of Moxico, much of Cunene and Cuando Cubango, have a high frequency of drought (30 to 62 %).

Figure 5: Spatial representation of the frequency of drought in the North, Center and South, for the period 1984-2020, respectively. These areas represent the division of Angola by region as shown in Fig.4a



3.3 Weather conditions associated with drought events

In this section, we evaluated the fields of rainfall anomalies and humidity transport (Fig6a, 6b, Fig7a, 7b, 7c and 7d) for the period from November to April for 1989/90, 1994/95, 2014/2015, 2018/2019. These years were considered more critical in terms of the impact on the population (Mateus and António, 2020; VOA, 2020; DW, 2021; DW,2019a, 2019b). During November and December in 1989, negative anomalies were observed around -0.2 to -1.8 mm/day in much of the Southern region and part of the center of the country, indicating a situation of rainfall deficit in the region. In January and February of 1990, the negative anomalies of rainfall (mm/day) are concentrated in the coastal part of the country (Fig. 6a), characterizing a situation of absence of rainfall.

In March of 1990, there was a period of return rainfall, characterizing the beginning of the rainfall season. However, negative rainfall anomalies arose again in April 1990, covering parts of the North, Central and South of the country. Thus, most negative rainfall anomalies around -0.2 to 1.8 were observed in the same regions, where the drought was comprehensive during 1989/1990 (Fig. 9).

In 1994/95, positive rainfall anomalies were observed in most North and Central regions. However, from November to January, a continuous period of negative anomalies persists in the eastern part of the Southern region, where the drought condition was verified during the analysis period. However, in February 1995, positive anomalies were established in most parts of the country; in March and April, there were negative rainfall anomalies in the south of Moxico province, where the drought was severe, as shown in Fig. 10.

In 2014/2015, negative rainfall anomalies were established on most of the country's western, northern and southern flanks. In these years, the drought was more intense in the provinces located in the North, where consequently negative rainfall anomalies are observed, indicating a situation of water stress. From November 2018, negative anomalies were more significant in most of the south of the country, becoming more critical in April 2019, reaching much of the center of the country. In these same regions, drought conditions ranging from moderate to exceptional were observed. These storm anomalies were associated with an anticyclonic anomaly installed in the region during the dry periods (Mateus and António, 2020). In addition, there was a La Niña event in these years, which may be associated with the induction of the anticyclonic anomaly (see following paragraphs and Fig. 6b). Thus, during the years analyzed, the beginning of the rainfall y season was interrupted in much of the Southern region and parts of the coast of the country. For example, in 1989/90, negative rainfall anomalies persisted from November to January, interrupting the start of the rainfall season in much of Bié province, southern Moxico, Cuando Cubango, Cunene, Huíla, Huambo and Cuanza Sul, as well the other years analyzed

Fig.6a: rainfall anomalies (mm/day) for November(a,g), December(b,h), January(c,i), February(d,j), March(e,k), and April (f,m) for 1989/1990/ and 1994/1995, respectively.

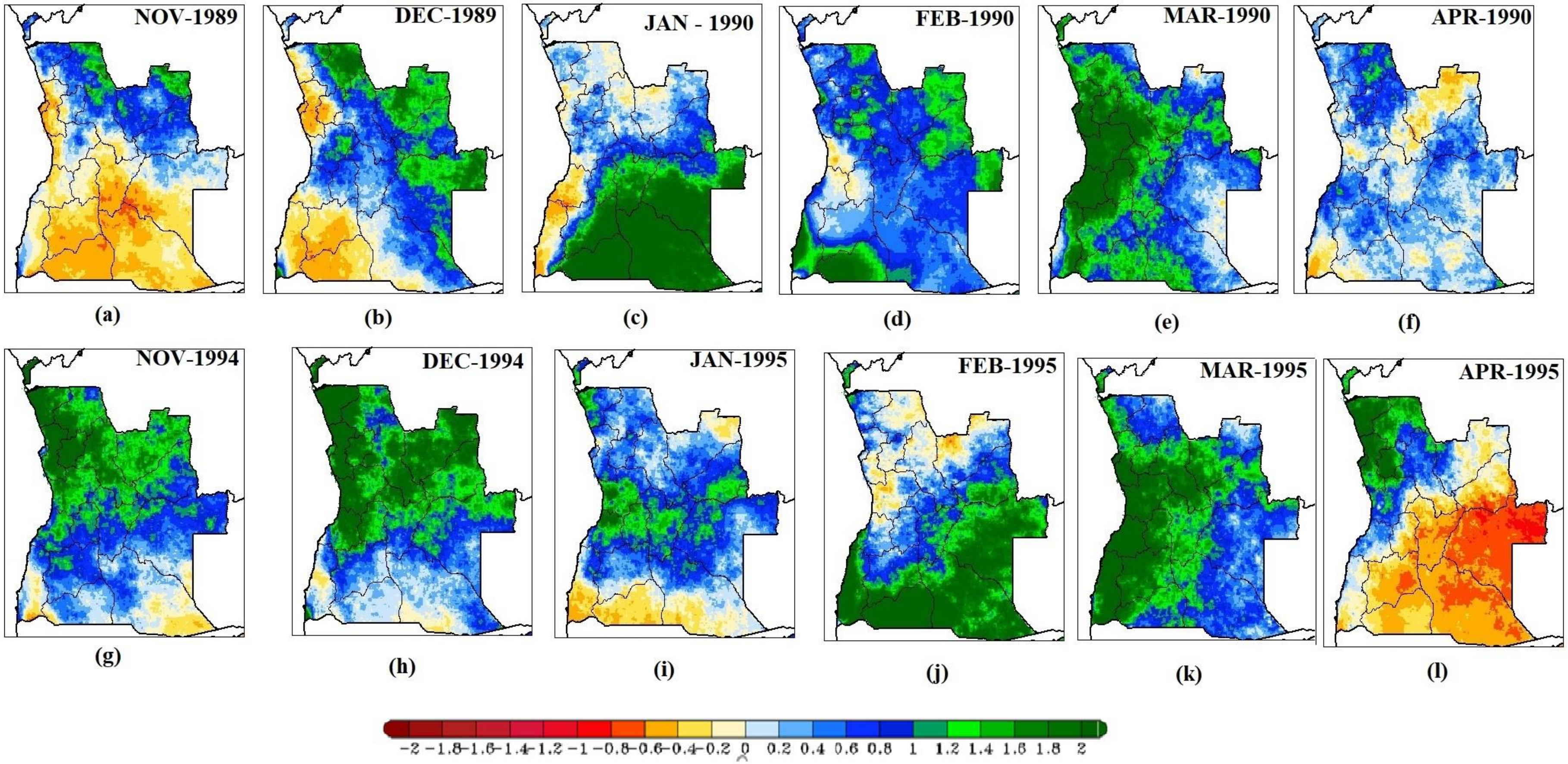


Fig.6b: rainfall anomalies (mm/day) for November(a,g), December(b,h), January(c,i), February(d,j), March(e,k), and April (f,m) for 2014/2015 and 2018/2019, respectively.

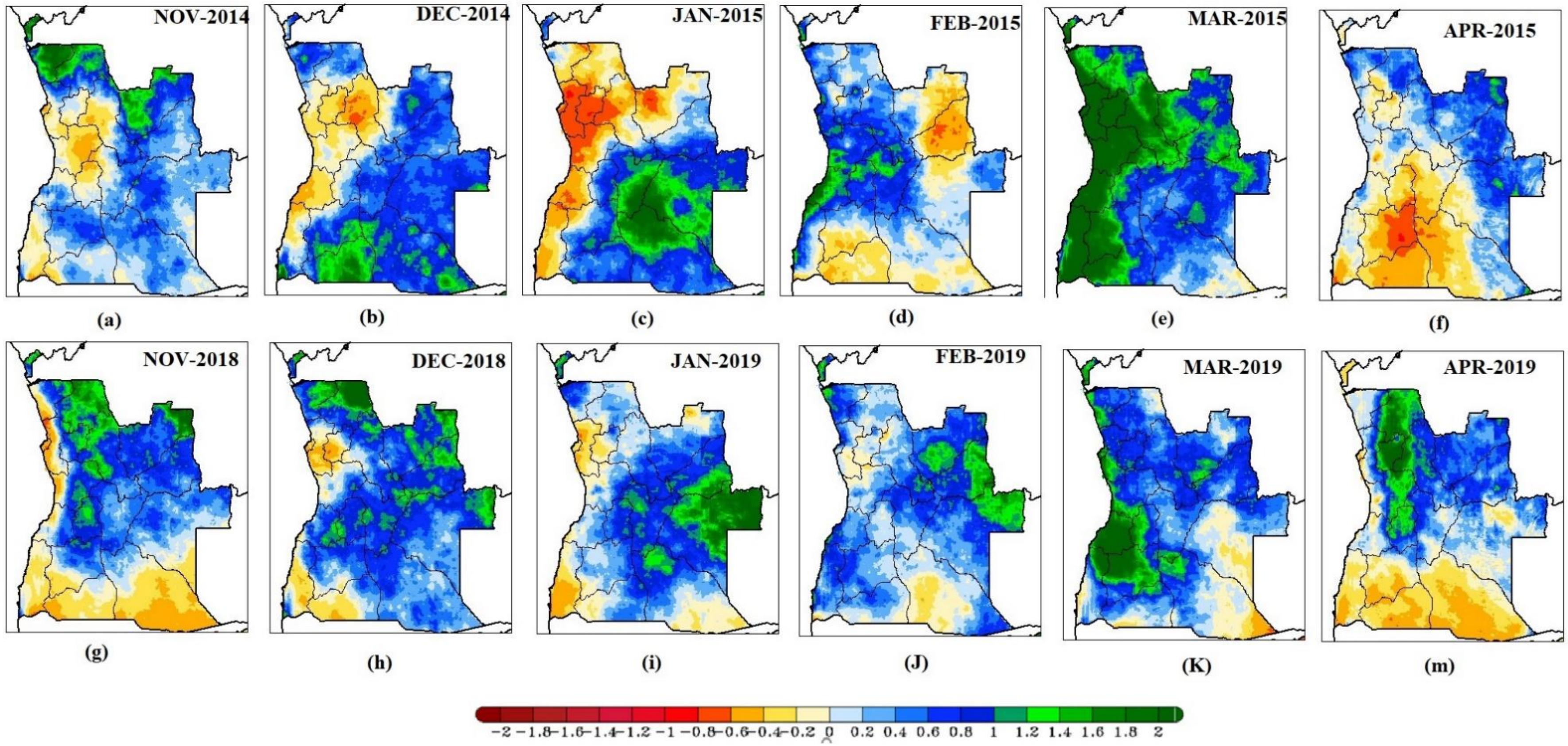


Figure 7 shows vertically integrated moisture fields at levels 1000-300 hPa (colour) and wind anomalies at 850 hPa (arrows). During the drought years, there is a predominance of two centers anticyclonic anomalies, one located in the ocean near the latitude of 5°S and the other located in the Congo basin, at latitude of 15°S, nearby acts a cyclonic anomaly, together configuring a situation of atmosphere blocking. This wide configuration makes circulation to show a more zonal characteristic in much of the country, which does not represent the typical pattern of circulation during a normal summer season. Thus, in summer, most of the transport of moisture arriving in the country is characterized by ITCZ, the low pressure of Angola and the Congo Air Convergence Zone (CACZ). Therefore, the circulation associated with these systems is mainly responsible for the contribution of moisture over the country (Xavier, 2013)

This broad approach allows us to infer that during the dry years, the predominance of these high-pressure anomalies, caused changes in circulation, making it difficult for the moisture transport to reach much of Angola. In other tropical regions, such as the Brazilian Pantanal or Amazonia, low moisture transport contributes to a late onset of the rainfall season and a weak summer rainfall, that can trigger drought under a warm and dry atmosphere during the drought of 2019-20 in these regions (Marengo *et al.*, 2021) or during the drought of Sao Paulo in 2013-14 (Nobre *et al.*, 2016). Back to Angola, there are significant similarities in circulation during 1989/90, 1994/95 and 2014/15. In these years, an anomalous anticyclonic circulation has been observed in the Congo and near the Gulf of Guinea, and a low performance in southwestern Angola (Fig 7).

The configuration of the systems mentioned above in the circulation fields modifies the flow in a more zonal way, something similar to circulation in the dry winter (Diogo, 2020; Mateus and António, 2020). In these years, the severity of the drought was higher in the West, North and South regions of the country, where there was a weakening of moisture transport. However, in 2018/2019, high anticyclonic anomaly still affects the region between Congo and Zambia and a low-pressure anomaly operates near the northwest of the country, favoring increased moisture transport. Therefore, this characteristic was only verified during the summer of 2018/2019 when the drought severity was higher in the South, east of the Central region and weak in the West (Fig.12a, 12b and 12c).

Fig.7: 1.000–300 hPa vertically integrated moisture transport (color, ms^-1.kg^-1) and 850 hPa winds (arrows, m/s) for the NDJFMA months 1989 / 90(a), 1994 / 95(b), 2014 / 15(c) and 2018/19(d)

a) **c)**

b)

3.4 Correlation of ocean-atmospheric indices with rainfall in drought years

This section explores the physical mechanisms behind the drought events of 1989/90, 1994/95, 2014/15 and 2018/2019. These evaluations are made through Pearson's spatial correlation between rainfall and TSA and TNA climate indices. These indices were chosen because previous studies showed relationships between rainfall and SST anomalies in the Atlantic Ocean (Xavier, 2013; Karpouzoglou and Barron, 2014; Moura and Aimola, 2019; Kim *et al.*, 2021). Therefore, other indices such as Southern Oscillation Index (SOI), Pacific Decadal Oscillation (PDO) and Atlantic multidecadal Oscillation (AMO) were tested but did not present such expressive correlation; some showed a good correlation, however, distant from the regions where drought was observed spatially.

The results of the correlation analysis are shown in Fig. 8, for 1989/90, in which the drought covered most of the west, center and some parts of the east (Fig.9a, 9b and 9c). These regions have a positive correlation between the TSA index and rainfall in much of the country's coastal strip and a negative correlation in parts of the Central East. The correlation was significant and positive at the level of 95% (dotted regions) in the provinces of Cabinda, Moxico, Zaire, Uíge, Luanda, Bengo, Malanje, Cuanza Norte, Benguela and northeast Huila. This result suggests that variations in the SST are directly related to rainfall on the west coast of the country and the relationship is noisy in parts of the Center and East (MOURA and AIMOA, 2019). That is, when the SST cools in the South Atlantic Ocean, the rainfall has decreased much of the West Coast, and in parts of the Central and Eastern region, the opposite happens. If the waters of the South Atlantic are warm, the retracted regions will show increased rainfall.

During 1994/95, the correlation was negative and significant between the TNA index and the rainfall, showing that the drought was mostly related to SST variations in the North Atlantic Ocean. The provinces most affected were Moxico, Lunda Norte and Lunda Sul, Bié and Huambo, where consequently the severity of the drought was higher, indicating that the colling SST in the North Atlantic is related to the decrease rainfall in much of the Center of Angola. However, in 2014/15, the TSA index showed a negative correlation in the north of Zaíre, north of Uíge and Lunda Norte, indicating that rainfall deficit in these regions, was associated with increased SST in the South Atlantic (Fig 8).

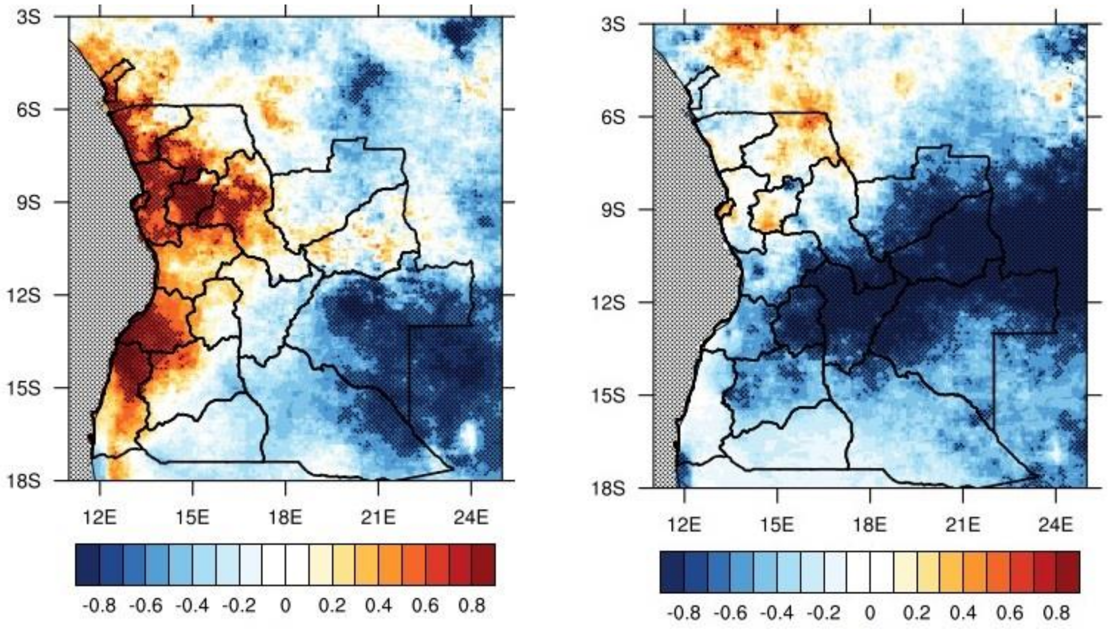
The strong intensity of the drought that occurred in Moxico (2018/2019) was not explained by the year of the TSA. Thus, although the negative values of the TSA consider with some drought events, this does not mean that all drought events that occur in Angola are necessarily correlated with the TSA. According to Aja *et al.* (2017), the drought that occurred during this year in some regions of the center Angola, were related to an El Niño event.

In 2018/2019, the correlation with TNA showed two patterns, one with a negative correlation pattern in northern and western parts of the country and another with positive correlation in much of the Eastern sector and parts of southern Angola, with statistical significance in most regions where the drought occurred. Thus, the rainfall deficit observed in Malanje, Uíge, western Zaire and north of Lunda Norte, was related to the increase in SST in the South Atlantic. Moreover, in the provinces of Moxico, south of

Lunda Norte, in Lunda Sul, north of Bié, south of Malanje, Cunene and much of Moxico, the decrease in rainfall was associated with the cooling of the SST of the South Atlantic.

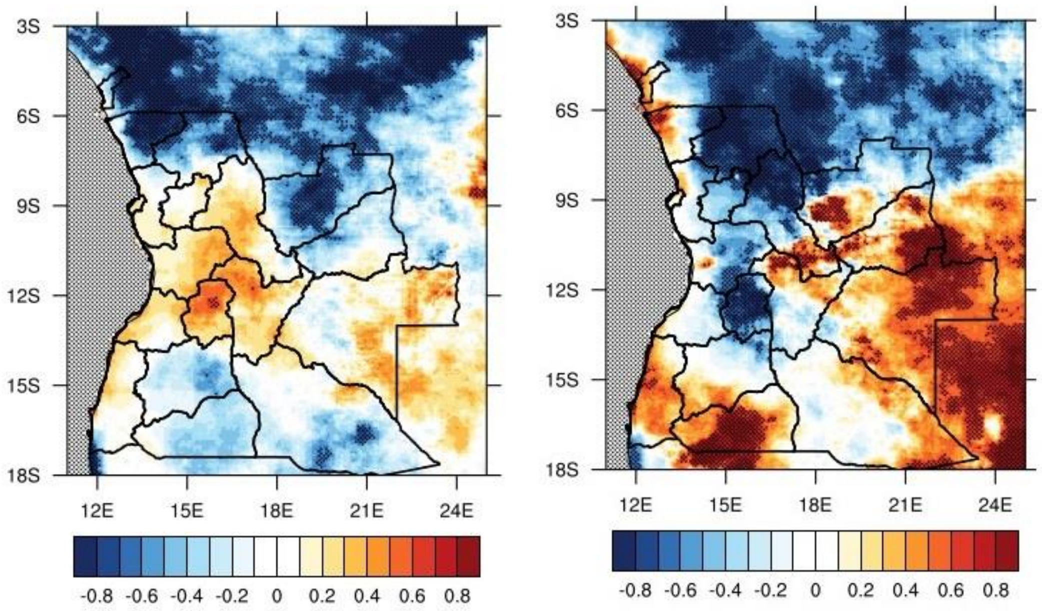
The results indicate that most drought events in Angola showed strong correlations with the TSA and TNA indices, which indicates that SST variations in the North and South Atlantic oceans strongly influence the occurrence of drought events in the country. The variations in the tropical Atlantic play a key role in the rainfall regime in much of Angola. In addition, the variations in the SST, influence the migration of the ITCZ, responsible for distribution of rainfall in the North and Center of country. This confirms previous studied by Moura and Aimola (2019), Funk *et al.* (2018), and Xavier (2013).

Fig.8: Correlation between a) TSA (1989/90), b) TNA (1994/95), c) TSA (2014/15), d) TNA (2018/19) and rainfall for NDJFMA, for the respective years. The dotted regions are those showing 95% of significance.



a)

b)



b)

c)

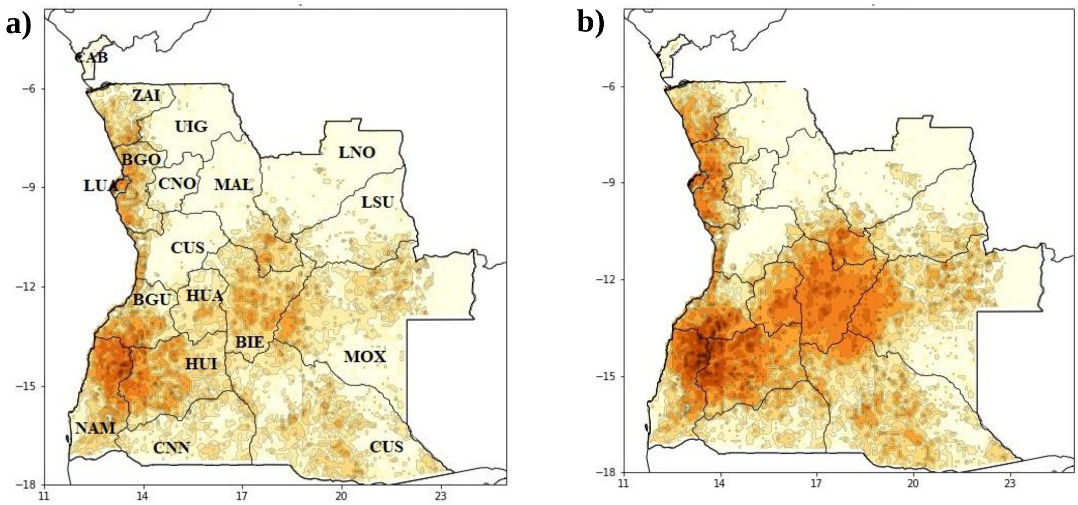
3.5 Spatial evaluation of drought events from IDI

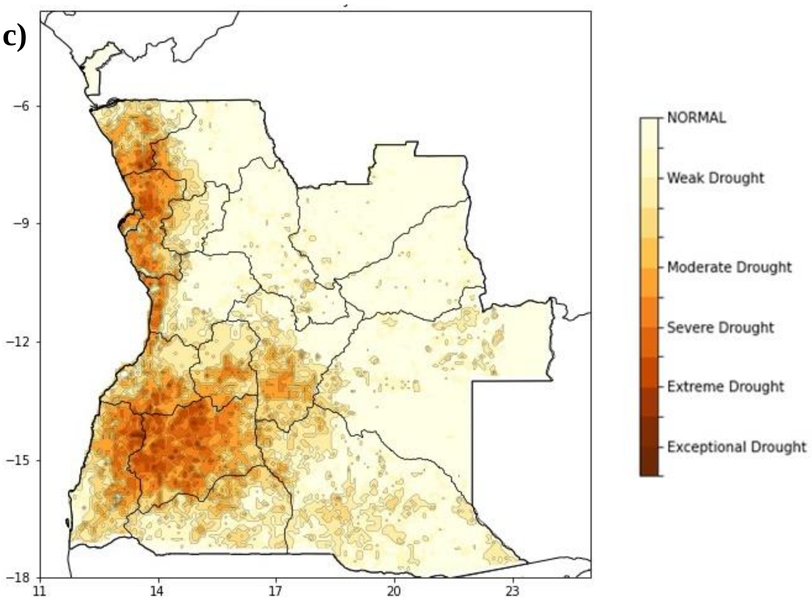
This section introduces the spatial variation of the main drought events that occurred in 1989/90, 1994/95, 2014/15, and 2018/19. All these events were evaluated through the IDI on the 03 (IDI-3), 06 (IDI-6), and 12 (IDI-12) months scales. Figure 9 shows the drought condition (1989/1990) in the analysis of IDI-3 and IDI-6 has great application to respond to short-term changes in soil moisture and agriculture.

The provinces affected with the category of severe to exceptional drought in 1989/1990 were the provinces of Zaire (ZAI), Uíge (UIG), Bengo(BGO), Luanda (LSU), Cuanza Norte (CNO), Cuanz Sul (CUS), Benguela (BGU), Namibe (NAM), Huíla (HUI), Huambo (HUA), Bié(BIE) and Cunene(CUN) as shown Fig.9a, 9b, 9c and Table 3. These affected provinces embrace an area of 111,718, 60 kilometres squared, equivalent to 8.95 % of the country's territorial extension (Table 3). Thus, most of the provinces affected by severe and exceptional droughts, such as Uíge, Bengo, Cuanza Sul, Cuanza Norte, Huíla, Huambo and Benguela, are the ones that produce the most coffee in the country. According the survey made by the consulate general of the port (CGP,1992), between 1989/1990, there was a decrease in agricultural production of 3%, affecting the food acquisition by the population. At that time, agricultural areas were limited due to the planting of mines placed in the soil during the war, making rural agriculture even more difficult almost national territory (CGP, 1992).

On the 12-month scale (IDI-12), drought severity decreases in almost all country regions, although exceptional extreme drought conditions are still observed in the provinces listed in Table 3. This condition may be associated with the period of return of rainfall as observed in Fig 6. However, it is important to remember that much of the western province of Namibe, which is a desert, can interfere in the realistic representation of drought intensity for this region; this line of reasoning should follow the other analyses later.

Fig. 9: Spatial evaluation of drought (1989/90) for IDI_03 (a), IDI_06 (b) and IDI_12 (c). The abbreviations in the figure represent the ISO code of each province. CAB (Cabinda), ZAI (Zaire), UIG(Uíge), BGO(Bengo), LUA(Luanda), CNO (Cuanza Norte), MAL(Malanje), LNO (Lunda Norte), LSU (Lunda Sul), CUS (Cuando Cubango), BGU(Benguela), NAM(Namibe), HUI(Huila), HUA(Huambo), CNN(Cunene), BIE(BIE), CCU (Cuando Cubango), MOX(Moxico).

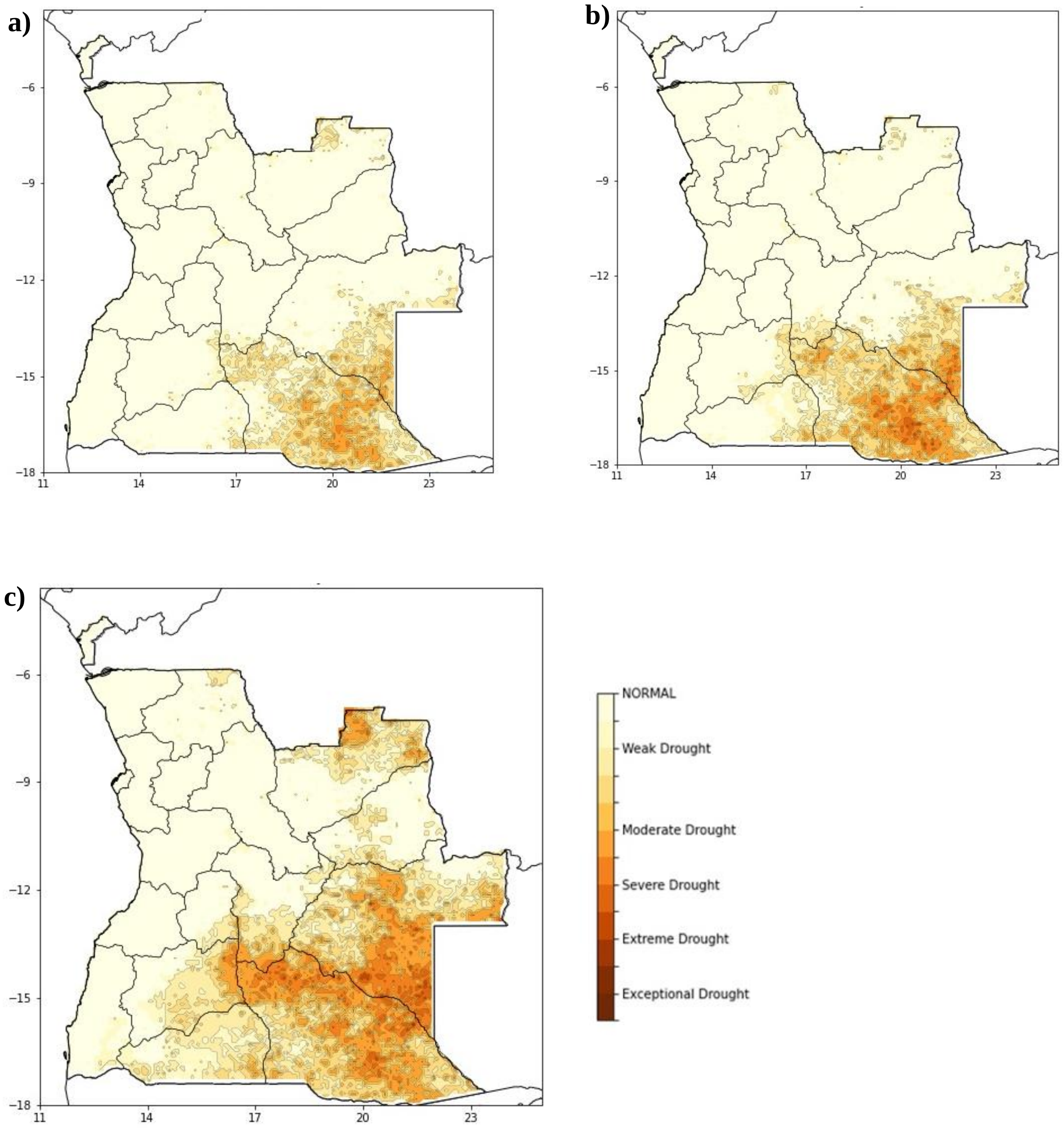




In 1994/1995, the drought hit parts of the southeast and north of Angola on the scales of 03 and 06 months (Fig. 10a, 10b and 10c). On a 12-month scale, the drought has intensified and covered parts of the North and Center of the country. The drought covered an area of 93.712, 663 square kilometers, corresponding to 7.51% of Angola's territorial extension. The affected provinces with the severe to exceptional category were the provinces of Luanda Norte, Moxico, Cuando Cubango, Huíla, Bié (Table 3).

According to an article published by Folha de S.Paulo (1994), during 1994 in Angola, a deficit equivalent to 1.4 million tons of lost food was estimated. In those same years, while the country witnessed a tragic moment of tension in the civil war, the population suffered from hunger and lack of water.

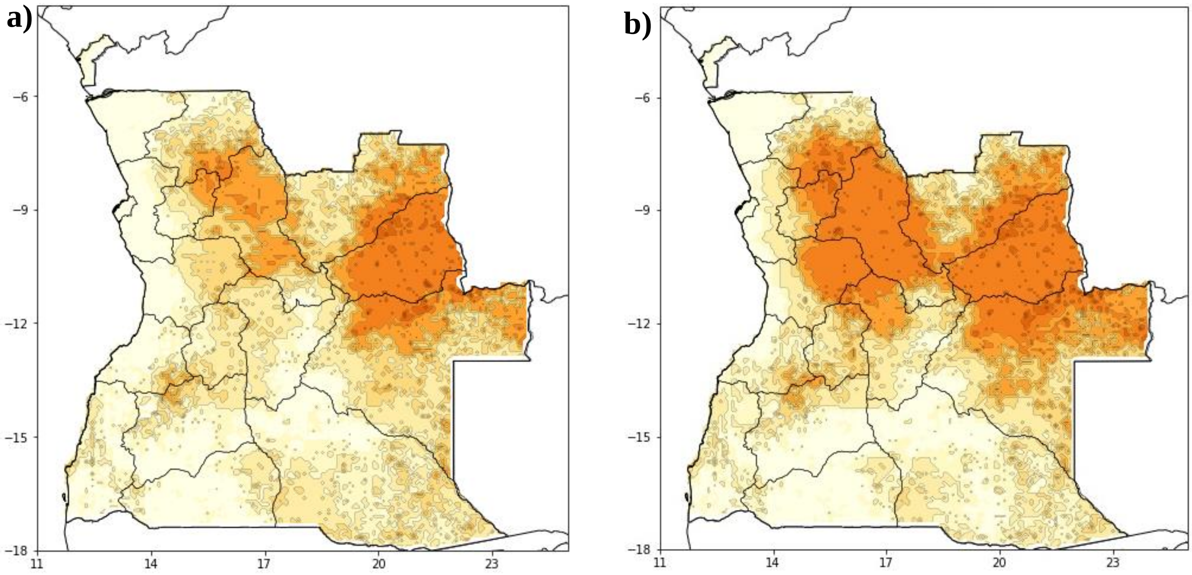
Fig. 10: Same as Fig.9, but for 1994/95.

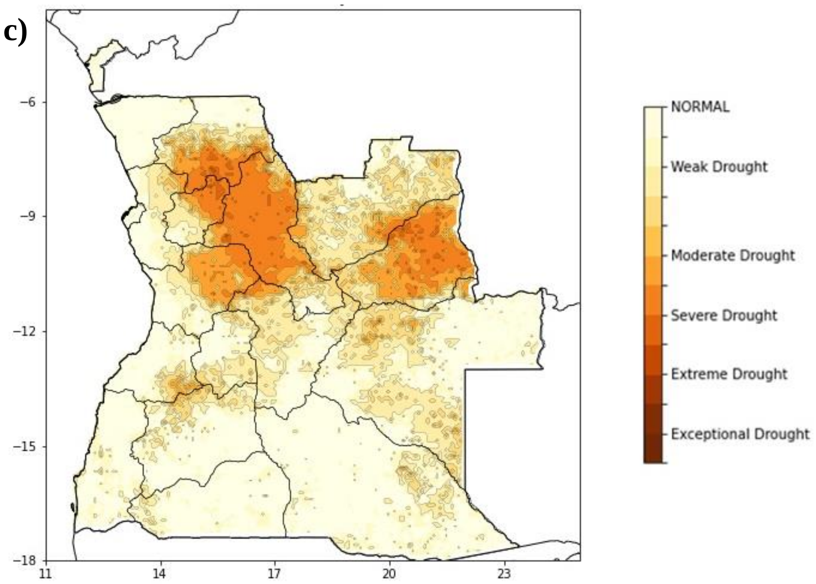


Between 2014/2015 (Fig. 11a,11b,11c), the drought affected a large part of the North region and parts of the central and southern regions, on the scales of 03 (Fig.11a), 06 (Fig.11b) and 12 (Fig.11c) months. In those years, the drought was severe and exceptional in an area equivalent to 120.211,60 square kilometers, approximately 8.63 % of the national territory area (Table 3). The provinces affected in the severe to exceptional category were the provinces of Malanje, Cuanza Sul, Uíge, Bié, Benguela, Lunda Sul, Moxico and Cuanza Norte.

According to a report published by Angola's Civil Defense, the drought impact in some provinces mentioned above (Cuanza Sul, Benguela, Lunda Sul and Bié) significantly contributed to the number of hospitalizations and deaths due to malnutrition in 2014. For example, in the province from Huila and Cunene, there was an increase in cases of malnutrition due to hunger from 1357 to 8092 and 3031 to 6044, respectively. Thus, lower food production and limited access to food negatively influenced food security. On the other hand, food consumption registered a decrease in terms of qualities and quantities (Aja *et al.*, 2017). In addition, in this year (2014/2015) there was an increase in cases of school abandonment, child labor and greater student absenteeism due to the impacts of the drought, directly related to hunger and lack of water. It is estimated that the losses and damages in the agricultural sector, food security, water supply and basic sanitation vary around 297, 2 to 452.4 million dollars (Aja *et al.*, 2017).

Fig. 11: Same as Fig. 9, but for 2014/15.





In 2018/19 (Fig. 12), the drought condition covered a large part of the center, the entire southern region, and parts of the North. On the scales of 03 and 06 months, the intensity of the drought was more expressive from the center to the south of the country. The provinces affected by drought in the severe to exceptional category were the provinces of Namibe, Cunene, Cuando Cubango, Bié, Moxico, Lunda Norte, Lunda Sul, Cuanza Norte, Cuanza Sul, Benguela and Uíge, comprising an area of 58,263, 975 square kilometers, equivalent to 4.67% of the total area of the national territory (Table 3). These provinces constitute one of the main agricultural bases in the country; according to a report by the Food and Agriculture Organization of the United Nations (FAO), the country registered losses in agricultural production in these years, and the cause was directly related to the drought which spanned the country, with 54% of the population living in rural areas and primarily dependent on agriculture (DW, 2019). In Benguela province in 2018/2019, the drought affected around 50 thousand peasant families; there were thousands of hectares of lost crops that left about 500 thousand people without access to food and water (DW, 2021; DW, 2019a; ONU News, 2019; VOA,2020; Novo Jornal, 2019).

Fig. 12: Same as Fig. 9, but for 2018/19

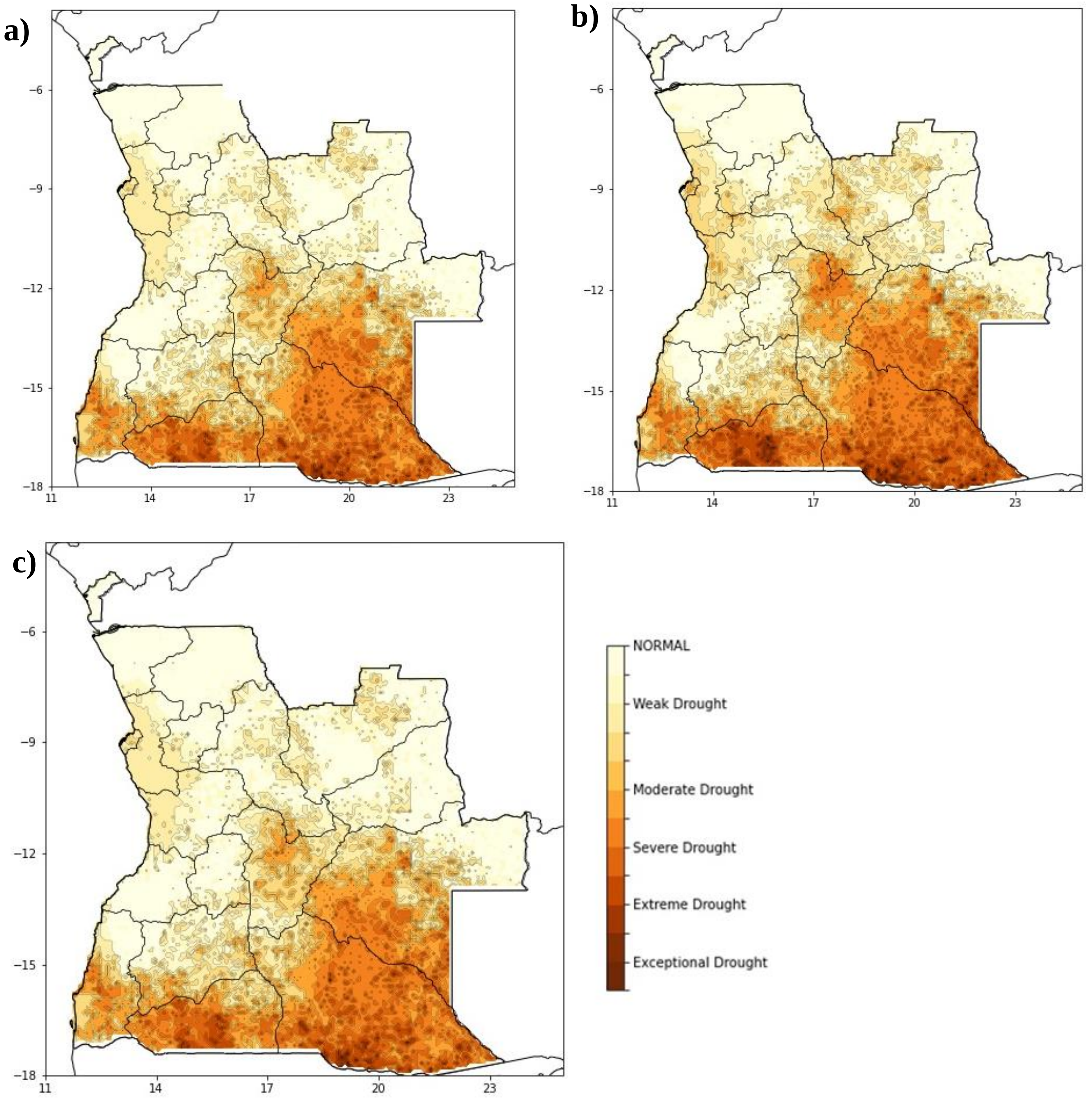


Table 3: Total area in square kilometers and percentage of the affected provinces by drought in the category of severe to exceptional, for the IDI -12 months (1989/1990, 1994/1995,2014/2015 and 2018/2019).

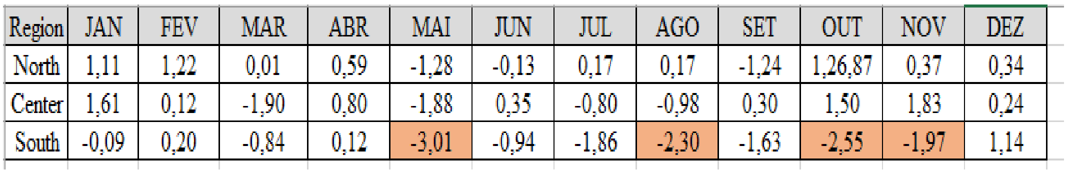
Year	**Affected Provinces (severe to exceptional drought).**	**Total Area (square kilometers and percentage)**
1989/1990	Zaire, Uíge, Bengo, Luanda, Cuanza Norte, Cuanza Sul,	111.171,860

	Benguela, Namibe, Huíla, Huambo, Bié, Cunene	(8,95%)
1994/1995	Lunda Norte, Moxico, Cuando Cubango, Huíla, Bié	93.71,266 (7,51 %)
2014/2015	Malanje, Cuanza Sul, Uíge, Bié, Benguela, Lunda Sul, Moxico, Cuanza Norte.	120.21,160 (8,63 %)
2018/2019	Namibe, Cunene, Cuando Cubango, Bié, Moxico, Lunda Norte, Malanje, Luanda, Bengo, Lunda Sul, Cuanza Norte, Cuanza Sul, Benguela, Uíge.	58.26,397 (4,67 %)
Total Area of Angola		1.247.421,924 km²

3.6 Rainfall trend analysis

Rainfall trend analysis shows an increasing trend of negative rainfall anomalies in the North during the rainfall season (NDJFMA) from 1989 to 2020. However, although the trend is increasing, it is not statistically significant for this region (Fig.13). In the Center, the trend is also increasing throughout the rainfall season, but not significant. Concerning the South region, the rainfall rend is mainly decreasing, statistically significant in May, August, October and November. However, the trend is positive and not significant in February, December and April. Thus, these results suggest that the North and Central regions are subject to a growing rainfall deficit, which can lead to the origin of drought events; these results are extremely relevant since the North and Central regions of Angola have the largest economic asset country, such as agriculture, minerals, provision of water resources among others (Aja *et al.*, 2017).

Fig.13: Analysis of the rainfall trend with the Mann-Kendall test from 1984 to 2020. The Z values in the table indicate the Trends for each month, being significative (crescent) if Z>1.96 and decreasing if Z<-1.96. The values painted with light brown color have statistical significance.



Region	JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	NOV	DEZ
North	1,11	1,22	0,01	0,59	-1,28	-0,13	0,17	0,17	-1,24	1,26,87	0,37	0,34
Center	1,61	0,12	-1,90	0,80	-1,88	0,35	-0,80	-0,98	0,30	1,50	1,83	0,24
South	-0,09	0,20	-0,84	0,12	-3,01	-0,94	-1,86	-2,30	-1,63	-2,55	-1,97	1,14

4 Discussions and conclusions

Angola has been recurrently affected by drought events. The most prolonged drought events were identified in the South and Center of the country. In the Southern region, the longest drought occurred from 1992 to 1997, totaling 83 successive months of drought in the region, in the Center the longest event occurred during the years 1994 to 1997, and in the North region between 2003 and 2005, totaling 46 and 23 months, respectively.

The spatial evaluation of drought intensities showed that the events with greater intensity occur in the southern region of Angola, with greater prominence in the provinces of Cunene and Cuando Cubango, both presenting SPI values lower than -2. In the central region, more intense values were observed in the province of Huíla, west of Malange and center of Bié, with SPI values between 1 and -2.5, this range of values was also observed in some provinces of the North, such as Malanje and northern Luanda Norte.

Identifying the spatial distribution of drought intensity provides a more regional view of this phenomenon. Thus, the drought events identified in these regions can generate significant losses in a socioeconomic context, especially between the Central and Southern regions. For example, the drought event in 2019 forced 70% of children to drop out of school to seek water in the southern provinces. One of the families shared a well 15 meters deep with five other families in the municipality of Ombadj (Namibe), and to draw water it took an effort of approximately 4 hours, excavating the surface to obtain a maximum of 20 liters of water for each family (ONU News, 2019).

From a climatic point of view, most drought events were associated with negative rainfall anomalies influenced by the presence of anticyclonic circulation anomalies that alter the common pattern of moisture transport in the region. The drought events showed strong correlations with the TSA and TNA indices. These correlations allow us to conclude that; the cooling of SST in the South Atlantic are associated with decreased rainfall on the country's west coast and increased rainfall in some central provinces such as Moxico and Cuando Cubango. On the other hand, the TNA index showed a negative correlation with rainfall in much of central and northeastern Angola, indicating that the warming of SST in the north Atlantic contributes to reducing rainfall in these regions, as also shown in previous studies (Moura and Aimoa, 2019 and Xavier, 2013). In addition, the events evaluated from 1984 to 2020, throughout the region of Angola, were associated with years of Occurrence of El Niño and La Niña, which influences the rainfall pattern in Angola. According to Preethi et al. (2015) and Xavier (2013), during the rainfall season, the occurrence of El Niño events influences rainfall patterns in much of the South and the Center. However, there is increased rainfall in the Northern region in some provinces, such as Zaire and parts of the central-east Uíge.

The spatial variation of the main drought events in 1989/90, 1994/95, 2014/15 and 2018/19 showed that all events analyzed for each region (Center, South and North) presented the severe to exceptional dry category. Among the most affected provinces are the provinces of Zaire, Bengo, Luanda, Cuanza Norte, Cuanza Sul, Benguela, Huíla, Namibe, Huambo, Moxico, Bié, Cunene, Cuando Cubango, Lunda Norte, Uíge, and Lunda Sul. Considering these years analyzed, almost 29,7% in the area of the national territory affected by drought in the category of severe to exceptional. These results reinforce the application of these scales (IDI-03, IDI-06 and IDI-12) respond to short-term changes in soil moisture and agriculture. In addition, these more critical regions on these scales present significant losses in agriculture and agropastoral activities when exposed to drought events.

The trend analysis from 1984 to 2020 of negative rainfall anomalies showed that the rainfall deficit trend is increasing throughout the rainfall season for the central and northern regions. In the South, the trend is decreasing and statistically significant in May, August, October and November.

Based on the results found, our study provides the importance of knowing the climatic aspects behind the drought, revealing important aspects that were not known until then to Angola and that may help in the future the monitoring of drought. However, we propose further analyses, including climate modelling in the future, to understand drought-related climate impacts more robustly.

5 REFERENCES

Aja, J. *et al.* (2017) “Reconhecimentos Coordenação geral: Teresa Rocha, Comissão Nacional de Protecção Civil-Governo de Angola.”

Austin, D.W. (2008) “Drought in South Africa: Lessons lost and/or learnt from 1990 to 2005.” Available at: https://core.ac.uk/download/pdf/39665663.pdf (Accessed: January 11, 2022).

Baker, R.E. and Anttila-Hughes, J. (2020) “Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa,” *Scientific Reports 2020 10:1*, 10(1), pp. 1–10. doi:10.1038/s41598-020-74942-9.

Barker, L.J. *et al.* (2016) “From meteorological to hydrological drought using standardised indicators,” *Hydrology and Earth System Sciences*, 20(6), pp. 2483–2505. doi:10.5194/HESS-20-2483-2016.

CGP (1992) *Agricultura | República de Angola - Consulado Geral do Porto*. Available at: http://www.consuladogeralangola-porto.pt/pt/agricultura (Accessed: January 11, 2022).

CIMA, U. (2019) *AGO: Angola Perfil De Risco De Desastres - Inundações e Secas (2019) — GeoNode*. Available at: http://riskprofilesundrr.org/documents/1851 (Accessed: January 11, 2022).

Cooper, P.J.M. and Coe, R. (2011) “Assessing and addressing climate-induced risk in sub-saharan rainfed agriculture: foreword to a special issue of experimental agriculture,” *Experimental Agriculture*, 47(2), pp. 179–184. doi:10.1017/S0014479711000019.

Cunha, A.P.M.A. *et al.* (2019) “Extreme Drought Events over Brazil from 2011 to 2019,” *Atmosphere 2019, Vol. 10, Page 642*, 10(11), p. 642. doi:10.3390/ATMOS10110642.

Dai, A. (2011) “Drought under global warming: a review,” *Wiley Interdisciplinary Reviews: Climate Change*, 2(1), pp. 45–65. doi:10.1002/WCC.81.

Dias, J.R. (1981) “Famine and disease in the history of Angola c. 1830–1930*,” *The Journal of African History*, 22(3), pp. 349–378. doi:10.1017/S0021853700019575.

Dinku, T. *et al.* (2018) “Validation of the CHIRPS satellite rainfall estimates over eastern Africa,” *Quarterly Journal of the Royal Meteorological Society*, 144, pp. 292–312. doi:10.1002/QJ.3244.

Diogo, A.M. (2020) “Análise da distribuição espacial da fenologia de vegetação, precipitação e evapotranspiração, com base em imagens de sensoriamento remoto orbital em Angola.” Available at: https://lume.ufrgs.br/handle/10183/217460 (Accessed: January 11, 2022).

DW (2019a) *FAO: Angola regista queda na produção agrícola | NOTÍCIAS | DW | 15.10.2018*. Available at: https://www.dw.com/pt-002/fao-angola-regista-queda-na-produ%C3%A7%C3%A3o-agr%C3%ADcola/a-45899655 (Accessed: January 12, 2022).

DW (2019b) *Sul de Angola continua a sofrer com a seca e a fome | NOTÍCIAS | DW | 13.11.2018*. Available at: https://www.dw.com/pt-002/sul-de-angola-continua-a-sofrer-com-a-seca-e-a-fome/a-46270279 (Accessed: January 11, 2022).

DW (2021) *Sul de Angola: "Deslocados da fome" estão a fugir para a Namíbia | Angola | DW | 02.05.2021*. Available at: https://www.dw.com/pt-002/sul-de-angola-deslocados-da-fome-est%C3%A3o-a-fugir-para-a-nam%C3%ADbia/a-57405857 (Accessed: January 11, 2022).

Fechine, J.A.L. (2015) “Identificação de secas meteorológicas na região metropolitana de fortaleza, usando o índice de precipitação padronizada (SPI),” *Boletim de Geografia*, 33(2), pp. 18–33. doi:10.4025/bolgeogr.v33i2.22671.

Folha de S.Paulo (1994) *Folha de S.Paulo - Fome ameaça 2,2 mi em Angola, diz a ONU - 20/5/1994*. Available at: https://www1.folha.uol.com.br/fsp/1994/5/20/mundo/9.html (Accessed: January 11, 2022).

Funk, C. *et al.* (2015) “A global satellite-assisted precipitation climatology,” *Earth System Science Data*, 7(2), pp. 275–287. doi:10.5194/ESSD-7-275-2015.

Funk, C. *et al.* (2018) “Examining the role of unusually warm Indo-Pacific sea-surface temperatures in recent African droughts,” *Quarterly Journal of the Royal Meteorological Society*, 144, pp. 360–383. doi:10.1002/QJ.3266.

Gautam, M. *et al.* (2006a) “Managing Drought in Sub-Saharan Africa: Policy Perspectives.” doi:10.22004/AG.ECON.25608.

Gautam, M. *et al.* (2006b) “Managing Drought in Sub-Saharan Africa: Policy Perspectives.” doi:10.22004/AG.ECON.25608.

Giannini, A. (2010) “The Influence of Sea Surface Temperatures on African Climate,” pp. 6–9. Available at: http://www.fews.net], (Accessed: January 11, 2022).

Haile, G.G. *et al.* (2020) “Projected Impacts of Climate Change on Drought Patterns Over East Africa,” *Earth’s Future*, 8(7), p. e2020EF001502. doi:10.1029/2020EF001502.

IPCC - AR5 (2014) *AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability — IPCC*. Available at: https://www.ipcc.ch/report/ar5/wg2/ (Accessed: January 11, 2022).

Kalnay, E. *et al.* (1996) “The NCEP/NCAR 40-Year Reanalysis Project,” *Bulletin of the American Meteorological Society*, 77(3), pp. 437–472. doi:10.1175/1520-0477(1996)077.

Karpouzoglou, T. and Barron, J. (2014) “A global and regional perspective of rainwater harvesting in sub-Saharan Africa’s rainfed farming systems,” *Physics and Chemistry of the Earth, Parts A/B/C*, 72–75, pp. 43–53. doi:10.1016/J.PCE.2014.09.009.

Kendall, M. (1948) “Rank correlation methods.” Available at: https://psycnet.apa.org/record/1948-15040-000 (Accessed: January 12, 2022).

Kim, I.W. *et al.* (2021) “Tropical Indo-Pacific SST influences on vegetation variability in eastern Africa,” *Scientific Reports 2021 11:1*, 11(1), pp. 1–8. doi:10.1038/s41598-021-89824-x.

Kogan, F.N. (1995) “Droughts of the Late 1980s in the United States as Derived from NOAA Polar-Orbiting Satellite Data,” *Bulletin of the American Meteorological Society*, 76(5), pp. 655–668. doi:10.1175/1520-0477(1995)076.

Li, Y. *et al.* (2021) “Pairwise-rotated EOFs of global cloud cover and their linkages to sea surface temperature,” *International Journal of Climatology*, 41(4), pp. 2342–2359. doi:10.1002/JOC.6962.

Limones, N. *et al.* (2020) “Evaluating drought risk in data-scarce contexts. The case of southern Angola,” *Journal of Water and Climate Change*, 11(S1), pp. 44–67. doi:10.2166/WCC.2020.101.

Lottering, S., Mafongoya, P. and Lottering, R. (2020) “Drought and its impacts on small-scale farmers in sub-Saharan Africa: a review,” *https://doi.org/10.1080/03736245.2020.1795914*, 103(3), pp. 319–341. doi:10.1080/03736245.2020.1795914.

Luetkemeier, R., Mbidzo, M. and Liehr, S. (2021) “Water security and rangeland sustainability: Transdisciplinary research insights from Namibian-German collaborations,” *South African Journal of Science*, 117(1–2), pp. 1–9. doi:10.17159/SAJS.2021/7773.

Marengo, J.A. *et al.* (2015) “A seca e a crise hídrica de 2014-2015 em São Paulo,” *Revista USP*, (106), pp. 31–44. doi:10.11606/ISSN.2316-9036.V0I106P31-44.

Marengo, J.A. *et al.* (2021) “Extreme Drought in the Brazilian Pantanal in 2019–2020: Characterization, Causes, and Impacts,” *Frontiers in Water*, 3, p. 13. doi:10.3389/FRWA.2021.639204/BIBTEX.

Mateus, N.P.A. and António, J.F. (2020) “Seca no sul da Angola: uma avaliação do episódio extremo de 2018/2019,” *Revista Científica Multidisciplinar Núcleo do Conhecimento*, pp. 24–45. doi:10.32749/nucleodoconhecimento.com.br/agronomia/seca-no-sul.

Meza, I., Rezaei, E. E., Siebert, S., Ghazaryan, G., Nouri, H., Dubovyk, O., ... & Hagenlocher, M. (2021). Drivers, spatial patterns, and implications for drought risk management. Science of the Total Environment, v. 799, p. 149505, 2021

MCKEE, B.T. (1995) “Drought monitoring with multiple time scales,” *Proceedings of 9th Conference on Applied Climatology, Boston, 1995* [Preprint]. Available at: https://ci.nii.ac.jp/naid/10028178079 (Accessed: January 12, 2022).

Mckee, T.B., Doesken, N.J. and Kleist, J. (1993) “the relationship of drought frequency and duration to time scales,” *Eighth Conference on Applied Climatology*, pp. 17–22.

Moura, M. do N. and Aimola, L.L. (2019) “The role of sea surface temperature in the rainfall regime in sub-saharan africa,” *Revista Brasileira de Climatologia*, 25(0). doi:10.5380/ABCLIMA.V25I0.60936.

Muthoni, F.K. *et al.* (2019) “Long-term spatial-temporal trends and variability of rainfall over Eastern and Southern Africa,” *Theoretical and Applied Climatology*, 137(3–4), pp. 1869–1882. doi:10.1007/S00704-018-2712-1/FIGURES/10.

Nnopuechi, J. (2021) *Report: The History of Recent Droughts in Africa (1980-2020). – Drought in Angola — Seca em Angola*. Available at: https://secaangola.hypotheses.org/176 (Accessed: January 11, 2022).

Nobre, C.A. *et al.* (2016) “Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015,” *Journal of Water Resource and Protection*, 8(2), pp. 252–262. doi:10.4236/JWARP.2016.82022.

Novo Jornal (2019) *Seca no Sul de Angola*. Available at: https://novojornal.co.ao//opiniao/interior/seca-no-sul-de-angola-79556.html (Accessed: January 11, 2022).

ONU News (2019) *Seca afeta 2,3 milhões de pessoas no sul de Angola | ONU News*. Available at: https://news.un.org/pt/story/2019/05/1674041 (Accessed: October 29, 2021).

Preethi, B. *et al.* (2015) “Impacts of the ENSO Modoki and other Tropical Indo-Pacific Climate-Drivers on African Rainfall,” *Scientific Reports 2015 5:1*, 5(1), pp. 1–15. doi:10.1038/srep16653.

reliefweb (2021) *Drought in south-western Angola drives severe hunger - Angola | ReliefWeb*. Available at: https://reliefweb.int/report/angola/drought-south-western-angola-drives-severe-hunger (Accessed: January 12, 2022).

RFI (2019) *ONU ajuda Angola contra a seca com 465 milhões de dólares*. Available at: https://www.rfi.fr/pt/angola/20190829-onu-ajuda-angola-contra-seca-com-465-milhoes-de-dolares-africa-lusofona (Accessed: January 11, 2022).

RFI (2021) *Angola: mais de um milhão de pessoas à fome devido à seca*. Available at: https://www.rfi.fr/pt/angola/20210401-angola-mais-de-um-milh%C3%A3o-de-pessoas-%C3%A0-fome-devido-%C3%A0-seca (Accessed: January 11, 2022).

VOA (2019) *Combate à seca requer estudos científicos, dizem especialistas angolanos*. Available at: https://www.voaportugues.com/a/combate-%C3%A0-seca-requer-estudos-cient%C3%ADficos-dizem-especialistas-angolanos/5188445.html (Accessed: January 12, 2022).

Xavier, J.A. (2013) *Reconstrucción de la variabilidad pluviométrica en Angola en el periodo 1979-2003*. Universidad Complutense de Madrid

3 FINAL CONSIDERATIONS

Angola has been recurrently affected by drought events. The most prolonged drought events were identified in the South and Center of the country. In the Southern region, the longest drought occurred from 1992 to 1997, totaling 83 successive months of drought in the region, in the Center, the longest event occurred during the years 1994 to 1997, and in the North region between 2003 and 2005, totaling 46 and 23 months, respectively. The spatial evaluation of drought intensities showed that the events with greater intensity occur in the southern region of Angola, with greater prominence in the provinces of Cunene and Cuando Cubango, both presenting SPI values lower than -2. In the central region, more intense values were observed in the province of Huíla, west of Malange and center of Bié, with SPI values between 1 and -2.5, this range of values was also observed in some provinces of the North, such as Malanje and northern Luanda Norte.

The present study showed the impacts caused by drought in Angola. Drought triggers several pathologies, including malnutrition that leads to many children dying. Data published by the CIMA Research Foundation show that about 7.2 million head of cattle (47.6% of the livestock population) were affected during the period 1979/2018, comprising 47.6% of the cattle population nationwide. From the perspective of future projections, this number tends to rise the equivalent of 68.5% of the cattle population in the country; that is, more than half of the cattle will be affected. In the electricity sector, the impact of drought shows frequent losses exceeding US$100 million.

Identifying the spatial distribution of drought intensity provides a better regional view of this phenomenon. The drought events identified in these regions can generate significant losses in a socioeconomic context, especially between the Central and Southern regions. For example, the drought event in 2019 forced 70% of children to drop out of school to seek water in the southern provinces. One of the families shared a well 15 meters deep with five other families in the municipality of Ombadj (Namibe), and to draw water, it took an effort of approximately 4 hours, excavating the surface to obtain a maximum of 20 liters of water for each family (ONU News, 2019).

From a climatic point of view, most drought events were associated with negative rainfall anomalies influenced by the presence of anticyclonic circulation anomalies that alter the typical pattern of moisture transport in the region. The drought events showed strong correlations with the TSA and TNA indices. These correlations allow us to conclude that; the cooling of SST in the South Atlantic are associated with decreased rainfall on the country's west coast and increased rainfall in some central provinces such as Moxico and Cuando Cubango. On the other hand, the TNA index showed a negative correlation with rainfall in much of central and northeastern Angola, indicating that the warming of SST in the North Atlantic contributes to reducing rainfall in these regions, as also shown in previous studies (Moura and Aimoa, 2019 and Xavier, 2013). In addition, the events evaluated from 1984 to 2020, throughout the region of Angola, were associated with years of Occurrence of El Niño and La Niña, which influences the rainfall pattern in Angola. According to Preethi et al. (2015) and Xavier (2013), during the rainfall season, the occurrence of El Niño events influences rainfall patterns in much of the South and the Center. However, increased rainfall is observed in some provinces in the northern region, such as Zaire and parts of the central-east Uíge, increased rainfall is observed.

The spatial variation of the main drought events in 1989/90, 1994/95, 2014/15 and 2018/19 showed that all events analyzed for each region (Center, South and North) presented the severe to exceptional dry category. Among the most affected provinces are the provinces of Zaire, Bengo, Luanda, Cuanza Norte, Cuanza Sul, Benguela, Huíla, Namibe, Huambo, Moxico, Bié, Cunene, Cuando Cubango, Lunda Norte, Uíge, and Lunda Sul. Considering these years analyzed, almost 29,7% in the area of the national territory affected by drought in the category of severe to exceptional. These results reinforce the application of these scales (IDI-03, IDI-06 and IDI-12) respond to short-term changes in soil moisture and agriculture. In addition, these more critical regions on these scales present significant losses in agriculture and agropastoral activities when exposed to drought events.

The trend analysis from 1984 to 2020 of negative rainfall anomalies showed that the rainfall deficit trend is increasing throughout the rainfall season for the central and northern regions. In the South, the trend is decreasing and statistically significant in May, August, October and November.

There is a need for action for drought monitoring in Angola. Among the main gaps we have the poor knowledge of causes and trends of drought of the region, and studies on drought-related applied research in the country. Among these aspects, we highlight education, communication and capacity to respond to the impact of drought.

In general, the implementation of various actions related to drought on monitoring and impacts assessments, institutions in Angola must develop strategies to understand the characteristics of the threat of drought and establish cooperation for impact assessments of drought-related consequences. For example, the Ministry of Agriculture and Forests, Ministry of the Environment, and universities, NGOs, the Meteorological Institute of Angola (INAMET) should act to provide relevant data and information on knowledge of the drought including threats and vulnerability. This also should include international collaboration on drought issues.

On the other hand, it is proposed in this study that there is an urgent need to implement a drought monitoring system in the future. This system should focus on drought indicators to characterize time and space details of drought. Indices of drought impacts are of paramount importance since they are focused on people. That is, monitoring should focus on reaching the people affected and providing them with meaningful information to build resilience. In this context, monitoring the risk of drought in Angola should include the social, environmental, economic and responsive sectors in relation to possible risks.

Therefore, based on the results found, our study provides the importance of knowing the climatic aspects behind the drought, revealing important aspects that were not known until then to Angola and that may help the monitoring of drought in the future. However, we propose further analyses, including climate modeling in the future, to understand drought-related climate impacts more robustly and actions that should be considered for monitoring drought and drought impacts in Angola as well to produce risk assessments. Lastly, there is a need for the main government entities to work together to facilitate communication, providing better efficiency to drought monitoring. Such bodies include, the Ministry of Agriculture and Forestry (MINAGRIP), the National Institute of Meteorology (INAMET), civil protection, ministry of transport and environment, among other bodies that can help to this end.

REFERENCES

AJA, J. *et al.* (2017) “Seca em Angola 2012 – 2016” Reconhecimentos Coordenação geral: Teresa Rocha, Comissão Nacional de Protecção Civil-Governo de Angola.”

BAKER, R. E.; Hughes, A. J. Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa**. Scientific reports**, v. 10, n. 1, p. 1-10, 2020.

AUSTIN, “Drought in South Africa: Lessons lost and/or learnt from 1990 to 2005.”. ***D.W***. (2008) Available at: https://core.ac.uk/download/pdf/39665663.pdf (Accessed: January 11, 2022).

BAKER, R.E., Anttila-Hughes, J. (2020) “Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa,” **Scientific Reports** *2020 10:1*, 10(1), pp. 1–10. doi:10.1038/s41598-020-74942-9.

BARKER, L.J. *et al.* (2016) “From meteorological to hydrological drought using standardised indicators,” **Hydrology and Earth System Sciences**, 20(6), pp. 2483–2505. doi:10.5194/HESS-20-2483-2016.

Agricultura | República de Angola - Consulado Geral do Porto. **CGP (1992)**. Disponível em: http://www.consuladogeralangola-porto.pt/pt/agricultura (Accessed: January 11, 2022).

Angola Perfil De Risco De Desastres - Inundações e Secas (2019) — GeoNode. **CIMA, U. (2019)** ***AGO***. *Disponível em*: http://riskprofilesundrr.org/documents/1851 (Accessed: January 11, 2022).

COOPER, P.J.M. and Coe, R. (2011) “Assessing and addressing climate-induced risk in sub-saharan rainfed agriculture: foreword to a special issue of experimental agriculture,” **Experimental Agriculture**, 47(2), pp. 179–184. doi:10.1017/S0014479711000019.

Cunha, A.P.M.A; Zeri M., Leal K. D.; Costa L.; Cuartas, L. A; Marengo; Tomasella, J.; Vieira R. M.; Barbosa, A. A; Cunniangham C., Garcia J. V.; Broedel E.; Alvalá, R.; Neto, G. R. (2019) “Extreme Drought Events over Brazil from 2011 to 2019,” **Atmosphere** *2019, Vol. 10, Page 642*, 10(11), p. 642. doi:10.3390/ATMOS10110642.

Drought under global warming: a review. **Dai, A. (2011)**. *Wiley Interdisciplinary Reviews: Climate Change*, 2(1), pp. 45–65. doi:10.1002/WCC.81.

Dias, J.R. (1981) “Famine and disease in the history of Angola c. 1830–1930*,” **The Journal of African History**, 22(3), pp. 349–378. doi:10.1017/S0021853700019575.

Dinku, T. *et al.* (2018) “Validation of the CHIRPS satellite rainfall estimates over eastern Africa,” **Quarterly Journal of the Royal Meteorological Society**, 144, pp. 292–312. doi:10.1002/QJ.3244.

Diogo, A.M. (2020) “Análise da distribuição espacial da fenologia de vegetação, precipitação e evapotranspiração, com base em imagens de sensoriamento remoto orbital em Angola.” Disponível em: https://lume.ufrgs.br/handle/10183/217460 (Accessed: January 11, 2022).

Angola regista queda na produção agrícola | NOTÍCIAS | **DW** | *15.10.2018*. Available at: https://www.dw.com/pt-002/fao-angola-regista-queda-na-produ%C3%A7%C3%A3o-agr%C3%ADcola/a-45899655 (Accessed: January 12, 2022).

Sul de Angola continua a sofrer com a seca e a fome | NOTÍCIAS | ***DW*** | *13.11.2018*. Available at: https://www.dw.com/pt-002/sul-de-angola-continua-a-sofrer-com-a-seca-e-a-fome/a-46270279 (Accessed: January 11, 2022).

Sul de Angola: ″Deslocados da fome″ estão a fugir para a Namíbia | Angola | DW | 02.05.2021. Available at: https://www.dw.com/pt-002/sul-de-angola-deslocados-da-fome-est%C3%A3o-a-fugir-para-a-nam%C3%ADbia/a-57405857 (Accessed: January 11, 2022).

Fechine, J.A.L. (2015) “Identificação de secas meteorológicas na região metropolitana de fortaleza, usando o índice de precipitação padronizada (SPI),” **Boletim de Geografia,** 33(2), pp. 18–33. doi:10.4025/bolgeogr.v33i2.22671.

Fome ameaça 2,2 mi em Angola, *diz a ONU - 20/5/1994*. ***Folha de S.Paulo (1994)*** . Disponível em: https://www1.folha.uol.com.br/fsp/1994/5/20/mundo/9.html (Accessed: January 11, 2022).

FUNK, C. *et al.* (2015) “A global satellite-assisted precipitation climatology,” **Earth System Science Data**, 7(2), pp. 275–287. doi:10.5194/ESSD-7-275-2015.

FUNK, C. *et al.* (2018) “Examining the role of unusually warm Indo-Pacific sea-surface temperatures in recent African droughts,” **Quarterly Journal of the Royal Meteorological Society**, 144, pp. 360–383. doi:10.1002/QJ.3266.

GAUTAM, M. *et al.* (2006a) “Managing Drought in Sub-Saharan Africa: Policy Perspectives.” doi:10.22004/AG.ECON.25608.

GAUTAM, M. *et al.* (2006b) “Managing Drought in Sub-Saharan Africa: Policy Perspectives.” **AG.ECON** . doi:10.22004/AG.ECON.25608.

GIANNINI, A. (2010) “The Influence of Sea Surface Temperatures on African Climate,” pp. 6–9. Disponível em: http://www.fews.net], (Accessed: January 11, 2022).

HAILE, G.G. *et al.* (2020) “Projected Impacts of Climate Change on Drought Patterns Over East Africa,” , 8(7), p. e2020EF001502. doi:10.1029/2020EF001502.

GFDRR e World Bank (2018) *Building disaster resilience in sub-Saharan Africa program: result area 2 2014–16 activity report*. **Washington DC**: World Bank.

IPCC - AR5 (2014) *AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability* — **IPCC**. Available at: https://www.ipcc.ch/report/ar5/wg2/ (Accessed: January 11, 2022).

KALNAY, E. *et al.* (1996) “The NCEP/NCAR 40-Year Reanalysis Project,” **Bulletin of the American Meteorological Society**, 77(3), pp. 437–472. doi:10.1175/1520-0477(1996)077.

KARPOUZOGLOU, T. and Barron, J. (2014) “A global and regional perspective of rainwater harvesting in sub-Saharan Africa’s rainfed farming systems,” **Physics and Chemistry of the Earth**, *Parts A/B/C,* 72–75, pp. 43–53. doi:10.1016/J.PCE.2014.09.009.

KENDALL, M. (1948) “Rank correlation methods.” Disponível em: https://psycnet.apa.org/record/1948-15040-000 (Accessed: January 12, 2022).

KIM, I.W. *et al.* (2021) “Tropical Indo-Pacific SST influences on vegetation variability in eastern Africa,” **Scientific Reports** *2021 11:1*, 11(1), pp. 1–8. doi:10.1038/s41598-021-89824-x.

KOGAN, F.N. (1995) “Droughts of the Late 1980s in the United States as Derived from NOAA Polar-Orbiting Satellite Data,” **Bulletin of the American Meteorological Society**, 76(5), pp. 655–668. doi:10.1175/1520-0477(1995)076.

LI, Y. *et al.* (2021) “Pairwise-rotated EOFs of global cloud cover and their linkages to sea surface temperature , 41(4), pp. 2342–2359. doi:10.1002/JOC.6962.

LIMONES, N. *et al.* (2020) “Evaluating drought risk in data-scarce contexts. The case of southern Angola,” **Journal of Water and Climate Change**, 11(S1), pp. 44–67. doi:10.2166/WCC.2020.101.

LOTTERING, S., Mafongoya, P. and Lottering, R. (2020) “Drought and its impacts on small-scale farmers in sub-Saharan Africa: a review,” *https://doi.org/10.1080/03736245.2020.1795914*, 103(3), pp. 319–341. doi:10.1080/03736245.2020.1795914.

LUETKEMEIER, R., Mbidzo, M. and Liehr, S. (2021) “Water security and rangeland sustainability: Transdisciplinary research insights from Namibian-German collaborations,” **south african journal of science**, 117(1–2), pp. 1–9. doi:10.17159/SAJS.2021/7773.

KUNDU RN, Kumar SS. The impacts and evidence of Australian droughts on agricultural crops and drought related policy issues-A review article. **International Journal of Agricultural Technology.** *2021Vol.* 2021;17(3):1061-1076.

MARENGO, J.A. *et al.* (2015) “A seca e a crise hídrica de 2014-2015 em São Paulo,” **Revista USP**, (106), pp. 31–44. doi:10.11606/ISSN.2316-9036.V0I106P31-44.

MARENGO, J.A. *et al.* (2021) “Extreme Drought in the Brazilian Pantanal in 2019–2020: Characterization, Causes, and Impacts,” **Frontiers in Water**, 3, p. 13. doi:10.3389/FRWA.2021.639204/BIBTEX.

MATEUS, N.P.A. and António, J.F. (2020) “Seca no sul da Angola: uma avaliação do episódio extremo de 2018/2019,” ***Revista Científica Multidisciplinar Núcleo do Conhecimento***, pp. 24–45. doi:10.32749/nucleodoconhecimento.com.br/agronomia/seca-no-sul.

MCKEE, B.T. (1995) “Drought monitoring with multiple time scales,” *Proceedings of 9th Conference on Applied Climatology, Boston, 1995* [Preprint]. Available at: https://ci.nii.ac.jp/naid/10028178079.

MCKEE, T.B., Doesken, N.J. and Kleist, J. (1993) “the relationship of drought frequency and duration to time scales,” **Eighth Conference on Applied Climatology**, pp. 17–22.

MOURA, M. do N. and Aimola, L.L. (2019) “The role of sea surface temperature in the rainfall regime in sub-saharan africa,” **Revista Brasileira de Climatologia**, 25(0). doi:10.5380/ABCLIMA.V25I0.60936.

MUTHONI, F.K. *et al.* (2019) “Long-term spatial-temporal trends and variability of rainfall over Eastern and Southern Africa,” **Theoretical and Applied Climatology**, 137(3–4), pp. 1869–1882. doi:10.1007/S00704-018-2712-1/FIGURES/10.

NNOPUECHI, J. (2021) *Report: The History of Recent Droughts in Africa (1980-2020). – Drought in Angola — Seca em Angola*. Available at: https://secaangola.hypotheses.org/176 (Accessed: January 11, 2022).

NOBRE, C.A. *et al.* (2016) “Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015,” **Journal of Water Resource and Protection**, 8(2), pp. 252–262. doi:10.4236/JWARP.2016.82022.

Seca no Sul de Angola. **Novo Jornal (2019)** . disponível em https://novojornal.co.ao//opiniao/interior/seca-no-sul-de-angola-79556.html (Accessed: January 11, 2022).

Seca afeta 2,3 milhões de pessoas no sul de Angola | ONU News. **ONU News (2019)**. Available at: https://news.un.org/pt/story/2019/05/1674041 (Accessed: October 29, 2021).

PREETHI, B. *et al.* (2015) “Impacts of the ENSO Modoki and other Tropical Indo-Pacific Climate-Drivers on African Rainfall *2015 5:1*, 5(1), pp. 1–15. doi:10.1038/srep16653.

Peters LER. Disaster Risk Reduction and violent conflict in Africa and Arab states: Implications for the Sendai Framework priorities Mapping the Missing Millions View project Rethinking the disaster-conflict-peace nexus View project. Published online 2018. doi:10.13140/RG.2.2.19197.20962

Drought in south-western Angola drives severe hunger - Angola | **reliefweb (2021).** Available at: https://reliefweb.int/report/angola/drought-south-western-angola-drives-severe-hunger (Accessed: January 12, 2022).

ONU ajuda Angola contra a seca com 465 milhões de dólares. **RFI (2019).** Available at: https://www.rfi.fr/pt/angola/20190829-onu-ajuda-angola-contra-seca-com-465-milhoes-de-dolares-africa-lusofona (Accessed: January 11, 2022).

RICHARD Y, Fauchereau N, Poccard I, Rouault M, Trzaska S. 20th century droughts in Southern Africa: Spatial and temporal variability, teleconnections with oceanic and atmospheric conditions. **International Journal of Climatology**. 2001;21(7):873-885. doi:10.1002/joc.656

Angola: mais de um milhão de pessoas à fome devido à seca. **RFI (2021).** Disponível em: https://www.rfi.fr/pt/angola/20210401-angola-mais-de-um-milh%C3%A3o-de-pessoas-%C3%A0-fome-devido-%C3%A0-seca (Accessed: January 11, 2022).

SAMSEMBELE, A. Seca severa continua a fustigar o sul de Angola, com risco de catástrofe humanitária. **VATICAN NEWS**, Luanda/Angola, 07/08/2019. Seção (se houver). Disponível em: < https://www.vaticannews.va/pt/africa/news/2019-08/angola-seca-severa-continua-a-fustigar-o-sul-do-pais-com-risco.html>. Acesso em: 04/08/2020.

Combate à seca requer estudos científicos, dizem especialistas angolanos. **VOA (2019)**. Disponível: https://www.voaportugues.com/a/combate-%C3%A0-seca-requer-estudos-cient%C3%ADficos-dizem-especialistas-angolanos/5188445.html (Accessed: January 12, 2022).

XAVIER, J.A. (2013) *Reconstrucción de la variabilidad pluviométrica en Angola en el periodo 1979-2003*. Universidad Complutense de Madrid.