IGAD Climate Prediction and Application Centre (ICPAC)

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The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2)

CLIMATE VARIABILITY and EXTREME EVENTS REPORT

2019

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LIST OF ABBREVIATIONS

ACE-WATER-2	African Networks of Centres of Excellence on Water Sciences PHASE II
AMCOW	African Ministers' Council On Water
AU-NEPAD	African Union - NEw Partnership for Africa's Development
BN	Blue Nile
BNB	Blue Nile Basin
CDAT	Climate Data Analysis Tools
CEANWATCE	Central-Eastern Africa Network of WATer Centers of Excellence
CHG	Climate Hazard Group
CHIRPS	Climate Hazards Group Infrared Precipitation with Station
CoEs	Centres of Excellence
CORDEX	Coordinated Regional Downscaling Experiment
CRU	Climate Research Unite
CV	Climate Variability
DJF	December-January-February
EAC	East African Community
ENSO	El Nino Southern Oscillation
EU	European Union
GDP	Gross Domestic Product
GHA	Greater Horn of Africa
GIS	Geospatial Information System
GrADS	Grid Analysis and Display System
ICPAC	IGAD Climate Prediction and Applications Centre
IGAD	Inter-Governmental Authority on Development
IOD	Indian Ocean Dipole
ITCZ	Inter-Tropical Convergence Zone
JJA	June-July-August
JJAS	June-July-August-September
JRC	Joint Research Centre

LVB	Lake Victoria Basin
MAM	March-April-May
NCL	NCAR Command Language
NetCDF	Network Common Data Form
OND	October-November-December
PET	Potential Evapo-Transpiration
RCP	Representative Concentration Pathway
SON	September-October-November
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
UBN	Upper Blue Nile
UNESCO	United Nations Educational, Scientific and Cultural Organization
WEFE	Water-Energy-Food-Ecosystem
WMO	World Meteorological Organization

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1 INTRODUCTION

The project "*The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2)*" aims at fostering sustainable capacity development at scientific, technical and institutional level in the water sector. The project supports twenty (20) AU-NEPAD African Network of Centres of Excellence in Water Sciences and Technology (CoEs) organized in three regional networks, in conducting high-end scientific research on water and related sectors, in order to provide effective scientific and educational support to governments. The project is implemented in partnership between UNESCO, in charge of the human capacity development component, and the JRC that coordinates the scientific component and leads the project.

In the framework of the project scientific component, the CEANWATCE (Central-Eastern Africa Network of WATer Centers of Excellence) identified, by means of collective sharing, the Blue Nile Basin (BNB) and the Lake Victoria Basin (LVB), as sub-catchments of the Nile being very relevant for the development of common research undertakings. These basins pose many challenges from a perspective of Water-Energy-Food-Ecosystem (WEFE) nexus, including, among others, hydropower, reservoir multipurpose optimization and release management (in particular the BNB), rain-fed and irrigated agriculture development, impact of land use and agricultural practices (including livestock and fisheries), role of ecosystem services (natural parks, wetlands), pressures on resources due to population increase and climate variability/change and extreme events risks (drought and flooding).

This project addresses WEFE nexus interdependences and evaluates sustainable bridging-gap solutions, based on state-of-the-art reviews and scientific analysis. Building on the discussions with CEANWATCE and the Inter-Governmental Authority on Development (IGAD), specific actions are to be implemented, taking into account scientific competencies of both CoE and JRC, and in view of an effective cooperation with other key regional stakeholders, towards the development of a dynamic web African Atlas on Water Cooperation, supporting decision making processes through scenarios-based-analysis.

Based on IGAD strategies and priorities and supported by AMCOW (declaration GA/10/2016/Dar/14) in the frame of the ACEWATER2 project, the following areas of scientific investigation relevant to WEFE nexus analysis have been identified:

1. Climate variability and extreme events
2. Hydrology, water balance and hydropower
3. Water and livelihood: agricultural water, health, quality, access, resilience

This report in on the scientific investigation of climate variability and extreme events.

1.1 GENERAL OBJECTIVES

To Assess WEFE interdependencies across the Nile River Basin, with a particular focus on the Blue Nile Basin and the Lake Victoria Basin. The specific objectives addressed by the IGAD Climate Prediction and Applications Centre (ICPAC) on climate variability and extreme events are;

1.1.1 Specific Objectives

1. Gather and collect data in a regional Hydro Climate Database (i.e. rainfall, temperature, including remote sensed datasets, ground stations and related time series).

2 Perform Climate Variability (CV) analysis, to assess extremes and seasonal anomalies and frequencies, and climate risk assessment on extreme events (droughts, floods), based on analysis of relevant indicators i.e. Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) and state of the art methodologies, at both regional and BNB/LVB scales.

1.2 INCEPTION PHASE OF THE PROJECT

Project Implementation started in July 2018. The component of climate variability and extreme events of the project is implemented by ICPAC, which will feed into the analysis by the Khartoum University, Makerere University, and Addis Ababa University. The expert assigned to this activity under ICPAC is Mr. Zachary Atheru (Head of Climate Diagnostic and Prediction), e-mail: zatheru@icpac.net, and is now fully registered as an expert in the EU portal.

The inception workshop was held in Kampala, Uganda from 7th to 9th of February, 2018, with the participation of representatives from Makerere University, Addis Ababa University, Khartoum University, JRC, UNESCO, and ICPAC (represented by Mr. Jully Ouma and Dr. Mohammed Hassan). The workshop focused on explaining the rationale and strategy of the project to all stakeholders, presenting project implementation procedures and discussing roles and responsibilities of each partner and opportunities for partnership during project implementation.

Goals and objectives, methodology and basic planned results as well as annual work plan and meetings for 2018/2019 were presented by the representative of JRC. Challenges and technical solutions for obtaining hydrological data from Tanzanian and Rwanda were presented and discussed. The 2018 work plan was revised after the inception workshop, it was then agreed by the all members that the implementation of the project activities will commence after the submission of the inception.

1.3 CONCEPTUAL FRAME WORK

Climate change presents new challenges in terms of climate variability, extremes such as drought and floods thus affecting the livelihood within the Lake Victoria and Blue Nile basins. This analysis asserts that the extent of risk prone areas will increase owing to the anticipated changes in climate. Figure 1 illustrates the steps that will be taken in this study to assess the variability in climate and expected changes. The datasets were made available online (http://geoportal.icpac.net/) for use by other centers as well as the public with no access credentials required.

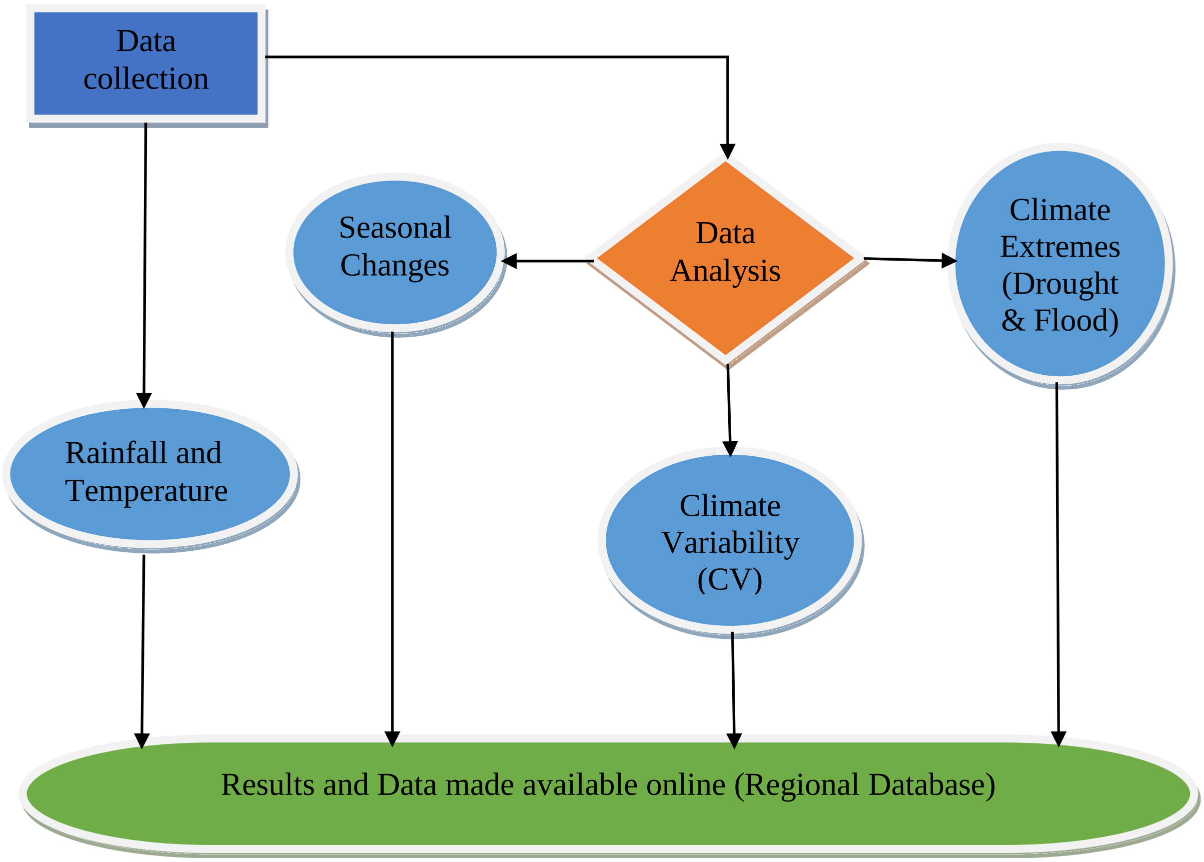

Figure 1: The research model demonstrating the research conceptual framework

2 DATA AND METHODS

Atmospheric observed/satellite data (rainfall, temperature (maximum, mean, and minimum), and potential evapotranspiration (PET)) will be obtained from ICPAC, Climate Hazard Group (CHG), and the Climate Research Unite (CRU) data library of the University of East Anglia will be used in this assessment. The Climate Hazards Group Infrared Precipitation with Station from CHG which is mainly satellite plus gauge station data at a resolution of 0.05^0 and a temporal resolution of one month from 1981 to 2017 (Funk et al., 2014; Katsanos et al., 2016). Monthly CRU data (rainfall, temperature, and PET) at a spatial resolution of 0.5^0 was used from 1901 to

2017 (Harris et al., 2014) to determine how climate has changed in the past. Climate Change data from the Coordinated Regional Downscaling Experiment (CORDEX) was used to assess the scenarios of the future (Osima et al., 2018) over the region with specific focus over the basins. The model ensemble used in analysis was made available in NetCDF format for use by other centers in their respective basins analysis.

Hydrological drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after many months of meteorological drought (Melo and Wendland, 2016). In this analysis meteorological drought indices (SPI and SPEI) were used to assess this hydrological drought at 12, 24, 36, and 48 time steps. The SPI method developed by McKee et al. (1993), was used to assess abnormal wet and dry conditions using precipitation only (Tsakiris & Vangelis, 2004; Türkeş & Tatlı, 2009). It's a normalized index representing the probability of occurrence of an observed rainfall amount when compared with the rainfall climatology at a certain geographical location over a long-term reference period. Negative SPI values signify deficit in rainfall, whereas positive SPI values signify surplus of rainfall. Drought intensity event can be classified based on the magnitude of negative SPI values such that the greater the negative values of SPI are, the more severe the event would be (Table 1). This method was adopted by the World Meteorological Organization (WMO) as a standard measure of meteorological drought and has been accepted worldwide a standard index for monitoring drought and extreme events in various timescales. This method only uses precipitation in computation of drought ignoring the contribution of temperature.

Table 1: Category of drought based on the SPI and SPEI value (Source: McKee et al., 1993 and Ghebrezgabher et al., 2016)

SPI	Drought Type
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ -2	Extreme drought

A more complex method of monitoring drought is the Standardized Precipitation-Evapotranspiration Index (SPEI). This method is said to be an extension of SPI which is widely used in drought monitoring, hydrology and climatology studies (Vicente-Serrano et. al., 2010; Beguería et al., 2014; Stagge et al., 2015). It takes into consideration the aspect of potential evapotranspiration and precipitation to determine drought using the timescale as that of SPI. This method sometimes is more preferred as it incorporates the contribution of potential evapotranspiration into drought monitoring. According to Vicente-Serrano et al. (2010) SPEI can be used to quantify the dry and wet conditions at different time scales. In this analysis, the following classification was adopted for both SPI and SPEI; Dry/Wet (-/+1 to -/+1.49), Very Dry/Wet (-/+1.5 to -/+2), and Extremely Dry/Wet (< -2/>+2).

In order to determine periodicities of these extremes, the concept of periodograms was adopted (Glynn et al., 2005). The x-axis on the periodograms are articulated in multiples of 1/12; noting the folding frequency to be 0.5 cycles per month there are 6 cycles per year. At the folding frequency, the features on this periodogram will be mirrored on the other side hence conventionally the higher frequencies are not plotted (Figure 2). The power spectra have a high peak at approximately 0.32 cycle per year (frequency of 0.3/12); corresponding to periods of about 37.5 months.

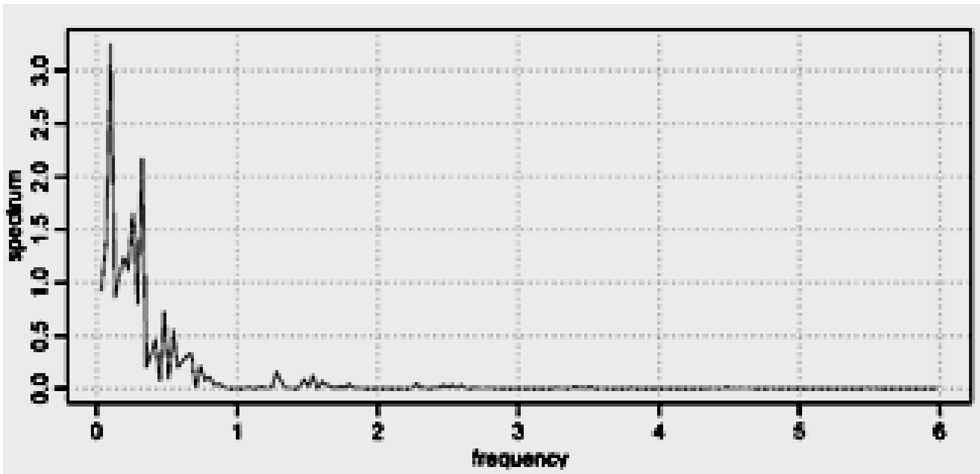

Figure 2: An illustration of the periodogram where x-axis represent the frequency of the periodicity and y-axis is the power of the spectra.

Analysis of both SPI and SPEI were done using R-Programming language and NCAR Command Language (NCL-https://www.ncl.ucar.edu/). The datasets used in this study have been shared though the online data portal available at ICPAC for ease of access (http://geoportal.icpac.net) with specific link given in the table under Section 3. This data portal is public with no login credentials required to download data, documents, and maps. The data portal is divided into sections and the ones that will be used here are; GIS Datasets (for spatial data storage e.g. Shapefiles data) and Documents/Maps for storing raster time series data, xlsx files, maps and reports).

2.1 Study Area

The analysis of this investigation was done over the Greater Horn of Africa (GHA) with major focus on the Blue Nile Basin and the Lake Victoria Basin (Figure 3). The GHA region is prone to extreme climate events such as droughts and floods (Ghebrezgabher et al., 2016) which has severe negative impacts on key socio-economic sectors since the region greatly depends on rain-fed agriculture as the back born of the region economy. The region has also hot and dry climate, particularly in the northern and eastern parts and the lowlands, with sparse vegetation, while precipitations are concentrated mostly in the highland areas. The climate of the region has three seasons i.e. March-April-May (MAM), June-July-August-September (JJAS), and October-

November-December (OND) (Mwesigwa et al., 2017). The MAM and OND are majorly over the equatorial and southern sector of the region while JJAS occurs in the northern sector. The major controller of the seasonality in the region is the Inter-Tropical Convergence Zone (ITCZ) together with the monsoon winds (Mwangi et al., 2014).

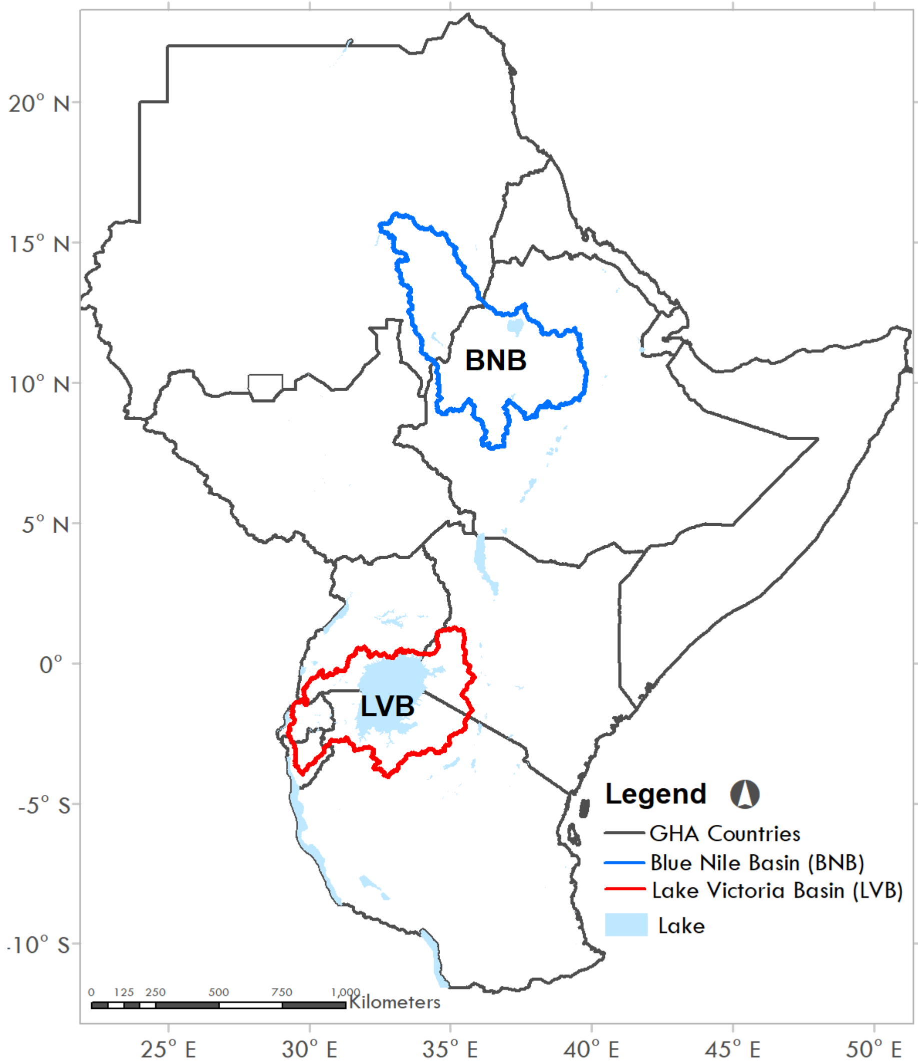

Figure 3: Study are of the Greater Horn of Africa with focus on Blue Nile Basin (Blue Color) and Lake Victoria Basin (Red Color).

2.1.1 Lave Victoria Basin

Lake Victoria is the world's largest tropical lake and the largest lake in the African Great Lakes region. The lake supports the largest freshwater fishery in the world, producing 1 million tons of fish per year and employing 200,000 people in supporting the livelihoods of 4 million people (Awange et al., 2007). The Lake Victoria Basin has a population of about 40 million people and the average population density is about 250 people per square kilometer. The LVB covers about

180,950km^2 and Kenya occupying 22%, Tanzania about 44%, Uganda 16%, Burundi 7% and Rwanda 11% (Awange et al., 2007).

The LVB has socioeconomic significance to East Africa and this is associated with the reason that it is a major inland water transport link for the East African Community (EAC) Partner States; largest inland water that act as fishing sanctuary; it is a source of domestic water, industrial water and also it is a major reservoir for generating hydroelectric power (USAID, 2018). Activities in the basin accounts for about 34% of the Gross Domestic Product (GDP) in Burundi, 32% in Rwanda, 29% in Kenya, 23% in Uganda and 25% in Tanzania (USAID, 2018). Besides, the LVB act as a significant climate modulator for the region.

The LVB on the Kenyan side has a high potential for hydropower development, however, this potential is still underutilized and only two sites have been developed to harness hydroelectric power, one each on river Sondu/Miriu and Kuja/Migori (Okungu et al., 2005). Waterfalls occur along most of these rivers such as Kuja, Nzoia, Sondu-Miriu and Yala have huge falls, thus have great potential for development of hydro power.

2.1.2 Blue Nile Basin

The Nile Basin is considered among the most complex and unique river basins due to its size associated with disparity in climate, hydrology, topography and demography throughout the basin. The Blue Nile (BN) sub basin comprises only 8% of the total Nile Basin catchment area; however, it contributes to almost 60% of the main Nile River flow at Aswan Dam in Egypt (El Shamy and Sharaky, 2014). The BN headwaters emanate at the outlet of Lake Tana in the Ethiopian highlands. It is joined by many important tributaries, draining the central and southwestern Ethiopian highlands, becoming a mighty river long before it reaches the lowlands and crosses into Sudan.

The BNB supports the livelihoods of many people residing along the basin and this through providing water for agricultural activities. Agriculture is the main source of income for people residing in the BNB since many are practicing irrigation agriculture. According to El Shamy and Sharaky (2014), basin is under consideration for various hydropower and irrigation projects. The Economic benefits of the BNB are closely related to additional hydropower generation, improved navigation and increased food production (Block and Strzepek, 2010).

Lives and livelihoods of the people in the BNB are strongly linked with livestock management and crop production. According to Haileslassie et al. (2012), over 95% of the food-producing sector in upstream areas (i.e. Ethiopia) is based on rain-fed agriculture. In Sudan, downstream, the Blue Nile supplies water for major irrigation development and also for livestock production.

3 Outputs and Results

Results obtained will be presented and discussed under this section. The results and outputs will be made available for download to other centers as discussed in section 2 above. The portal that is used to share this outputs and information is publicly available with no registration required (http://geoportal.icpac.net/documents), the datasets and shapefiles can be accessed directly through the links provided in Table 2. The contents shared on the portal will be available for lifetime of the portal thus it can be accessed anytime.

3.1 Rainfall and temperature data for the basins (Observed and projections) in grid format

Observed grid data over the basins for Rainfall, Temperature, and Potential Evapotranspiration were made available over ICPAC open access geoportal (http://geoportal.icpac.net). All historical data sets are at a resolution of 0.05 degrees and in NetCDF format which can be read by a number of software such as Xconv, CDAT, R, NCL, FERRET, GrADS, among others. Future CORDEX projection data sets were also provided for the basins and GHA. The GIS shapefiles for the basins (BNB and LVB) were also shared though the platform. Specific list and link to the shared data are available in Table 2 below.

Table 2: Summary of all data requested and shared with other centers which are also available on the ICPAC online data portal

Datasets	Lake Victoria Basin	Blue Nile Basin	Upper Blue Nile (UBN) Basin & GHA
GIS Shapefiles	Basin GIS Shapefile (Link).	Basin GIS Shapefile (Link).	-
CHIRPS	Rainfall 1981-2018 (Link)	Rainfall 1981-2018 (Link)	Rainfall 1981-2018 (Link) UBN
CRU data from 1901 to 2017	Rainfall (Link).	Rainfall (Link).	Rainfall (Link) UBN
	PET Data (Link).	PET Data (Link).	PET Data (Link) UBN
	Max. Temperature (Link).	Max. Temperature (Link).	Max. Temperature (Link) UBN
	Mean Temperature (Link).	Mean Temperature (Link).	Mean Temperature (Link) UBN

		Min. Temperature (Link).	Min. Temperature (Link).	Min. Temperature (Link) UBN
CORDEX Datasets	RCP 4.5 2006 – 2099	Rainfall (Link)	Rainfall (Link)	Rainfall (Link) GHA
		Max. Temperature (Link)	Max. Temperature (Link)	Max. Temperature (Link) GHA
		Min. Temperature (Link)	Min. Temperature (Link)	Min. Temperature (Link) GHA
	RCP 8.5 2006 – 2100	Rainfall (Link)	Rainfall (Link)	Rainfall (Link) GHA
		Max. Temperature (Link)	Max. Temperature (Link)	Max. Temperature (Link) GHA
		Min. Temperature (Link)	Min. Temperature (Link)	Min. Temperature (Link) GHA

3.2 CLIMATE EXTREME (FLOOD/DROUGHT-SPI AND SPEI)

The analysis was done using SPI/SPEI time steps (run) of 12, 24, 36, and 48 to represent hydrological drought. On a regional scale (Figure 4), there were more events on extreme wet condition (floods) observed between the periods 1901 to 1970. This started declining after the 70's with more dry conditions being observed. The wettest year in recorded from the analysis is 1961 while the driest year is 1984 and 2011 over the GHA region. Run 24 to 36 of Figure 4 shows a decreasing trend meaning that the region is likely to have more drought in the future. With a significant relationship between SPI and total storage deficit index (Awange et al., 2016), increase in dry condition will have a negative impact on surface water availability as well as ground water. This extreme events over the region can be attributed to the El Nino Southern Oscillation (ENSO) which plays a key role.

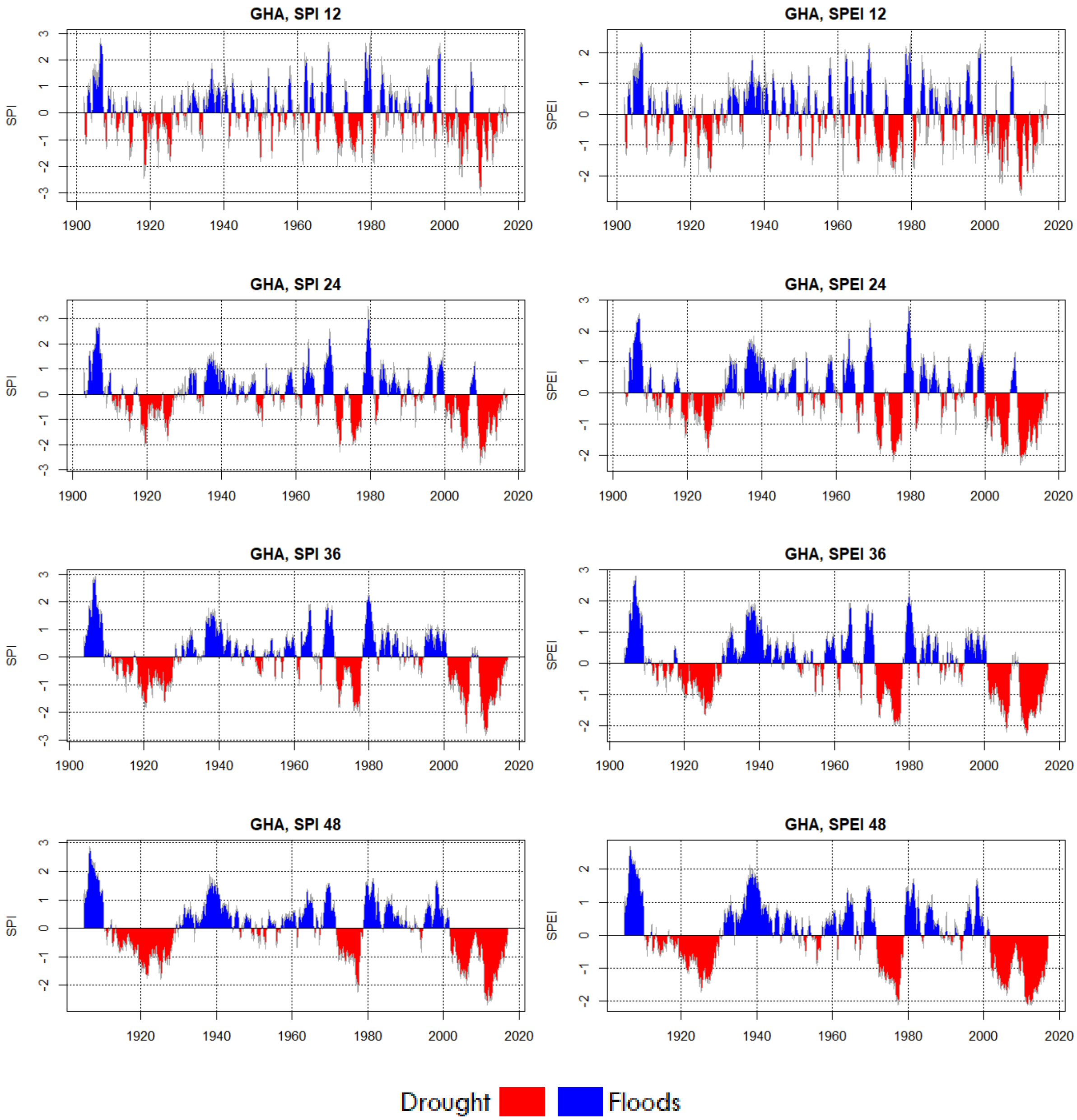

Figure 4 Standardized Precipitation Index (SPI) for the Greater Horn of Africa using CRU data for the period 1901-2017. The SPI time scales used are 12, 24, 36, and 48 months, where the red and blue colors represents drought and floods respectively.

Analysis over the LVB shows more occurrences of dry condition between 1901 to 1960 in all the runs (Figure 5) and more wet conditions from 1961 to 2017. The two major extremes observed in the recent past over the basins were 2005 for extreme dry condition and 1961 as the wettest year on record. The observed increasing trends over the basin may result to more extreme wet conditions that will lead to floods within the basin. These observed conditions are primarily attributed to the Indian Ocean Dipole (IOD) with a secondary contribution by the ENSO (Awange et. al., 2016).

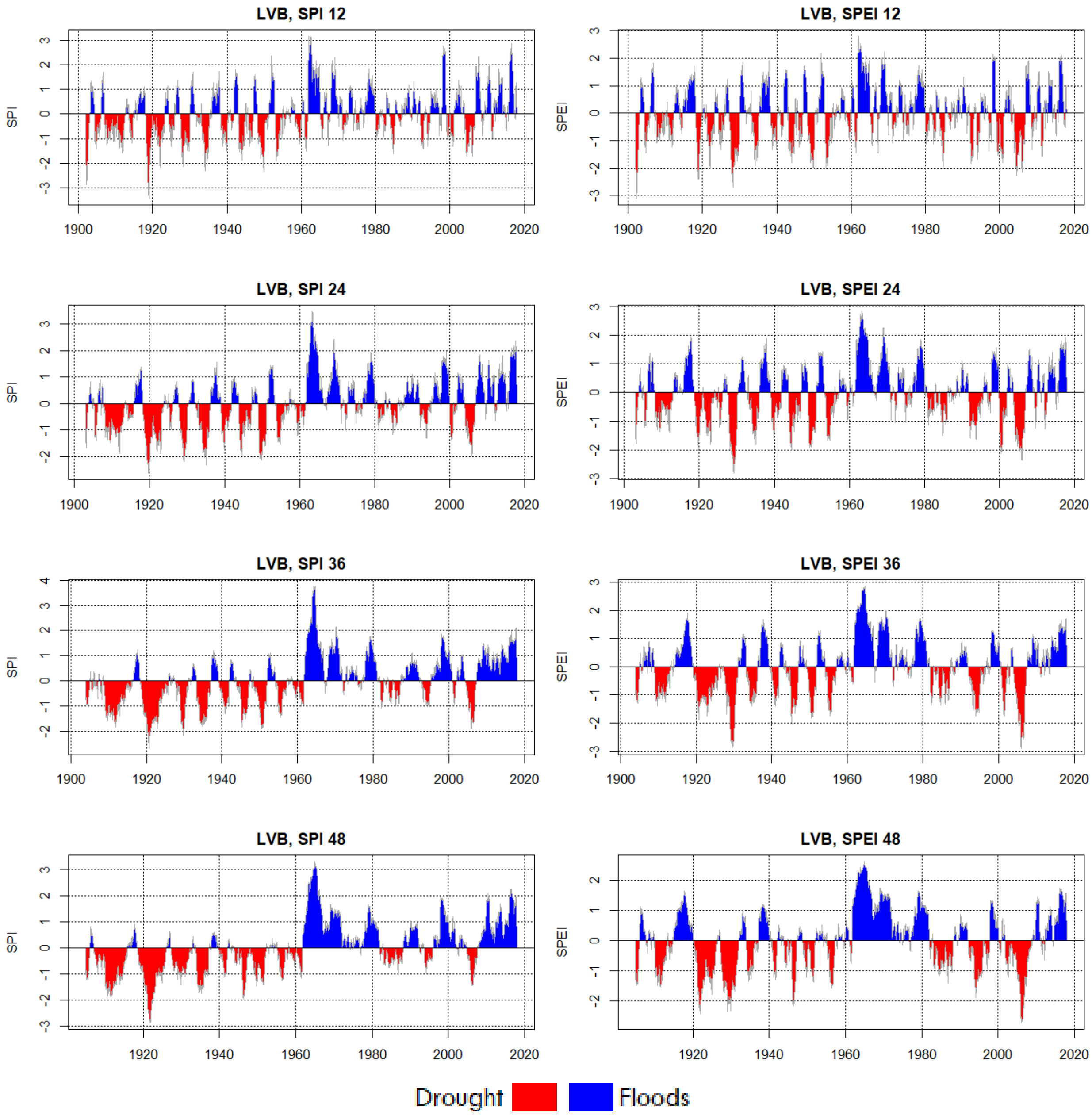

Figure 5 Standardized Precipitation Index (SPI) for Lave Victoria Basin using CRU data for the period 1901-2017. The SPI time scales used are 12, 24, 36, and 48 months, where the red and blue colors represents drought and floods respectively.

The drought index for BNB shows a decreasing trend overtime (Figure 6) observed in all the SPI/SPEI run time steps, meaning that, there were more drought in the recent past over the basin. The basin was also observed to have experienced one of the longest drought on record which occurred from 1980 to 1995, clearly shown in run 36 and 48 of Figure 6. A study by Elkollaly et al. (2018) over the eastern Nile shows that 1984 and 1987 were years of maximum drought severity which is in line with the finding of this study.

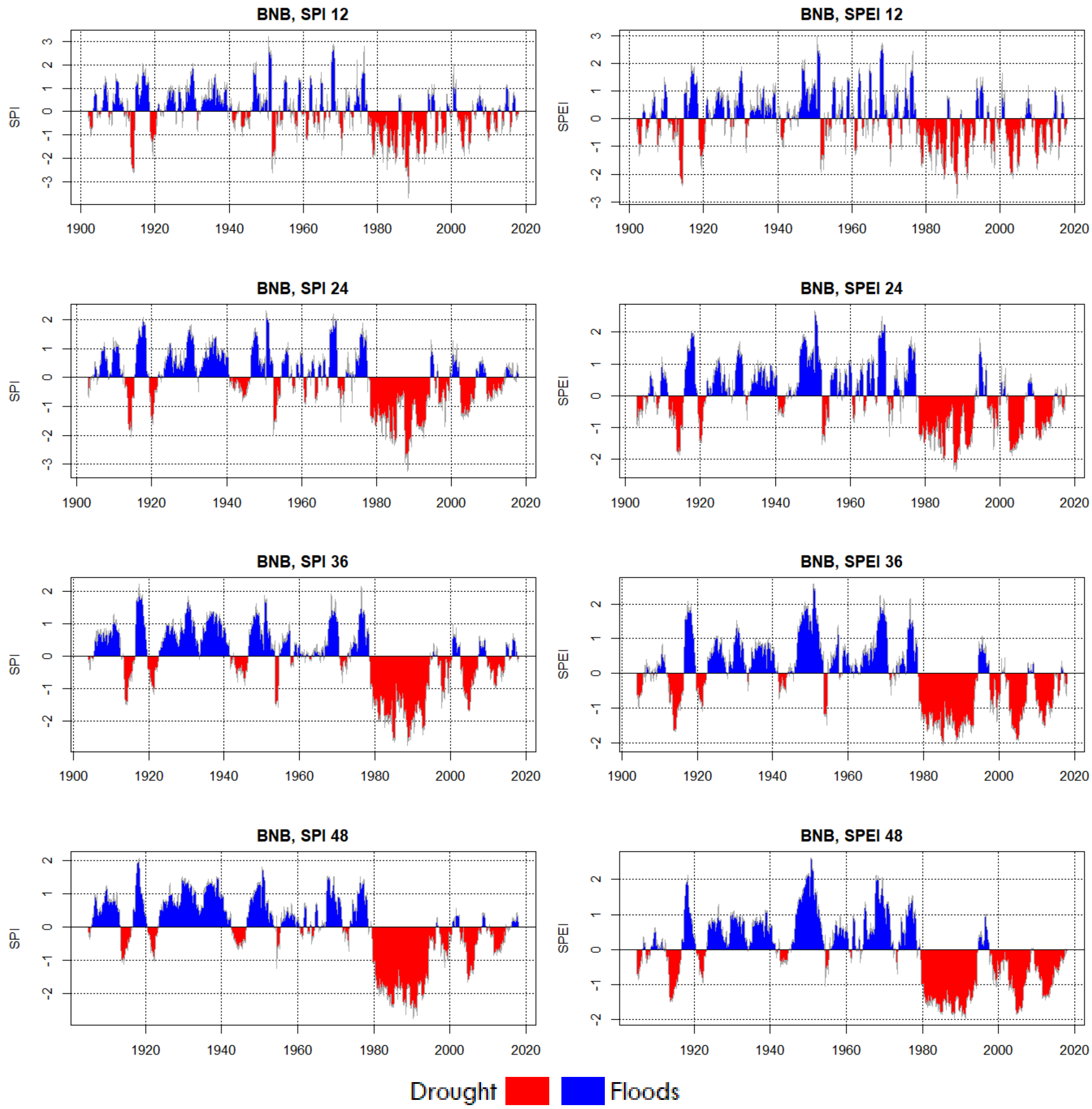

Figure 6 Standardized Precipitation Index (SPI) for Blue Nile Basin using CRU data for the period 1901-2017. The SPI time scales used are 12, 24, 36, and 48 months, where the red and blue colors represents drought and floods respectively.

3.3 Periodicity and Frequency

3.3.1 Periodicity

From the analysis, the periodograms for SPI and SPEI values computed at merely all scales under consideration (12, 24, 36 and 48 months) were found to yield same results. Variations in the drought episodes are here seen to have a period of about 3 years. The smoothing filters out noise of the sequence averaged periodograms on the 12 -month scaled SPIs from the BNB, across bandwidths 1 to 9 (Figure 7), show and example on a peak around frequency of 0.3. The blue dotted lines at top and red dotted lines at bottom are 95% confidence intervals.

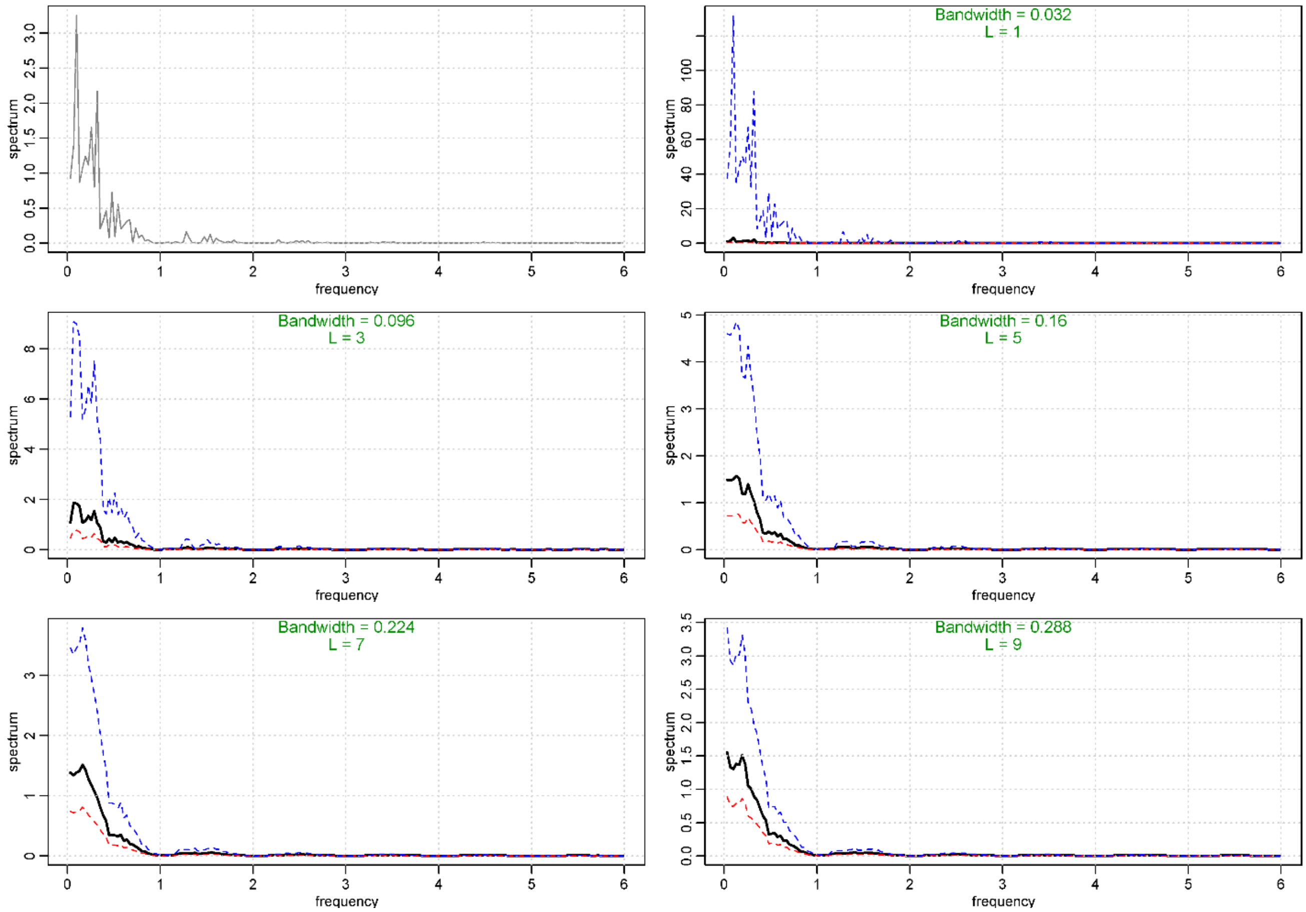

Figure 7 Sequence of averaged periodograms on the 12 -month scaled SPIs generated using precipitation data from the Blue Nile basin, across bandwidths 1 to 9.

3.3.2 Frequency

Spatial frequency analysis was used to filter spatial properties (Swearer, 2011) of drought over the region for SPI time steps of 12, 24, 36, and 48. Figure 8 presents the historical frequency of wet and dry conditions for time step 12 for both CRU and CORDEX. The frequency of dry/wet categories are higher than those of very dry/wet and extremely dry/wet categories in the region, for both CRU and CORDEX. The pattern of frequency observed in CRU is well replicated in CORDEX, but, the extreme dry/wet categories are not well represented over region by the model historical data. However, BNB and LVB signals are well captured in the extreme category of dry and wet. The SPI/SPEI classes for the categories used are presented in Table 3 below.

Table 3: Categories used to analyze the dry and wet condition over the region presented in the maps.

SPI/SPEI	***Category***	***SPI/SPEI***	***Category***
-1 to -1.49	Dry	+1 to +1.49	Wet
-1.5 to -2	Very Dry	+1.5 to +2	Very Wet
< -2	Extremely Dry	> +2	Extremely Wet

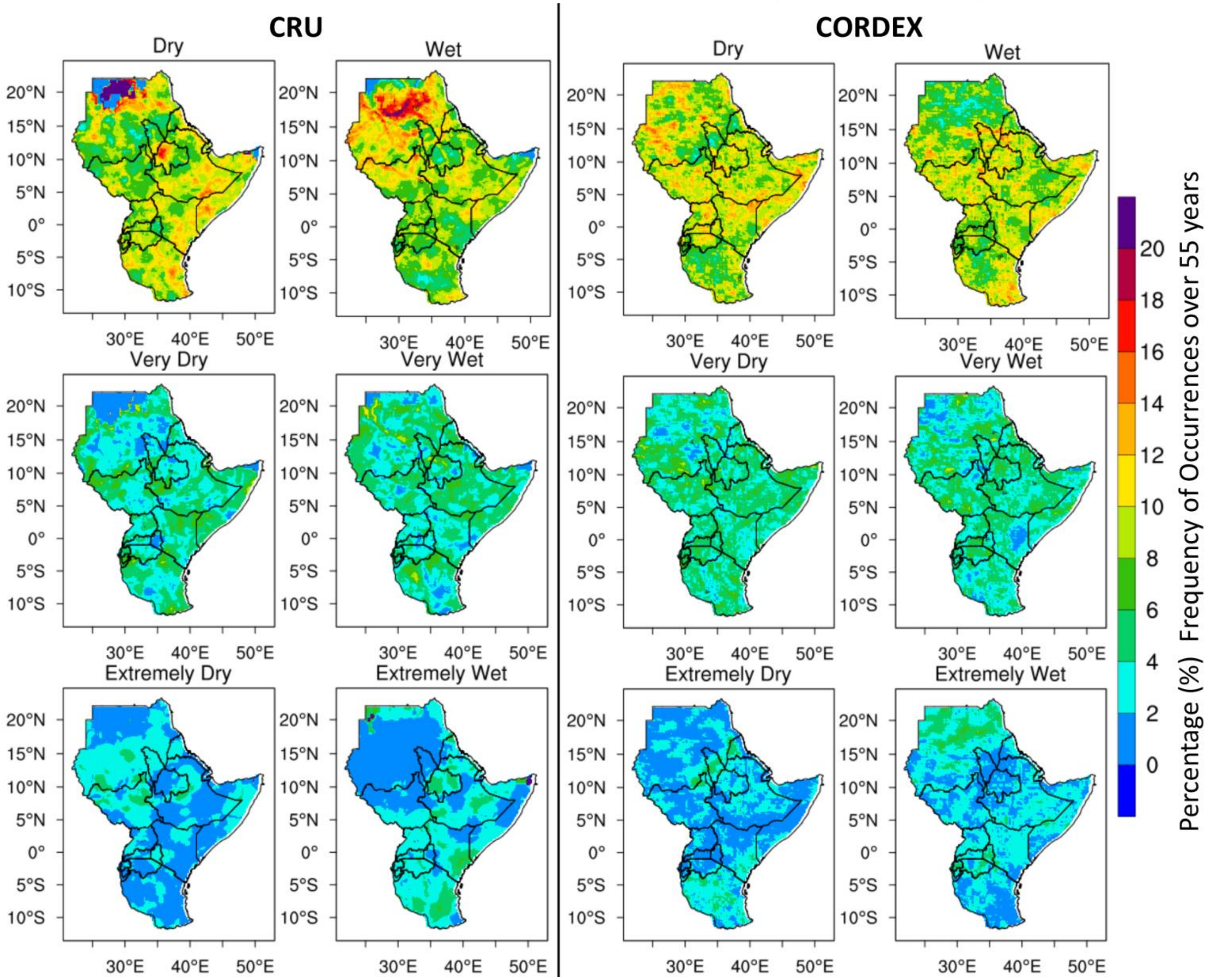

Figure 8: Historical flood and drought frequency maps for SPI-12 for CRU (left) and CORDEX (right) over a period of 55 years (1951 to 2005)**.**

3.3.3 Climate Variability and Seasonal Trend

This section present the annual climate variability (CV) over the two basins i.e. BNB and LVB (Figure 9) as well as the trends of seasonal total rainfall over the region (Figure 10). Much of the variability in the two basin is generally lower that 30 percent, except at the exit of BNB, where the variability is between 30 to 40 percent.

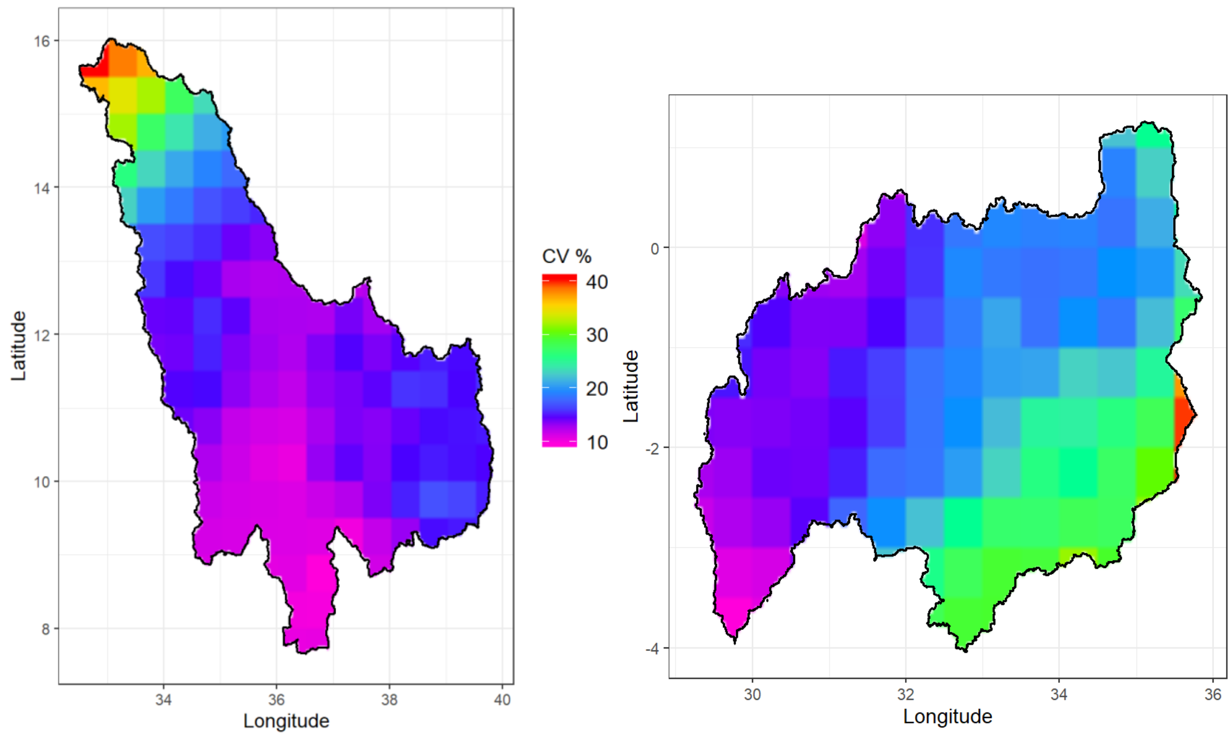

Figure 9: Annual climate variability over the Blue Nile Basin (left) and the Lake Victoria Basin (right) for the period 1901 to 2017 using CRU data.

The seasonal trends for MAM which is the long raining season over the equatorial/southern sector of the GHA indicates a slight decrease in rainfall trend. This pattern was also observed in June-July-August (JJA) season (Figure 10) which is the main season over the northern sector of the GHA region. However, increasing trend is evident in September-October-November (SON) and December-January-February (DJF) season with a high magnitude observed in SON season. SON is the short rain season over the equatorial/southern sector of the region and this increase may mean that the season is getting better, thus more water availability during September to February.

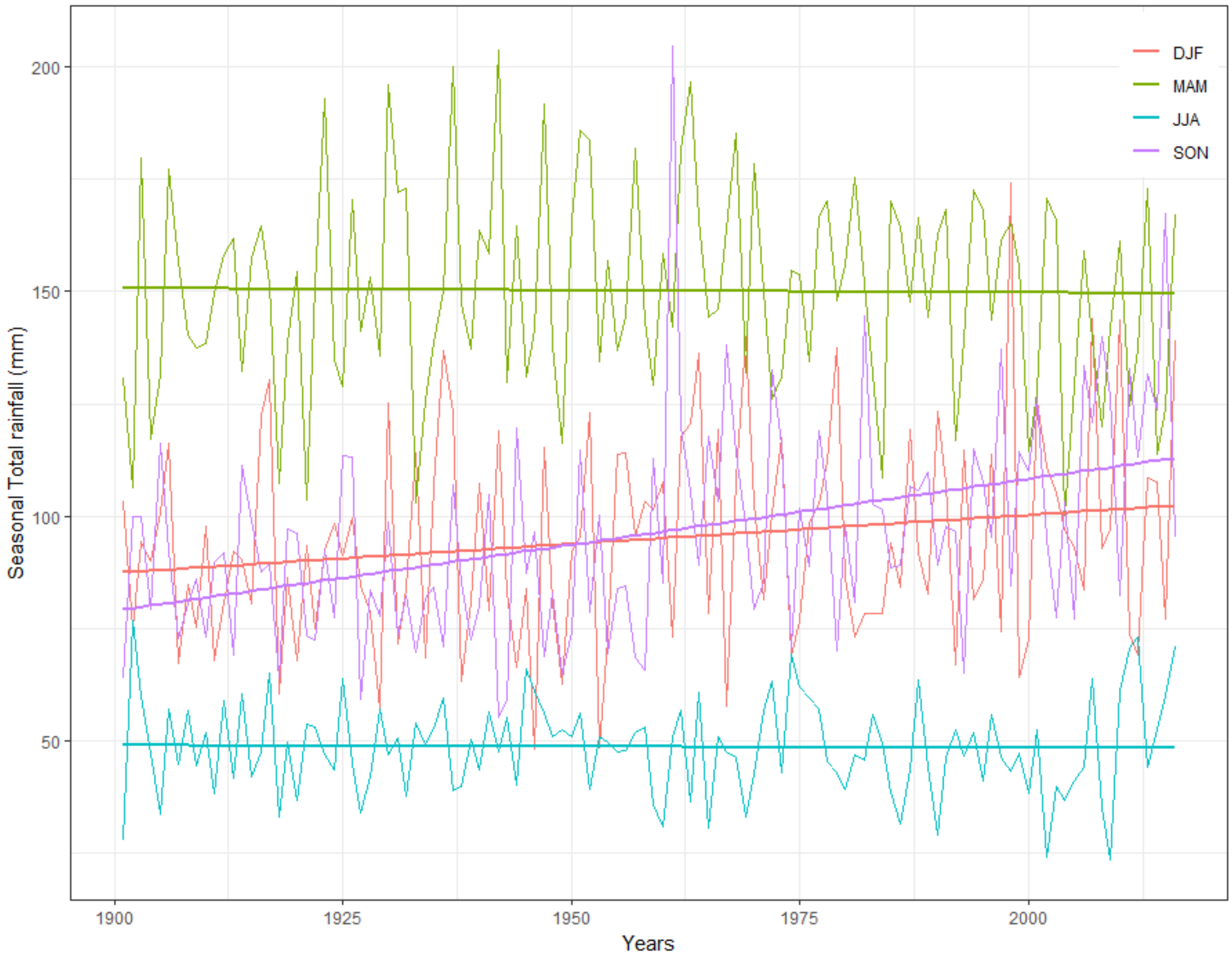

Figure 10: Trends of seasonal total rainfall (December-February, March-May, June-August, and September-November) over the GHA region from 1901 to 2017 using CRU data.

3.3.4 Future climate scenario maps for the GHA highlighting the two Basins (Flood/Drought)

We started by evaluating the coefficient of rainfall variation over the region and covering BNB as well as LVB. Figure 11 shows that historical CORDEX data can capture observed historical pattern. However, the intensity of the rainfall variation is not well captured. Distinct difference in intensity is observed over much of Sudan including the northern part of the BNB, much of Somalia, eastern Ethiopia, eastern Kenya, and much of central and southern parts of Tanzania. With this observation, the model analysis can only be used to give the expected pattern as well as direction but not the intensity of rainfall.

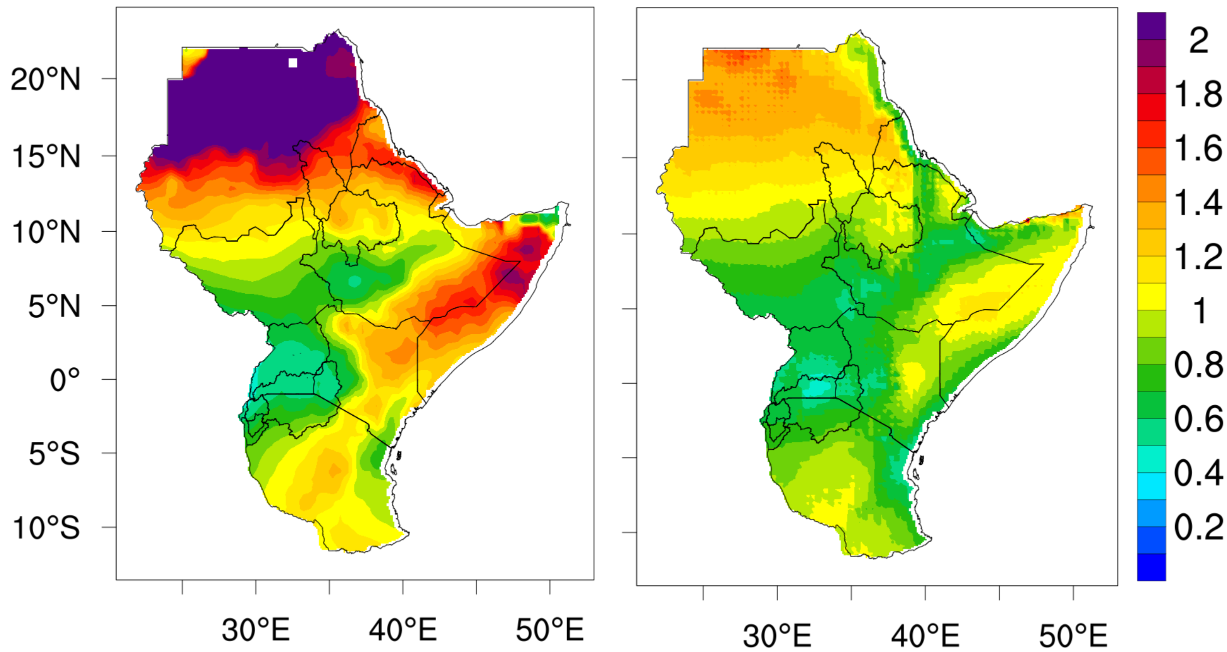

Figure 11: Panel plot for Coefficient of variation Blended rainfall observation (left) and historical CORDEX data (right) from 1951 to 2005.

The percentage frequency of drought (dry) and floods (wet) are high under the Dry/Wet category over the GHA region including the BNB and LVB basins, but very low under the extremely Dry/Wet category (**Figure 12**). This pattern is observed in all the time steps i.e. 12, 24, 36, and 48 used in this analysis for the different Representative Concentration Pathways (RCP) scenarios (RCP45 and RCP85) for the periods 2021-2050 (mid-century) Figures 12, 13, 14, &15 and 2061-2090 (end of century) Figures 16, 17, 18, & 19 in Annex. High frequency of Dry/Wet are not wide spread over the two basins but are seen as isolated patches. However, this gives an idea of how the future is like be. The categorization of Dry/Wet classes are given in **Table 3** found in section 3.3.2.

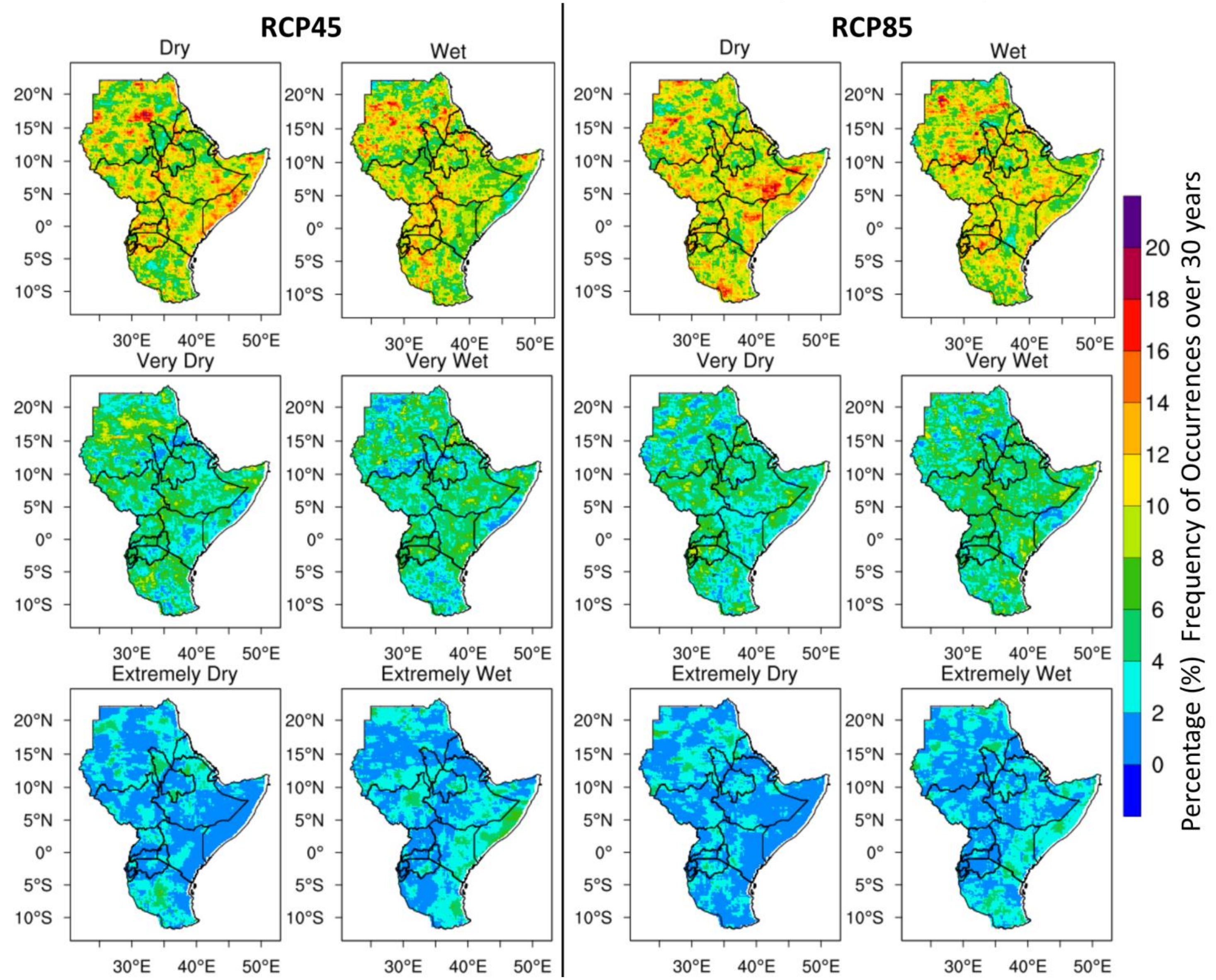

Figure 12: Projected flood and drought frequency maps for SPI-12 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2021 to 2050.

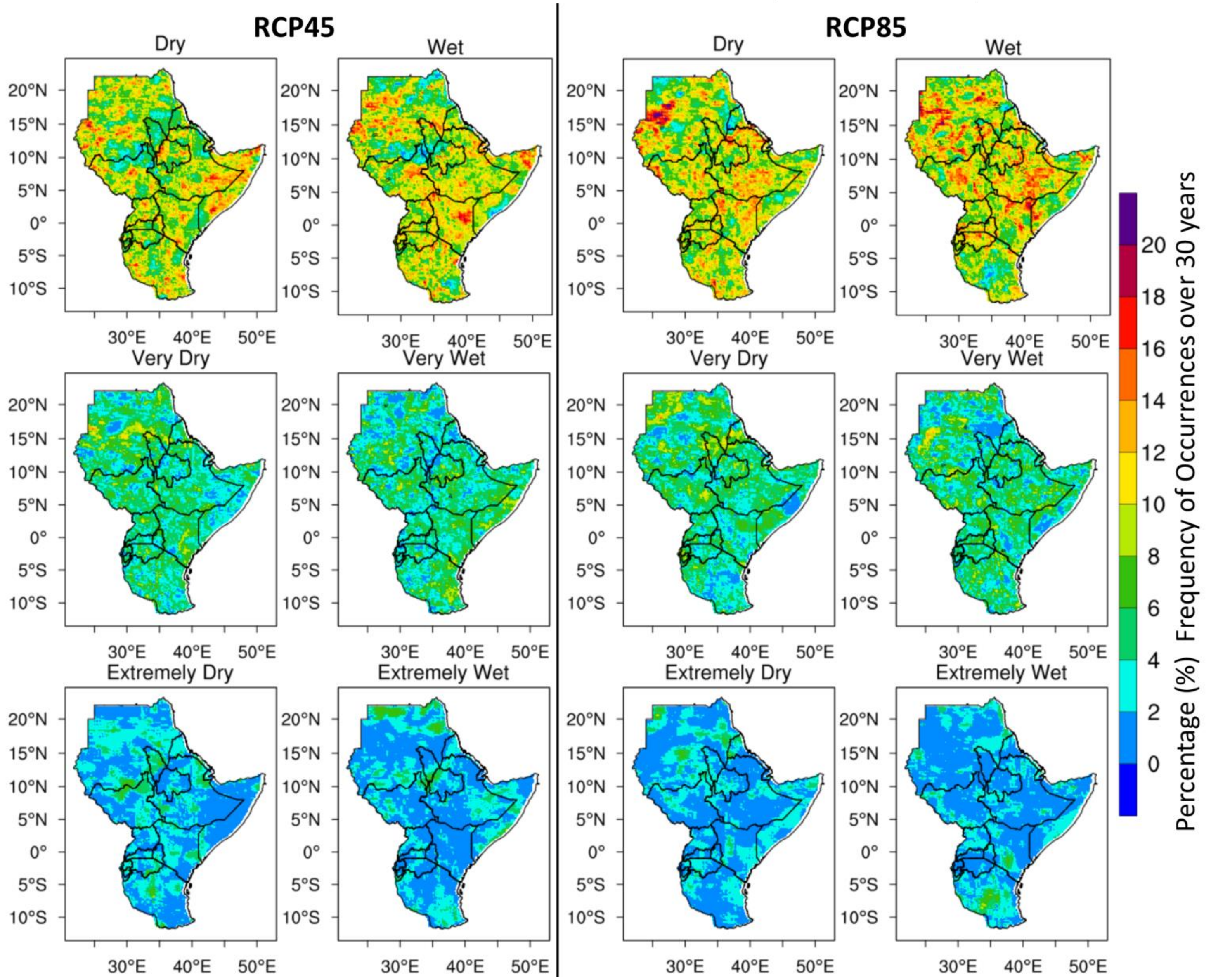

Figure 13: Projected flood and drought frequency maps for SPI-24 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2021 to 2050

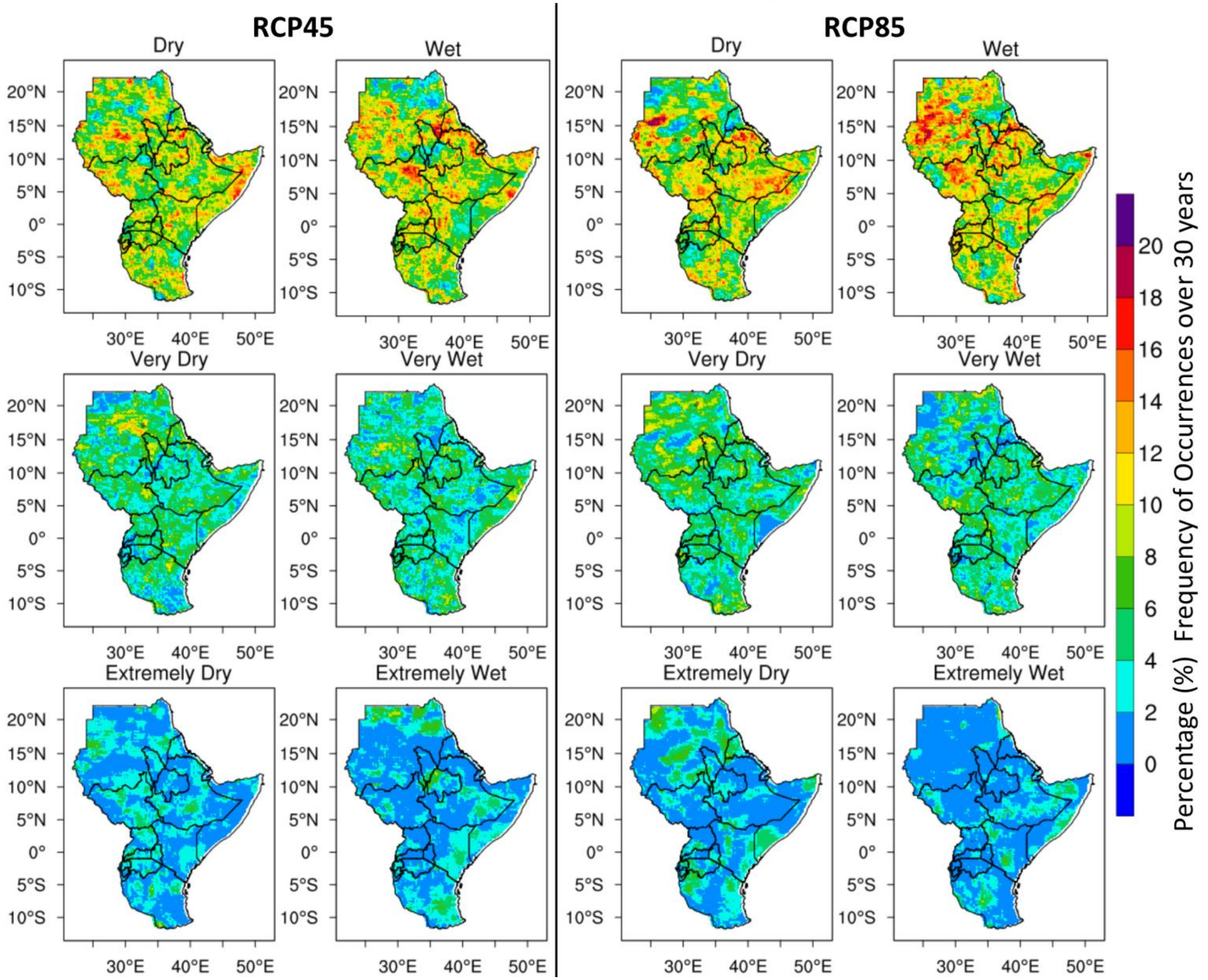

Figure 14: Projected flood and drought frequency maps for SPI-36 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2021 to 2050

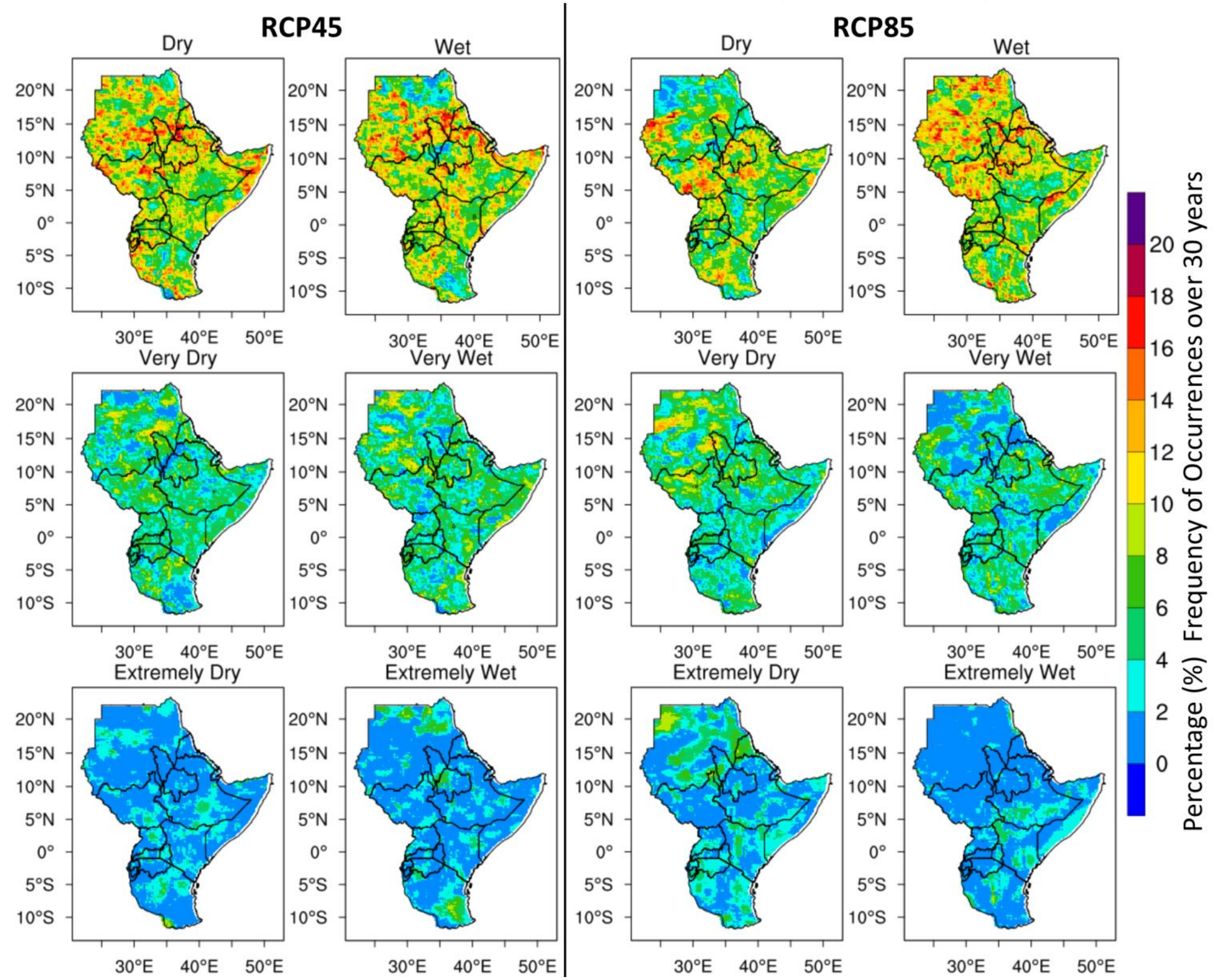

Figure 15: Projected flood and drought frequency maps for SPI-48 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2021 to 2050

4 CONCLUSION

We set out to assess climate variability and extreme events over the GHA region in perspective of WEFE nexus, inline of hydropower, reservoir multipurpose optimization and release management (in particular the BNB), rain-fed and irrigated agriculture development among others. The objective was to assess WEFE interdependencies across the Nile River Basin, with a particular focus on the BNB and the LVB. The result showed that, at the regional scale using SPI and SPEI, there were more extreme wet conditions before the 1970s with 1961 observed as the wettest on record. After the ’70s, more dry conditions were observed in the region with 1984 and 2011 observed noted as the extreme years. The periodicity of these dry/wet conditions was observed to be three years which can be attributed to the El Nino Southern Oscillation. The result confirmed that the recent food insecurity issues in the GHA region caused by extremely dry conditions. Results from the historical frequency analysis showed that the most affected areas in terms of drought were; Much of Sudan, eastern Ethiopia, much of Somalia, much of Kenya, central and eastern Tanzania, and much of the central part of BNB. Floods, on the other hand, affected mostly Sudan, the northern part of South Sudan, central Ethiopia, and northeastern Kenya.

An increasing trend of abnormal wet conditions from 1961 to current was observed over LVB. This implies more water available over the basin with increasing flood events. This is a good indication of recharge to the Nile River. However, the BNB has recorded more dry (drought) conditions in the recent past, thus reducing inflows into the Nile River. This basin was observed to have the longest drought on record which occurred from 1980 to 1995.

A projection into the future (2021-2050) indicates that the region will experience a high frequency of dry/wet conditions for both RCP45 and RCP85 covering wide areas. Countries that are likely to be affected during this period are; Sudan, South Sudan, eastern Ethiopia, eastern Kenya, and Somalia. This is also a clear indication of high rainfall variability in these countries since the frequency of both dry and wet conditions is high. Towards the end of the century (2061-2090), Somalia is likely to experience the highest impact of drought and floods in the region. The finding of this analysis will be published in a scientific journal that can be further used to inform policy formulation in region.

ANNEX

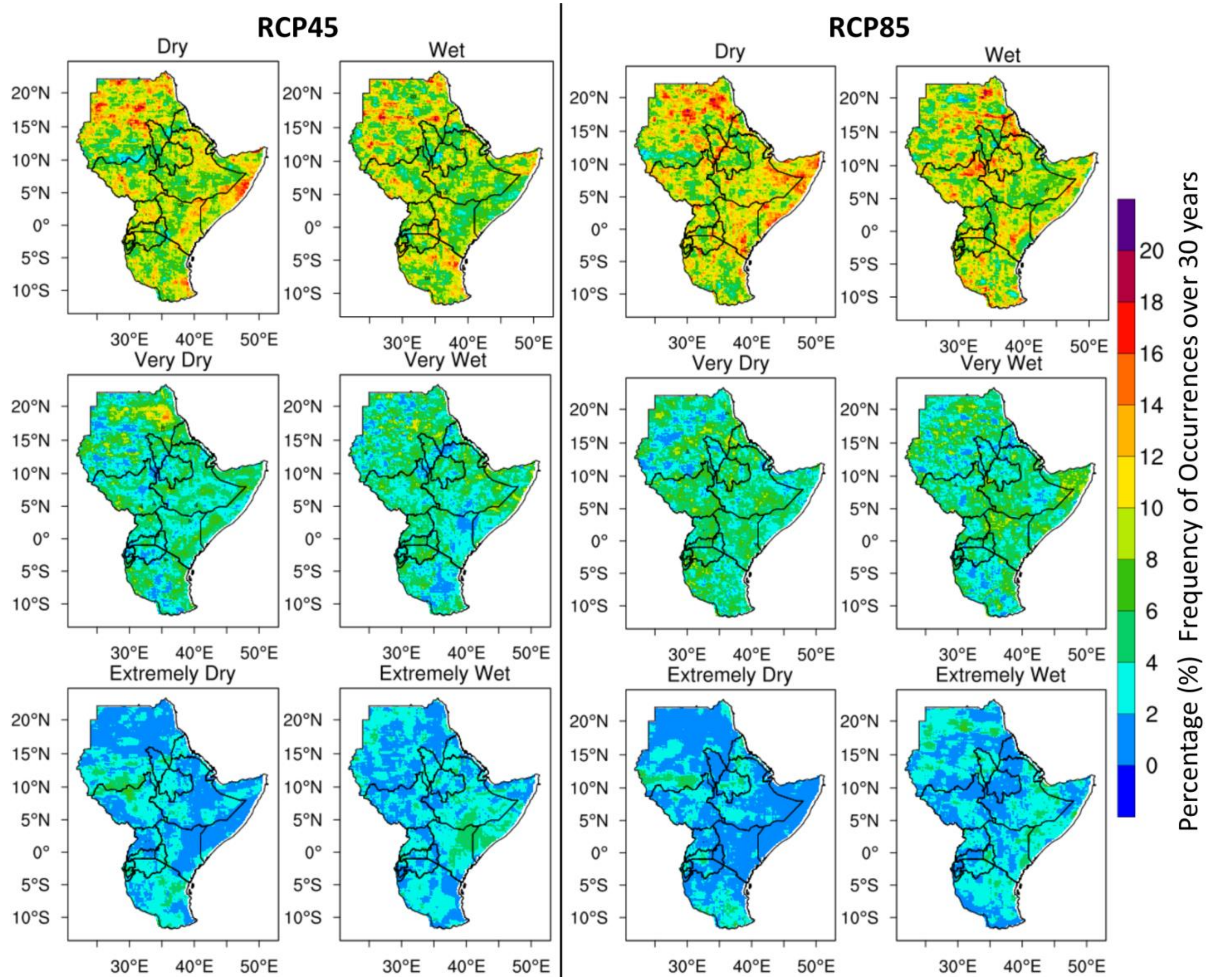

Figure 16: Projected flood and drought frequency maps for SPI-12 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2061 to 2090

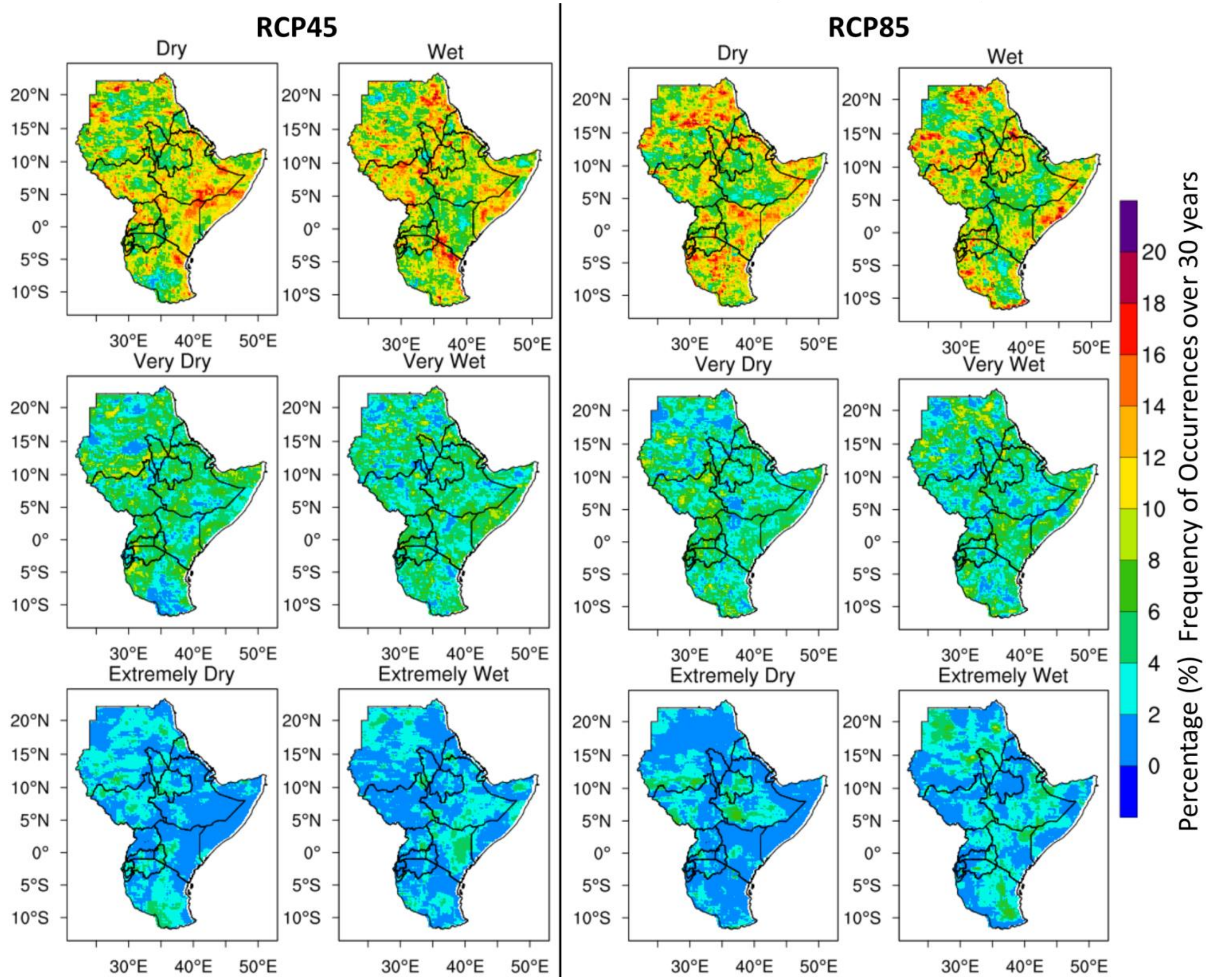

Figure 17: Projected flood and drought frequency maps for SPI-24 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2061 to 2090

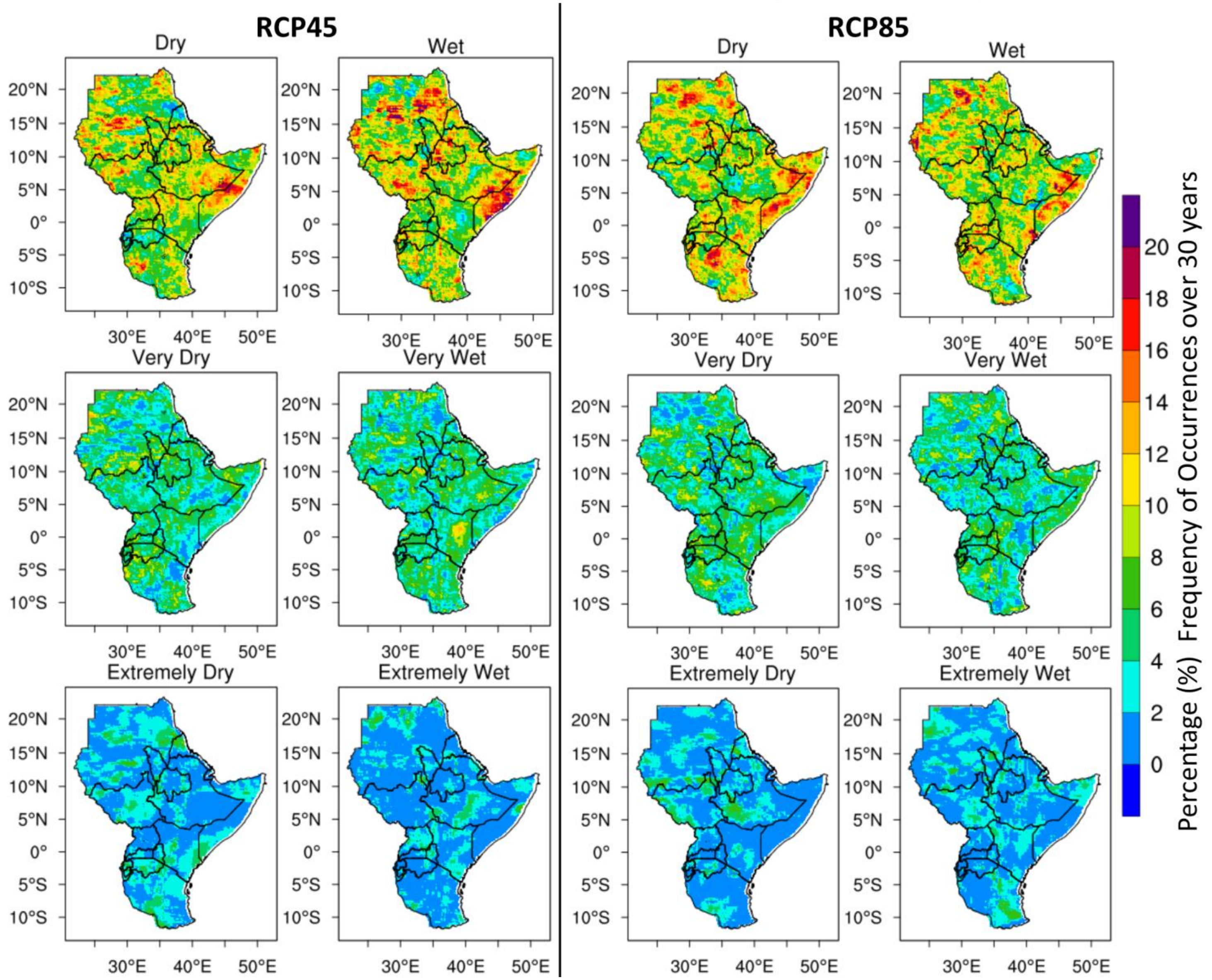

Figure 18: Projected flood and drought frequency maps for SPI-36 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2061 to 2090

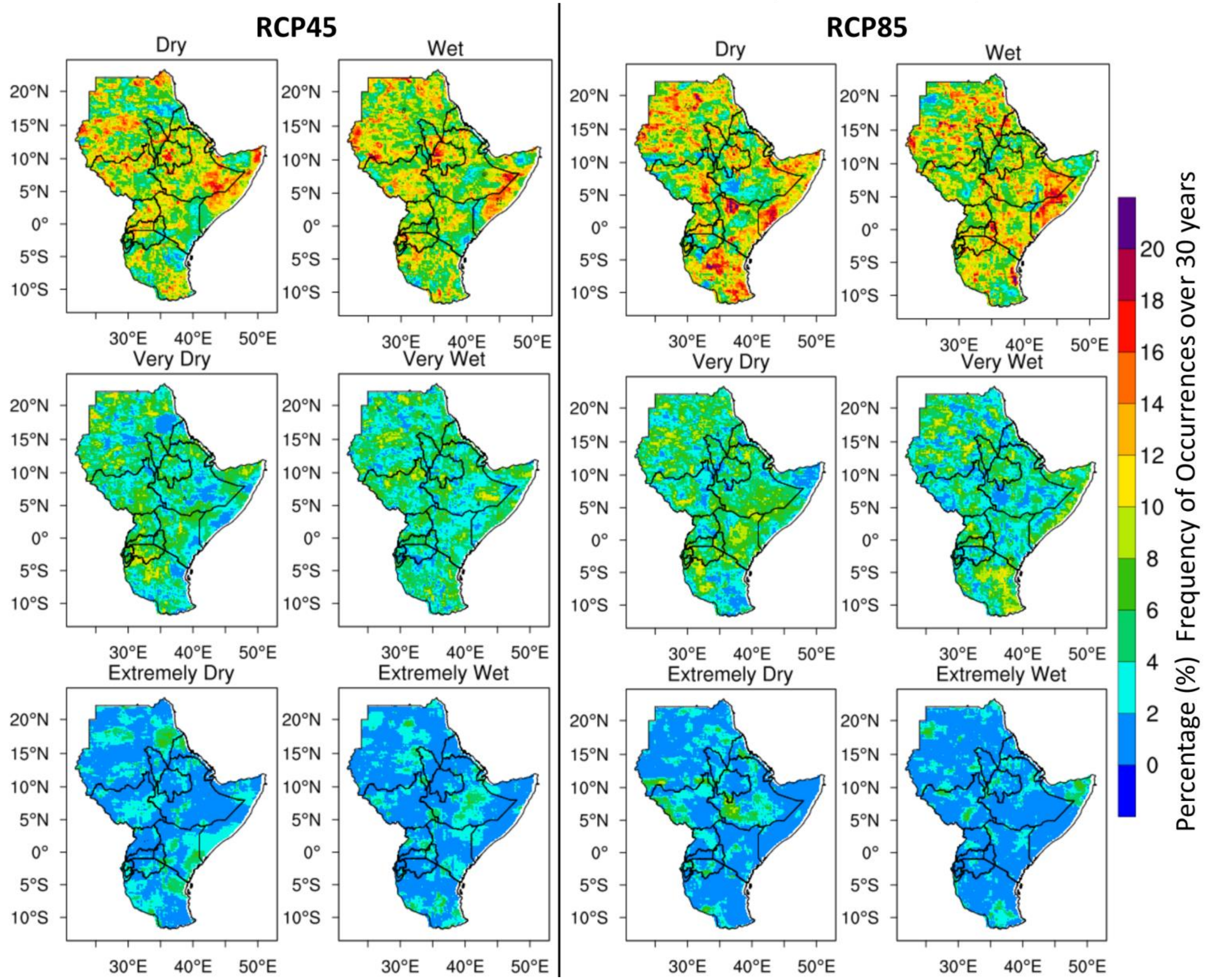

Figure 19: Projected flood and drought frequency maps for SPI-48 of RCP45 (left) and RCP85 (right) using CORDEX data for the period 2061 to 2090**.**

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