Meteorological drought trends in Burkina Faso (1991–2023): A monthly and seasonal rainfall anomaly index analysis

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ABSTRACT

This article analyzes monthly and seasonal spatial trends in drought within Burkina Faso using the Rainfall Anomaly Index (RAI). Rainfall data from the Burkina National Meteorological Agency (1991–2023) were processed using the R package 'precinctcon' and hydroTSM. Trends were then evaluated using Spearman's Rho (SR) tests and Inverse Distance Weighting (IDW) interpolation. The results demonstrated a seasonally differentiated distribution of droughts. While drought dominates the pre-wet season; a distinct wet phase occurs during the peak rainy months of July and August. In contrast, the post-wet season, exhibits fluctuating wet and drought periods. RAI values reflect high inter-seasonal variability, showing that rainfall is concentrated into only a few months. This exposes different regions of Burkina Faso to greater risks of drought. This concentration increases drought risk across various regions, creating significant challenges for farmers during the shoulder seasons and posing a major threat to food security for Burkina Faso's rural populations.

KEYWORDS

meteorological droughts; RAI; trend; spatial; Burkina Faso

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1. Introduction

Climate change is a phenomenon that affects many aspects of the climate. Among these, we observe an increase in evaporation (Al-Hasani et al. 2025; Minea et al. 2025), changes in hydrological regimes (León-Muñoz et al. 2024; Kour et al. 2016; Wanders et al. 2015) and increased variability in precipitation and temperatures (Mohammed et al. 2025; Fang et al. 2025; Panday et al. 2025) on a global scale. This situation has led to an increase in the frequency, severity, and duration of droughts (Tegegne et al. 2025; Abara and Budiastuti 2020; Spinoni et al. 2014; Hosseinizadeh et al. 2015; Lee and Kim 2013) have highlighted the impact of rising temperatures on increased evaporation and, consequently, on soil water deficits. This increase has led to more intense and prolonged droughts in many regions of the globe, as demonstrated by studies by Dai (2013) and Mukherjee et al. (2018).

According to projections, by the end of the century, around one-third of the land could be affected by moderate to severe drought if greenhouse gas emissions are not significantly reduced (Naumann et al. 2018; Cook et al. 2020; IPCC 2021; Zeng et al. 2023). It should be noted that several regions of the world are already affected by this extreme phenomenon. This dynamic has attracted considerable interest from several authors, who have undertaken to examine the issue on a global scale. Indeed, as demonstrated by several studies (Todaro et al. 2022; Luppichini et al. 2022), the Mediterranean region is facing a decrease in summer rainfall combined with rising temperatures. This combination of factors is leading to marked soil drying and longer and more intense droughts (Sousa et al. 2011; Castellanos et al. 2021).

Climate variability, which is reflected in an increase in extreme weather events (precipitation, temperatures) in West Africa (Yaméogo et al. 2026; Yaméogo 2025a; Yaméogo 2025b; Yaméogo 2024; Sylla et al. 2016; Barry et al. 2018; Mouhamed et al. 2013), Central Africa (Ndehedehe et al. 2016b), Southern Africa (Ngaina and Mutai 2013), and North Africa (Lelieveld et al. 2016; Ntoumos et al. 2022), causing frequent droughts throughout Africa. Indeed, in North Africa, countries such as Morocco, Algeria, and Tunisia are facing an increase in the frequency, duration, and severity of droughts (Simsek et al. 2025; Oubaha et al. 2025; Kheloufi Attou et al. 2025; Bouregaa 2023; Mohamed et al. 2023). According to the study by Lim Kam Sian et al. (2023), droughts of varying severity affected equatorial Africa, southern Africa, and Madagascar during the period 1983–2014. Indeed, the equatorial region is prone to the highest number of drought episodes, with longer periods of severe and extreme drought. East Africa is facing increasingly prolonged periods of drought. In contrast, southern West Africa and Madagascar are characterized by low and consistent drought severity across all categories.

West Africa is affected by droughts that vary in frequency, duration, and intensity (Noureldeen et al. 2020; Doukoro et al. 2022; Lim Kam Sian et al. 2023; Attiogbé et al. 2025). Burkina Faso, located in this region, is also affected by this phenomenon. Yaméogo (2025c) highlights the high variability of droughts in the Mouhoun-Comoé basin. However, a recurrence of drought was observed between 2010 and 2020, with adverse consequences for agricultural production, livestock farming, and malnutrition (Traore and Owiyo 2013; Sawadogo 2022). This situation has prompted many authors to study the droughts that

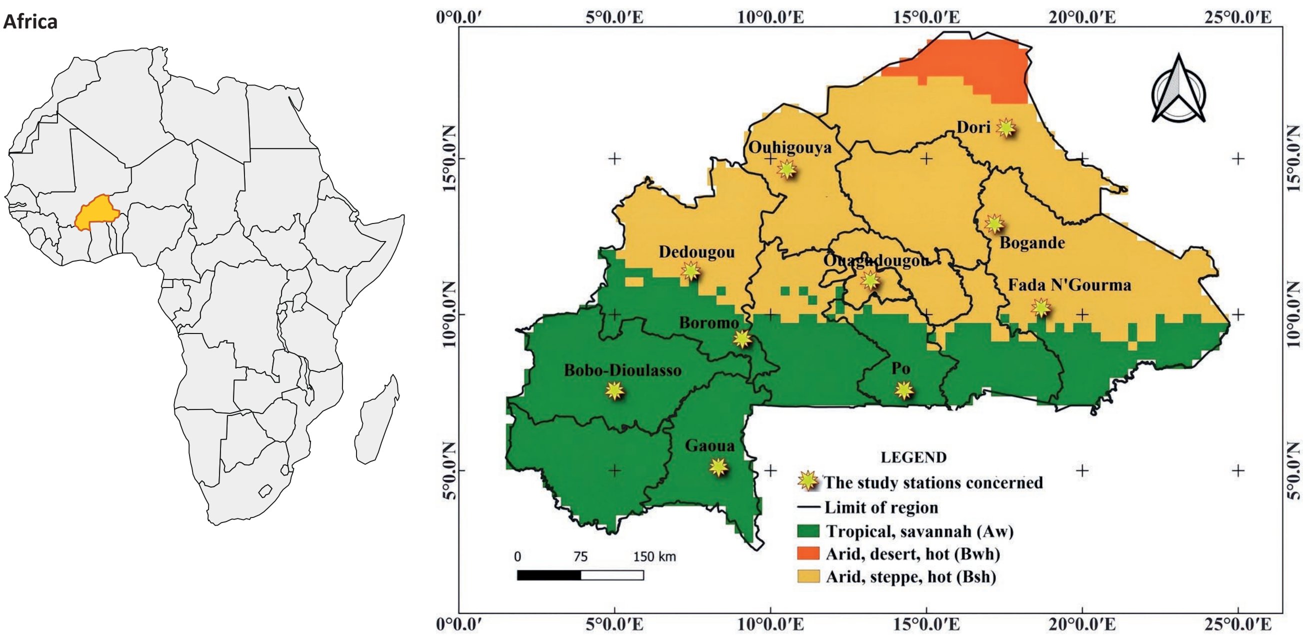

Fig. 1 Location of climate zones in Burkina Faso.

have occurred in Burkina Faso in recent decades. Studies have been conducted at the Volta Basin scale in Burkina Faso using several indices, such as the Standardized Precipitation Index (SPI), the Standardized Runoff Index (SRI), the Standardized Soil Moisture Index (SSI), and the Multivariate Standardized Drought Index (Ndehedehe et al. 2016a). Fowé et al. (2023) also analysed droughts in the Nakambè watershed using the Standardised Precipitation Index (SPI) and the Standardised Precipitation and Evapotranspiration Index (SPEI). These previous studies were only conducted at the local level, i.e. at the watershed level. The present study aims to complement this previous work and address these gaps. The study aims to analyse drought trends in Burkina Faso using the RAI. The main objective of the study is to analyze the spatio-temporal trend of droughts in Burkina Faso over the period 1991–2023.

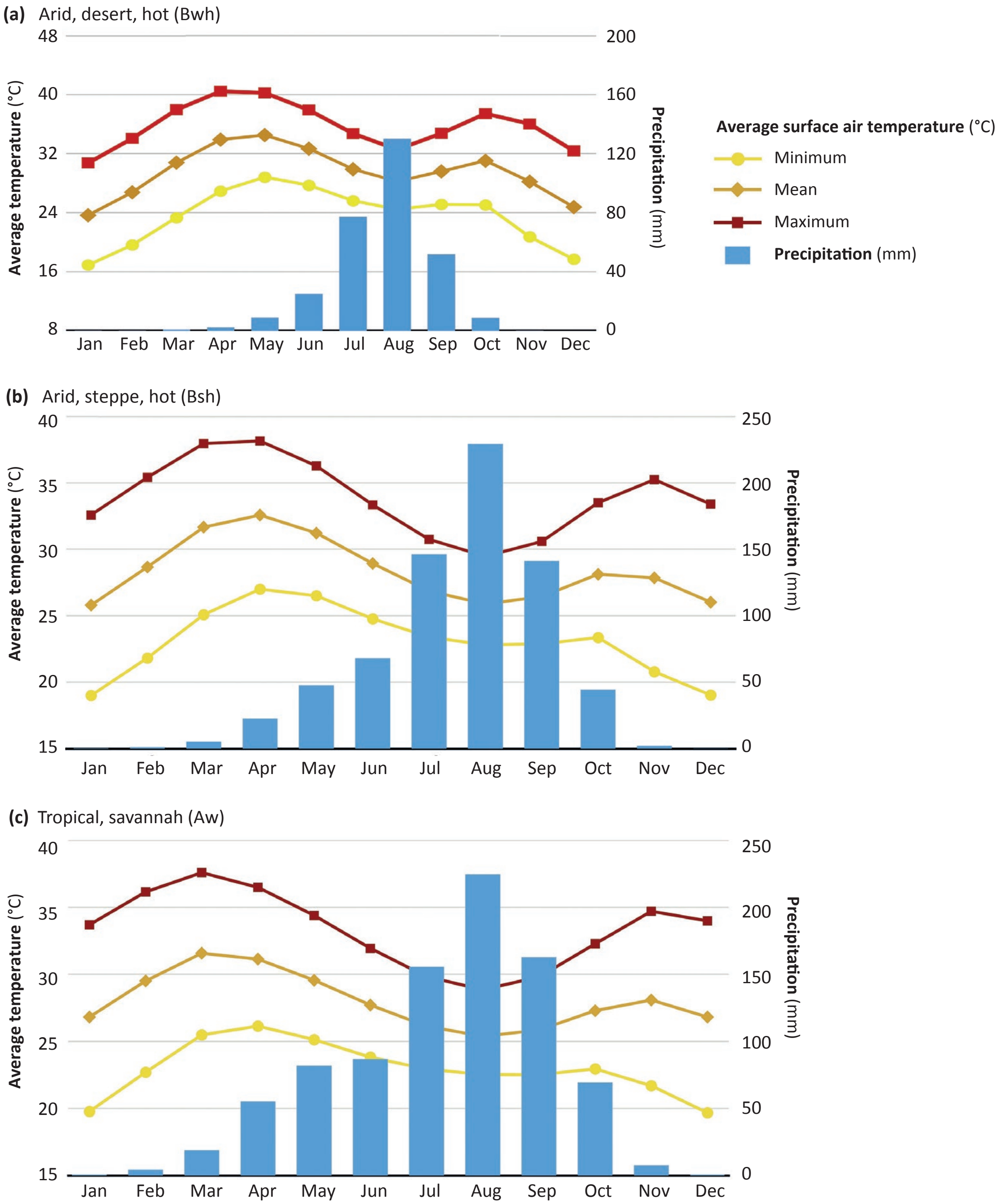

Fig. 2 Monthly precipitation and temperature trends in Burkina Faso over the period 1991–2023.

Tab. 1 Characteristics of selected stations from 1991 to 2023.

N°	Name station	Climate zone of the stations	Type of station	Latitude	Longitude	Elevation (m)
1	Bobo-Dioulasso	Aw	synoptic	11.16670	−4.3167	432
2	Bogande	Aw	climatological	12.98330	−0.1600	294
3	Boromo	Aw	synoptic	11.73000	−2.9200	264
4	Dédougou	Bsh	synoptic	12.47000	−3.4800	299
5	Dori	Bsh	synoptic	14.03330	−0.0333	276
6	Fada N'Gourma	Bsh	synoptic	12.06667	0.3500	308
7	Gaoua	Aw	synoptic	10.33000	−3.1800	292
8	Ouagadougou	Bsh	synoptic	12.35000	−2.1800	303
9	Ouahigouya	Bsh	synoptic	13.58000	−2.4300	335
10	Po	Aw	synoptic	11.17000	−1.1500	321

Source: ANAMBF, 2024.

2. Material and method

2.1 Study of area

Burkina Faso is a low-income country located in the Sahel region with limited natural resources. Its economy is mainly based on agriculture and mining. The country is divided into three climatic zones (Fig. 1). It has a tropical Sudano-Sahelian climate, characterized by two main seasons. The dry season, which lasts from October to May, is dominated by the harmattan, a hot, dry wind from the Sahara. This season is characterized by low annual rainfall and high temperatures. The rainy season lasts from June to September. The monsoon wind dominates during this period. It is characterized by heavy rainfall and moderate temperatures. The most important geographical factors influencing rainfall in Burkina Faso are: the prevailing winds, such as the Harmattan and the monsoon, and climatic variations according to latitude (less pronounced in the country), which create distinct zones, ranging from south to north. This also promotes rainfall in certain regions of Burkina Faso. It is vital to understand that the agricultural sector (sorghum, maize, rice) is key to both tackling hunger and making life better for the people of Burkina Faso.

Fig. 2 below also shows a decrease in precipitation and temperatures from north to south. This situation could be explained by the fact that the rainy season begins in the tropical savanna zone. This situation has led to heavy rainfall in the tropical savanna zones, followed by the arid, steppe, and hot zones of Burkina Faso. The arid, desert, and hot zone receives less precipitation.

2.2 Data

They come from Burkina Faso's national meteorological agency. They concern 10 stations, 90% of which are synoptic stations and 10% climatological stations (Tab. 1). The climate variable used is precipitation over the period 1991–2023.

2.3 Method

2.3.1 Rainfall Anomaly Index

Meteorological drought is a phenomenon characterized by a prolonged absence of precipitation (Alwan et al. 2018). It is defined as an event characterized by a precipitation deficit compared to the normal or average recorded over a period of at least 30 years (Harisuseno 2020). Several indices are used to analyze meteorological droughts, such as the Rainfall Anomaly Index (RAI), Deciles Index (DI), Nitzche Index, Standardized Precipitation Index (SPI), Percent of Normal Precipitation Index (PNPI), Z-Score, China Z Index (CZI) (Montaseri et al. 2017; Haied et al. 2017). The Rainfall Anomaly Index (RAI) is increasingly used as a drought index, similar to the SPI. Indeed, several criteria, including robustness, tractability, and transparency, show that this index is valid for analyzing drought in West Africa (Tab. 2).

Furthermore, the RAI is widely used in several studies, notably those by Khalil (2022) and Raziei

Tab. 2 Comparison of RAI and other drought indices used in West Africa.

Drought index	Robustness	Tractability	Transparency	Total weight	Rank
Standardized Precipitation Index (SPI)	1	4	5	3.33	2
Rainfall Anomaly Index (RAI)	1	5	5	3.66	1
Standardized Precipitation Evapotranspiration Index (SPEI)	1	4	1	2.00	3

Source: Quiring 2009; Keyantash and Dracup 2002.

Tab. 3 Classification of Rainfall Anomaly Index (RAI).

Index (RAI)	Classification
≥3	Extremely humid
2 to 2.99	Very humid
1 to 1.99	Moderately humid
0.5 to 0.99	Slightly humid
−0.49 to 0.49	Near normal
−0.99 to −0.5	Slightly dry
−1.99 to −1	Moderately dry
−2.99 to −2	Very dry
≤ −3	Extremely dry

Source: Van Rooy 1965; Hänsel et al. 2016; Abbas 2024.

Tab. 4 RSI values and classification.

Rainfall regime	RSI
Very equable	≤0.19
Balanced with a distinct wet season	0.20–0.39
Rather seasonal with a short drier season	0.40–0.59
Seasonal	0.60–0.79
Characterised by seasons, with a long dry season	0.80–0.99
Most rain in 3 months or less	1.00–1.19
Extreme, almost all rain in 1 to 2 months	≥1.20

Source: Walsh and Lawler 1981.

(2021), as there is a very strong correlation between the RAI and the SPI. Several other studies (Tsakiris et al. 2007; Silva and Azevedo 2020; Biswas and Karmegam 2023; Şener and Davraz 2024; Waghmare et al. 2022) have therefore used the RAI to analyse drought in Brazil and India. This confirms that the RAI is a robust drought index, as negative RAI values indicate insufficient rainfall and drought-related water stress (Hänsel et al. 2016).

The Rainfall Anomaly Index (RAI), developed by van Rooy in 1965, was used to illustrate periods of drought and wetness in the region (Sadiq et al. 2020). The RAI helps us understand the probability of dry conditions, including droughts. According to Shibru et al. (2023), the RAI can be used to assess the level of drought in a given area.

The RAI involves a ranking process that assigns magnitudes to positive and negative precipitation anomalies (Keyantash and Dracup 2002). The RAI is calculated as described below (Van Rooy 1965; Harisuseno 2020):

If, $P > \overline{P}$ anomaly is positive and drought index can be computed using the following equation:

$$RAI = +3\left(\frac{P-\bar{P}}{\bar{M}-\bar{P}}\right)$$

If, $P > \overline{P}$ anomaly is negative and droughts index can be determined using the following equation:

$$RAI = -3\left(\frac{P-\bar{P}}{\bar{X}-\bar{P}}\right)$$

Where, P = current monthly/yearly rainfall (mm), $\overline{P}$ = average precipitation, and M = the historical series' 10 highest monthly/yearly rainfall average (mm), X = the historical series' 10 lowest monthly/yearly rainfall average (mm).

Negative RAI values indicate drought-related water stress (Hänsel et al. 2016). Tab. 3 presents the classification of RAI according to Van Rooy 1965.

Seasonality plays a role in the Sahel region of West Africa (Nicholson 2013). It is therefore important to understand its spatial footprint over the ten-year period from 1991 to 2023.

2.3.2 Rainfall Seasonality Index (RSI)

The seasonality index indicates the distribution of precipitation over the entire seasonal cycle, which is used to classify different rainfall regimes (Guhathakurta and Saji 2013; Soren et al. 2025). According to Walsh and Lawler1981), its mathematical formula is as follows:

$$RSI = \frac{1}{\bar{P}}\sum_{n=1}^{12}\left|X_n - \frac{\bar{P}}{12}\right|$$

With, X_n is the of rainfall n month and $\overline{P}$ is the annual average of rainfall.

Thus, a high index indicates very irregular rainfall and increased vulnerability to drought during dry months. A low index indicates regular rainfall and a lower risk of seasonal drought. Tab. 4 below gives the interpretation intervals for the RSI.

2.3.3 Trend analysis methods

Analysing trends in time series data requires an understanding of normality. This enables the selection of the most appropriate trend tests to be more effective. In this study, the Kolmogorov-Smirnov test was chosen.

- Kolmogorov-Smirnov normality test

The Kolmogorov-Smirnov normality test was employed to ascertain the normality of the data distribution. The Kolmogorov-Smirnov test statistic is defined as follows (Sharma and Singh 2010):

$$D = max\left[F(X_i) - \frac{i-1}{N}, \frac{i}{N} - F(X_i)\right]$$

With, F is the theoretical cumulative distribution of measured values, and Xi is the random sample, i = 1, 2, ..., n.

The null hypothesis states that the normality of the data is accepted if the p-value is greater than 0.05. If this is not the case, the alternative hypothesis is rejected and, consequently, a nonparametric test must be used to analyze drought trends. The Kolmogorov-Smirnov test applied to the RAI data shows that 95% of the data does not follow a normal distribution over the period 1991–2023, as the p-values are

<0.0001. Therefore, the use of a non-parametric test is indicated in this study. The Spearman test (SR) was chosen because it is as powerful as the Mann-Kendall test for analyzing trends in time series of climate variables (Sneyers 1990).

- Spearman's rho (SR) test

SR is a non-parametric rank-order test like the Mann Kendall test (Yue et al. 2002). It is a powerful non-parametric test that can be used to determine trends in climate variables (Machiwal and Jha 2008). It postulates hypotheses H_0 defines that there is no trend in the series, while the alternative hypothesis H_1 defines a trend in the series at the chosen significance level (α) and data increase or decrease (Perera et al. 2020).

Spearman's rho is used to analyze trends in studies on droughts in Turkey (Esit et al. 2023; Tuğrul and Hinis 2024; Robleh et al. 2024), in Bangladesh (Kamruzzaman et al 2018a). Spatio-temporal analysis of climatic variables in the western part of Bangladesh. This test performed on the basis of time series data are identically distributed and independent (Perera et al. 2020). Spearman's Rho test is used to establish the correlation between two variables (Vijith and Dodge-Wan 2021).

It test was used to measure R and the Standardized test statistic (Z_{SR}) are obtained by applying the equation (Jayanta et al. 2020):

$$R = 1 - \frac{6\sum D^2}{n^3 - n} \qquad Z_{SR} = R\sqrt{\frac{n-2}{1-R^2}}$$

D is the rank of ith observation, I is the chronological order number, n is the total length of the time series data, and Z_{sp} is Student's t-distribution with (n-2) degree of freedom (Ahmad et al. 2015).

2.3.4 Inverse Distance Weighting (IDW)

This is a quintessential interpolator that employs the distance between sampled points to ascertain the value of points of interest (Ananias et al. 2021; Setianto and Triandini 2013). The IDW method offers satisfactory accuracy and reasonable calculation time (Maleika 2020). IDW is based on the theory that the value of an unknown point is more influenced by nearby points than distant ones (Ly et al. 2011). The IDW formulas are given as equations:

$$R_P = \sum_{i=1}^{N} w_i R_i \qquad w_i = \frac{{d_i}^{-\alpha}}{\sum_{i=1}^{N} {d^{-\alpha}}_i}$$

Arcmap 10.8 software was used for interpolation. Fig. 3 below presents a summary of the methodology.

3.Results

3.1 Seasonal spatial distribution of drought in Burkina Faso between 1991 and 2023

The presence or absence of water impacts the level of drought. As a result, seasonality has been determined according to the pre-rainy season, the rainy season, and the post-rainy season.

3.1.1 Spatial distribution of RAI during the pre-rainy season in Burkina Faso from 1991 to 2023

Fig. 4 shows that during the periods from April 1991 to 2023, the areas in northern Burkina Faso were hit by severe drought, which decreased as one moved southward, with RAI values ranging from −1.36 to −1.2.

Fig. 4d shows the spatial distribution of RAI values in the 2011–2023 period for the month of April,

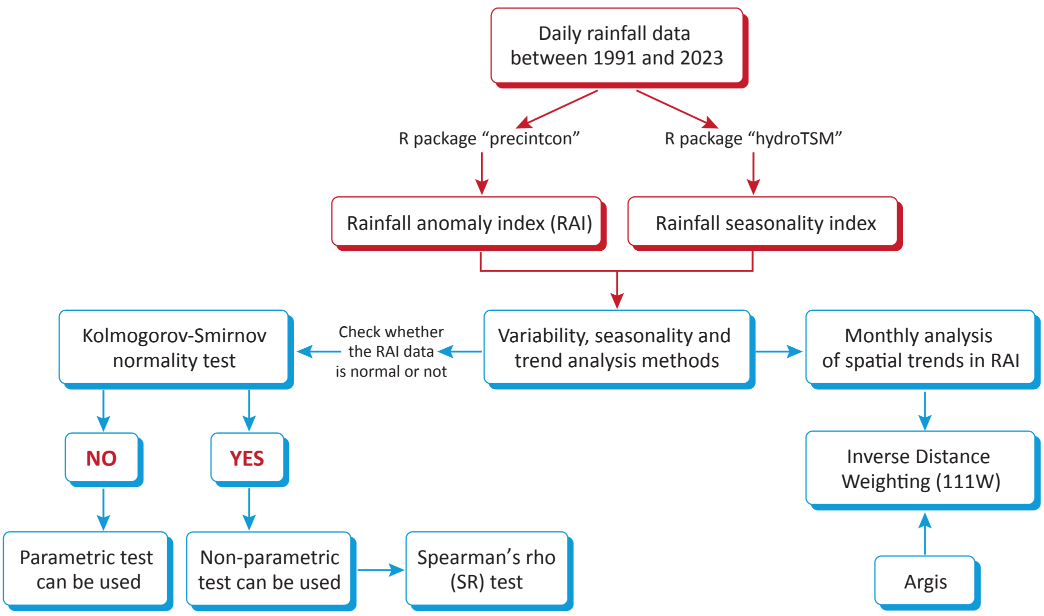

Fig. 3 Synopsis of the methodology.

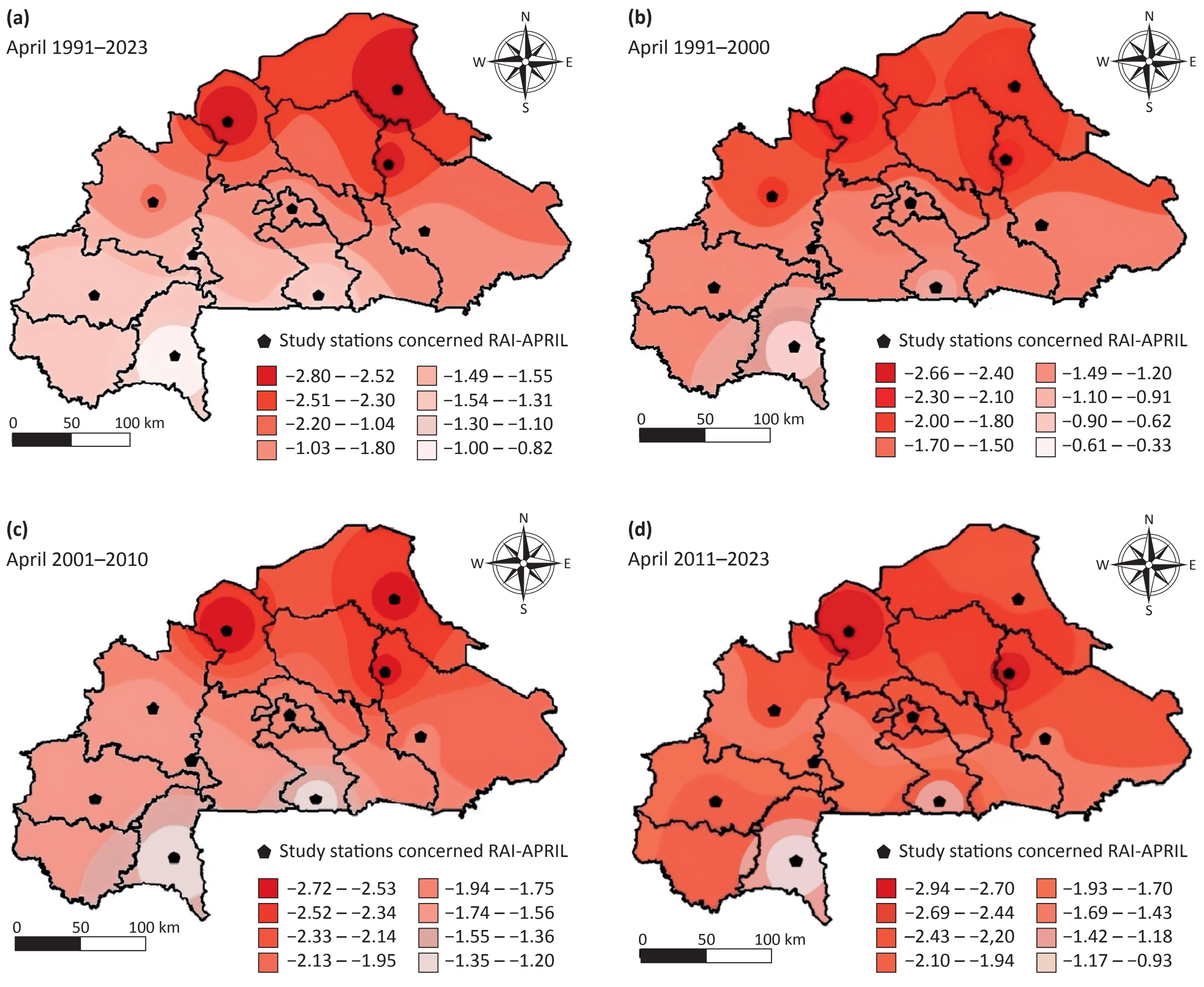

Fig. 4 Spatial distribution of RAI values for the month of April between 1991 and 2023 (a), 1991 and 2000 (b), 2001 and 2010 (c), and 2011 and 2023 (d).

ranging from −2.94 to −0.93. The northern and, to a lesser extent, central regions of Burkina Faso are affected by severe drought. This means that there has still been no rain in April to support agricultural activity. May seems to be no exception to this rule, but the intensity of the drought has decreased. Fig. 5 below shows that the RAI index fluctuates between 1991 and 2023, between 1991 and 2000, between 2001 and 2010, and then between 2011 and 2023. These indices are lower than those for April. This situation indicates a decrease in the level of drought across the entire territory, with the tropical savanna zone being the least affected.

Fig. 5 shows that the northern region was affected by drought, while drought conditions were less severe in the rest of the country. The decade 1991–2000 (Fig. 5b) also shows that, beyond the north, a wet period set in across the country and that the tropical savanna climate zone received rainfall during this period. However, the situation deteriorated in the decades 2001-2010 (Fig. 5c) and 2011–2023 (Fig. 5d) with a return of drought to the arid, steppe, and hot climate zone. Nevertheless, the tropical savanna zone experienced both slight drought and modest humidity during the decades 2001–2010 and 2011–2023.

3.1.2 Spatial distribution of RAI in Burkina Faso throughout the rainy season from 1991 to 2023

Fig. 6 shows a pronounced wet phase across the entire country during the month of June.

Fig. 6 shows that the RAI index increased significantly in June, indicating an increase in wet conditions. This contrasts with the RAI levels observed in April and May, which instead reveal a decrease in humidity and therefore an increase in drought conditions. Also, Fig. 6a shows that during the period 1991–2023, a slight humidity phase affects the tropical zone, savannah, and part of the arid zone, steppe, and hot zone. Most of the arid zone, desert, and hot zone, as well as the center of the country (arid zone, steppe, and hot zone), experience a slight humidity phase. This situation is confirmed in the decade 1991–2000 (Fig. 6b), with a more pronounced wet phase (RAI varies between 0.18 and 0.57 compared to −0.02 and 0.42

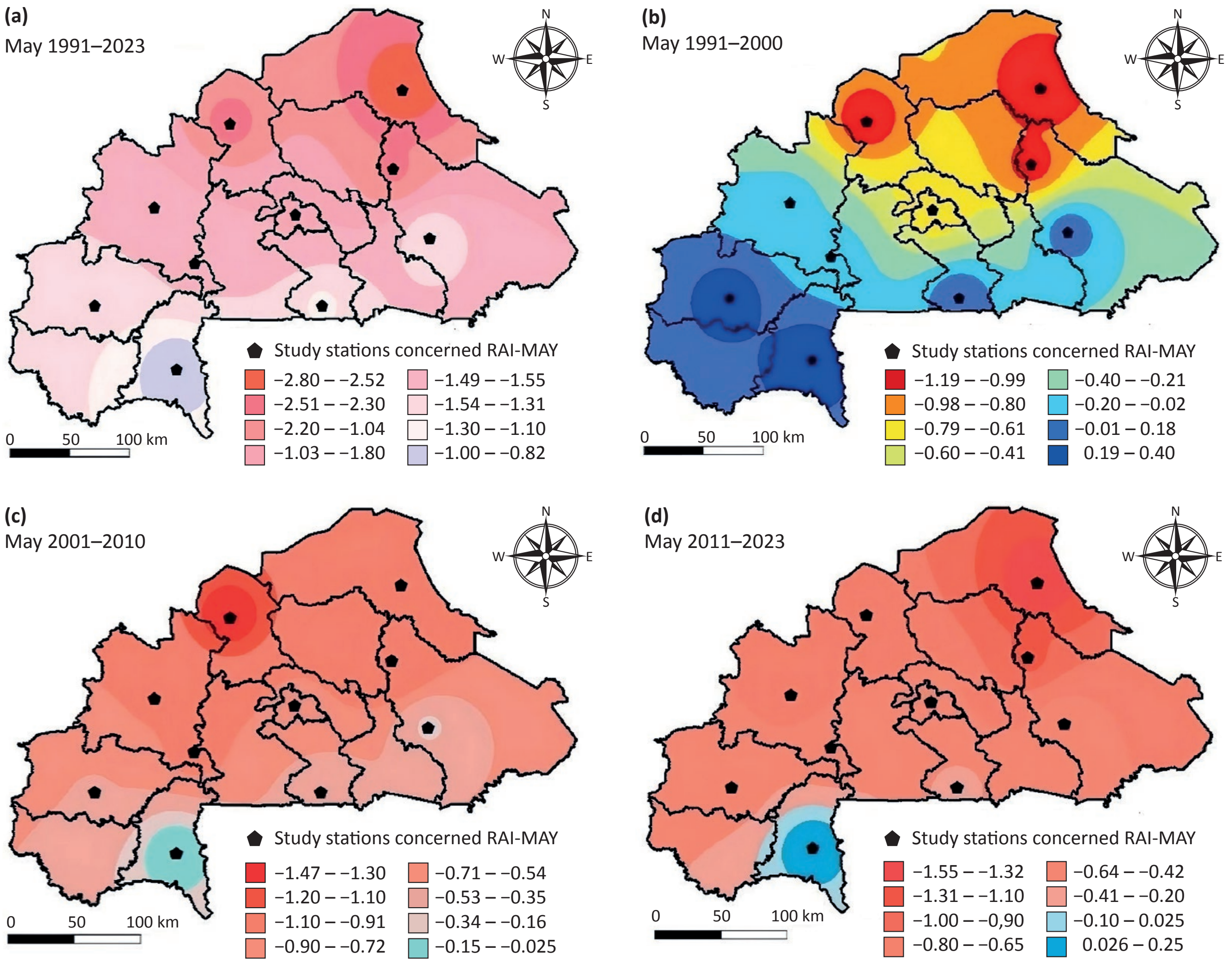

Fig. 5 Spatial distribution of RAI values for the month of May between 1991 and 2023 (a), 1991 and 2000 (b), 2001 and 2010 (c), and 2011 and 2023 (d).

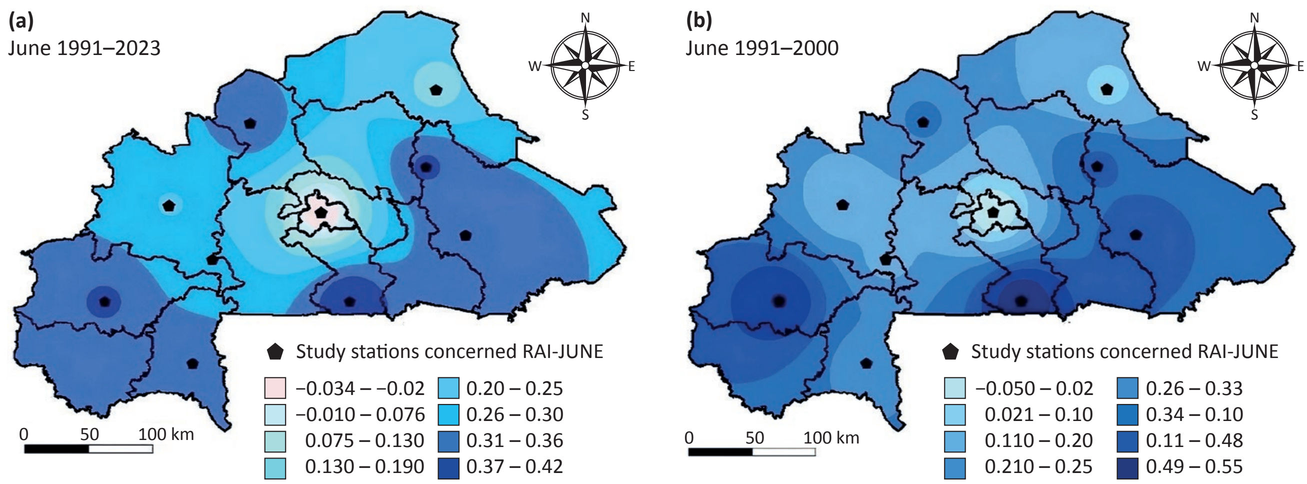

Fig. 6 Spatial distribution of RAI values for the month of June between 1991 and 2023 (a), 1991 and 2000 (b).

over the period 1991–2023, (Fig. 6a). However, the decade 2001–2000 (Fig. 6b) shows a reverse trend. During this period, the central part of the country experienced a slight period of drought extending southward. Only the eastern and southern parts of the country experienced a slight period of humidity. This means that the rainy season has not yet set in, especially in the center of the country, but particularly in the east. This means that June remains highly variable during the decade 2001–2010 (Fig. 6c), leading to a delayed onset of the rainy season in the center of the country and the onset of rain in the east.

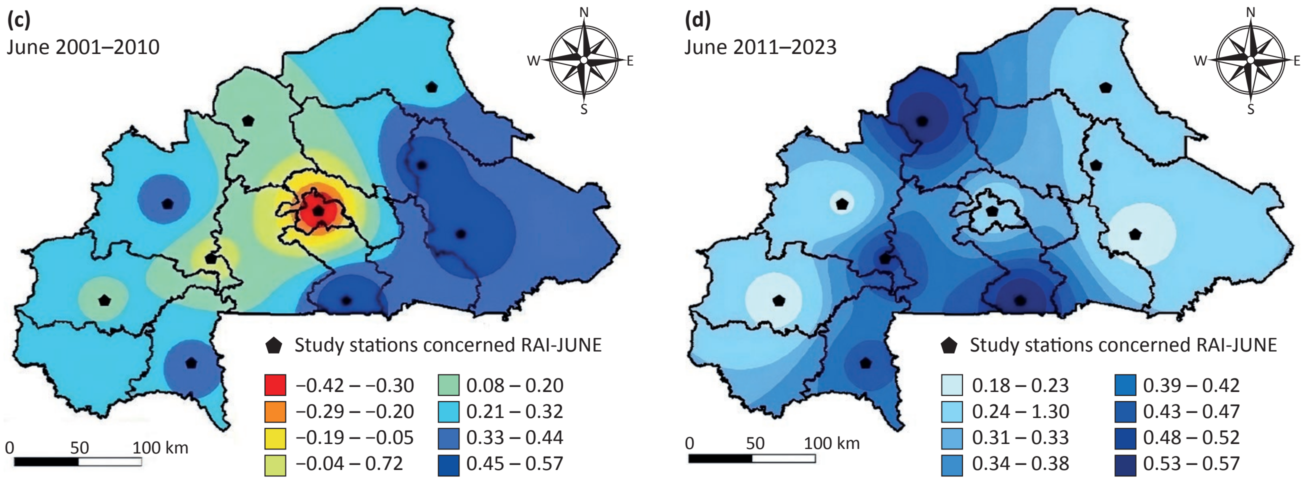

Fig. 6 Spatial distribution of RAI values for the month of June between 2001 and 2010 (c), and 2011 and 2023 (d).

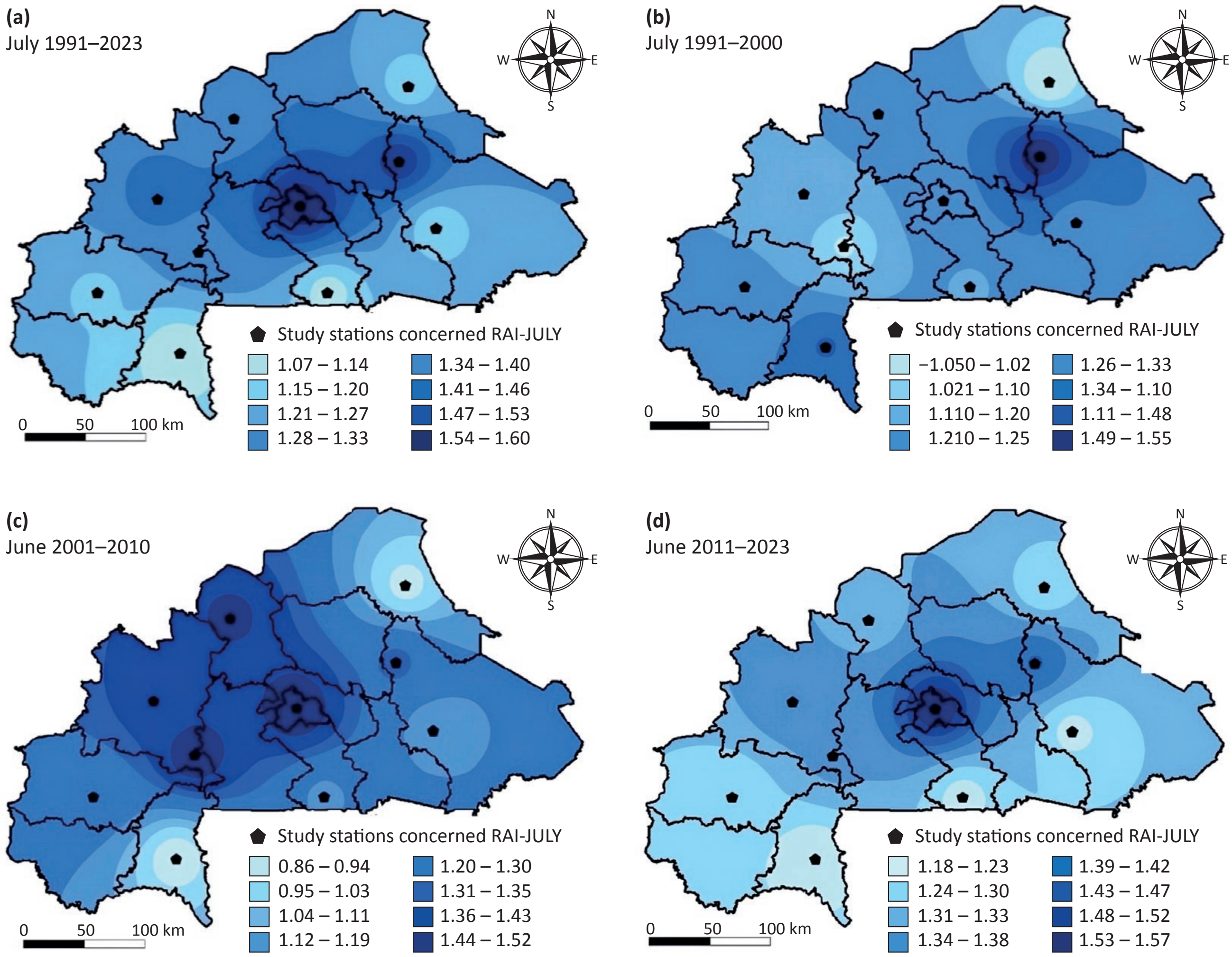

Fig. 7 Spatial distribution of RAI values for the month of July between 1991 and 2023 (a), 1991 and 2000 (b), 2001 and 2010 (c), and 2011 and 2023 (d).

However, July experiences a wet phase that shows the clear onset of the rainy season across the country (Fig. 7).

A wet phase is observed in July across the entire territory during the ten-year periods (1991–2000, 2001–2010, and 2011–2023) (Fig. 7b–d) and thirty-year periods (Fig. 7a). This situation changed in the decade 1991–2000 (Fig. 7b), as the central-eastern areas of the country experienced an increase in humidity. In the decade 2001–2010 (Fig. 7c), most of the arid, steppe, and hot areas received more rainfall than the rest of the country. The same was true in the

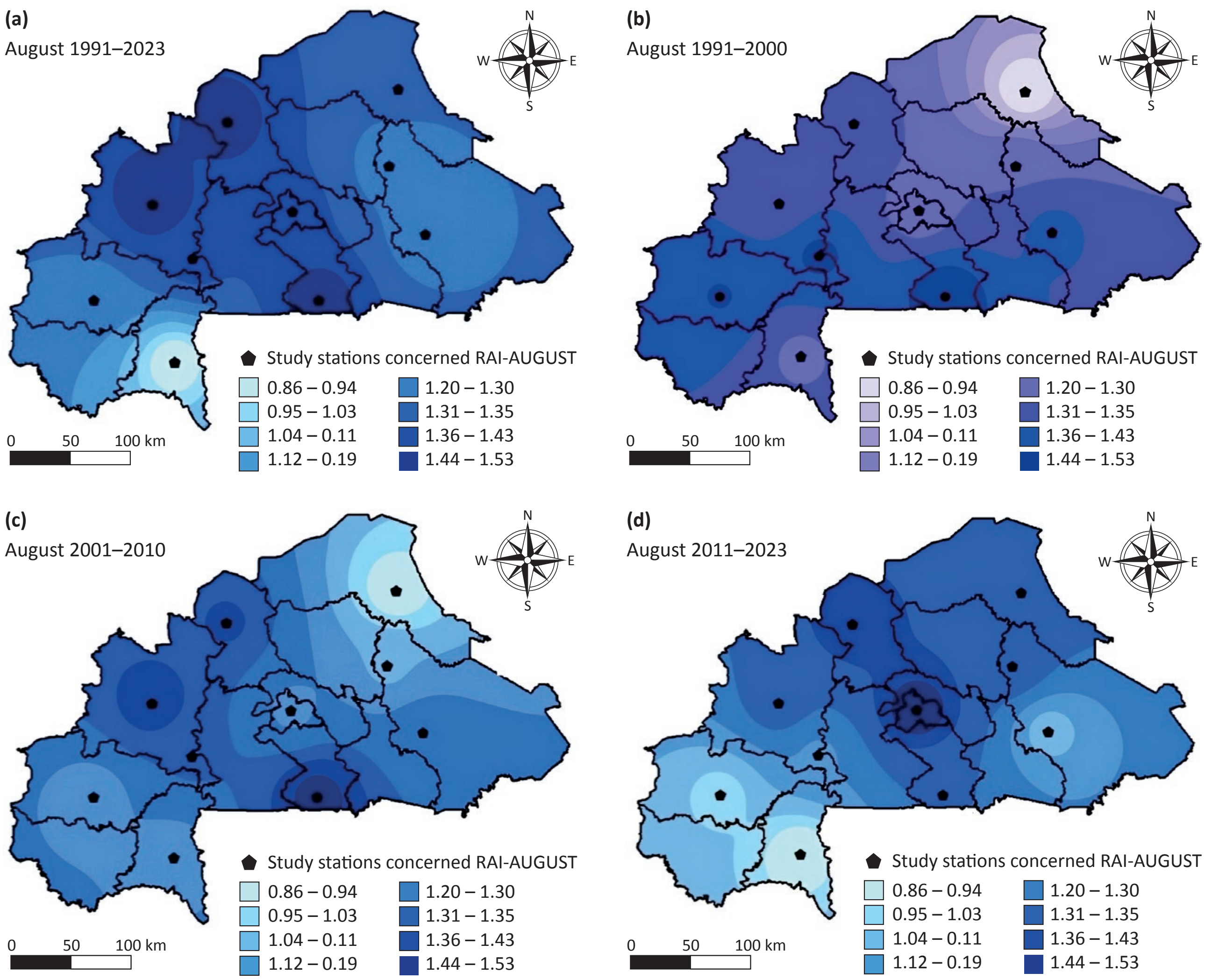

Fig. 8 Spatial distribution of RAI values for August between 1991 and 2023 (a), 1991 and 2000 (b), 2001 and 2010 (c), and 2011 and 2023 (d).

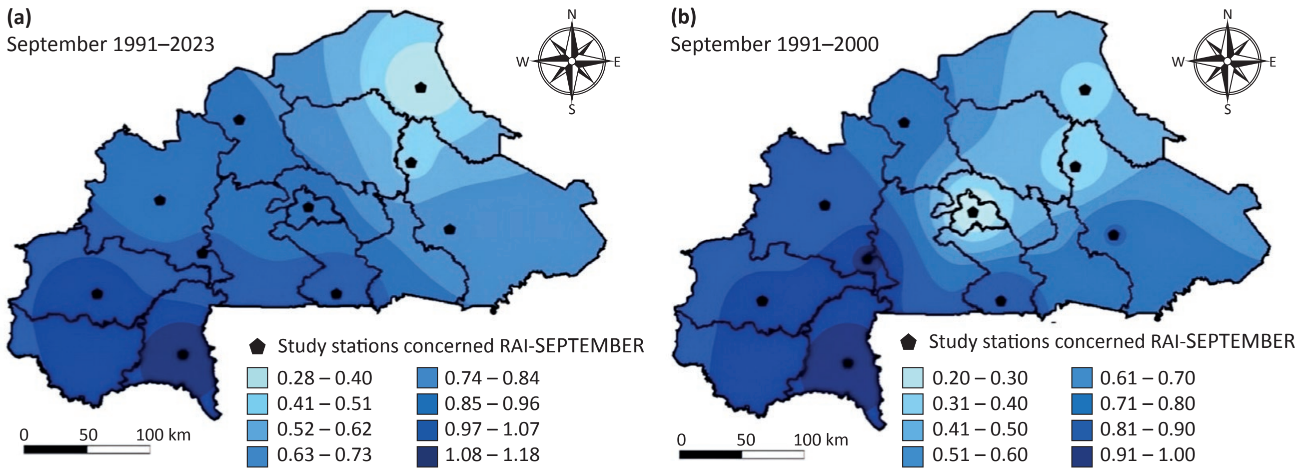

Fig. 9 Spatial distribution of RAI values for September between 1991 and 2023 (a), 1991 and 2000 (b).

decade 2011–2023 (Fig. 7d), but with a substantial increase in humidity (very humid phase (maximum RAI varies between 2.02 and 2.16) compared to the previous decade, when maximum RAI ranged from 1.43 to 1.52.

The month of August is the period with the highest rainfall, with maximum RAI values ranging from 1.97 to 2.07 and minimum RAI values ranging from 1.06 to 1.82 over the period 1991–2023. Fig. 8 illustrates this situation.

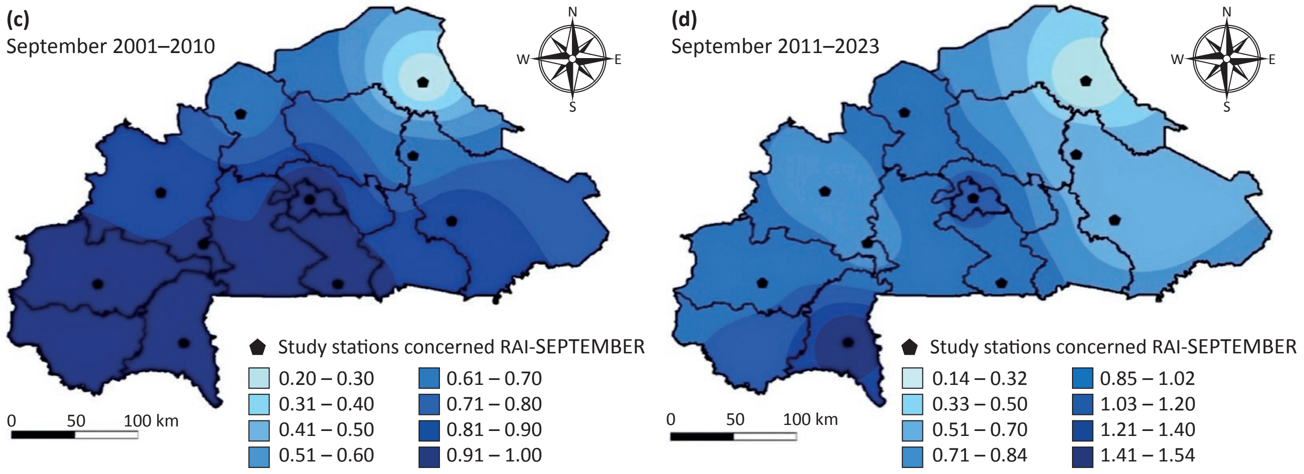

Fig. 9 Spatial distribution of RAI values for September between 2001 and 2010 (c), and 2011 and 2023 (d).

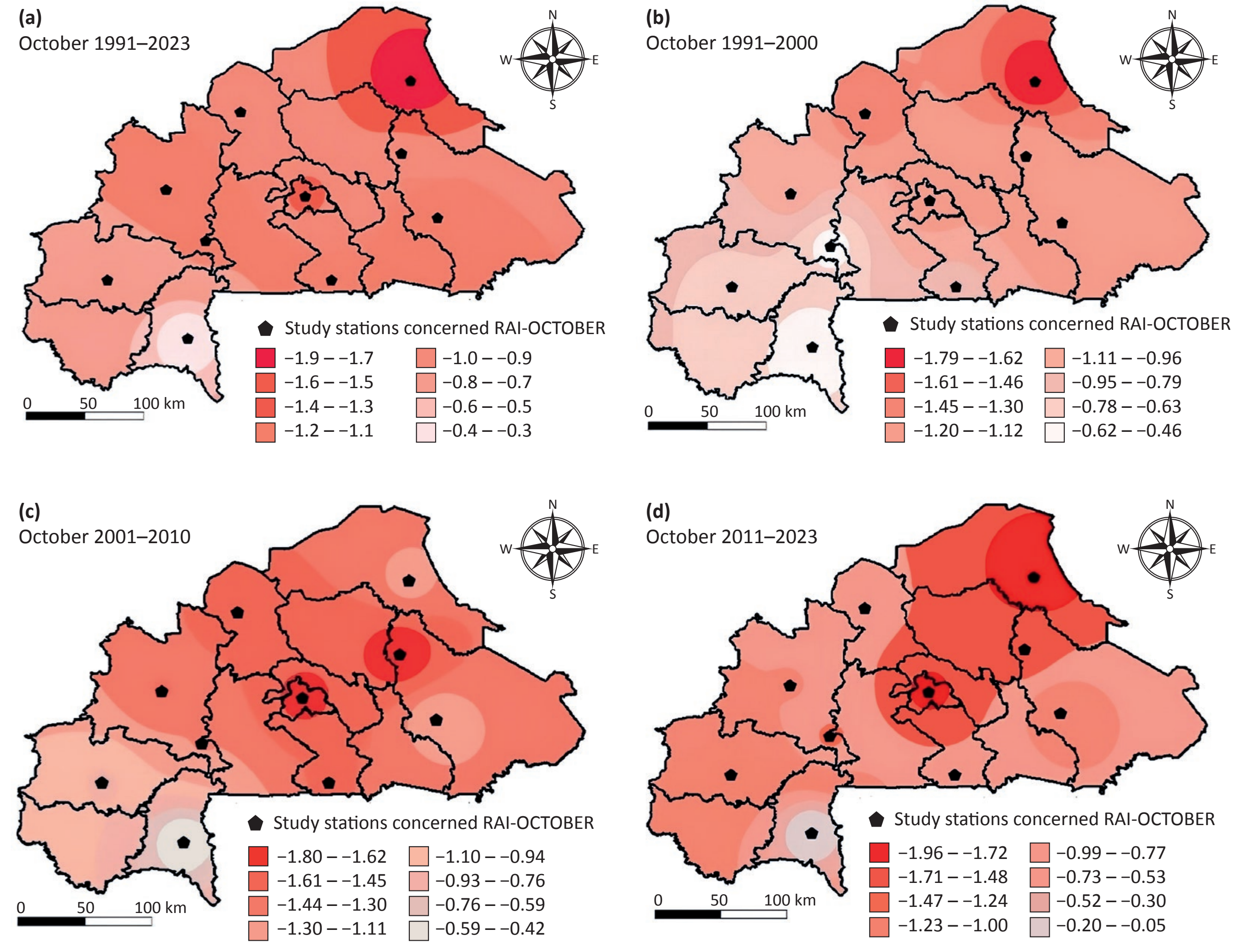

Fig. 10 Spatial distribution of RAI values for the month of October 1991 and 2023 (a), 1991 and 2000 (b), 2001 and 2010 (c), and 2011 and 2023 (d).

Fig. 8b–d show that wet and very wet phases are recorded throughout the country in August, but that these phases vary from one decade to another: 1991–2000, 2001–2010, and 2011–2023. In fact, in the decade 1991–2000 (Fig. 8b), only the arid, desert, and hot zone experienced a wet phase, while the rest of the country experienced a very wet phase (RAI ranging between 1.91 and 2.12). In the decade 2011–2023 (Fig. 8d), the month of August experienced a very wet increase across the country, except for the extreme

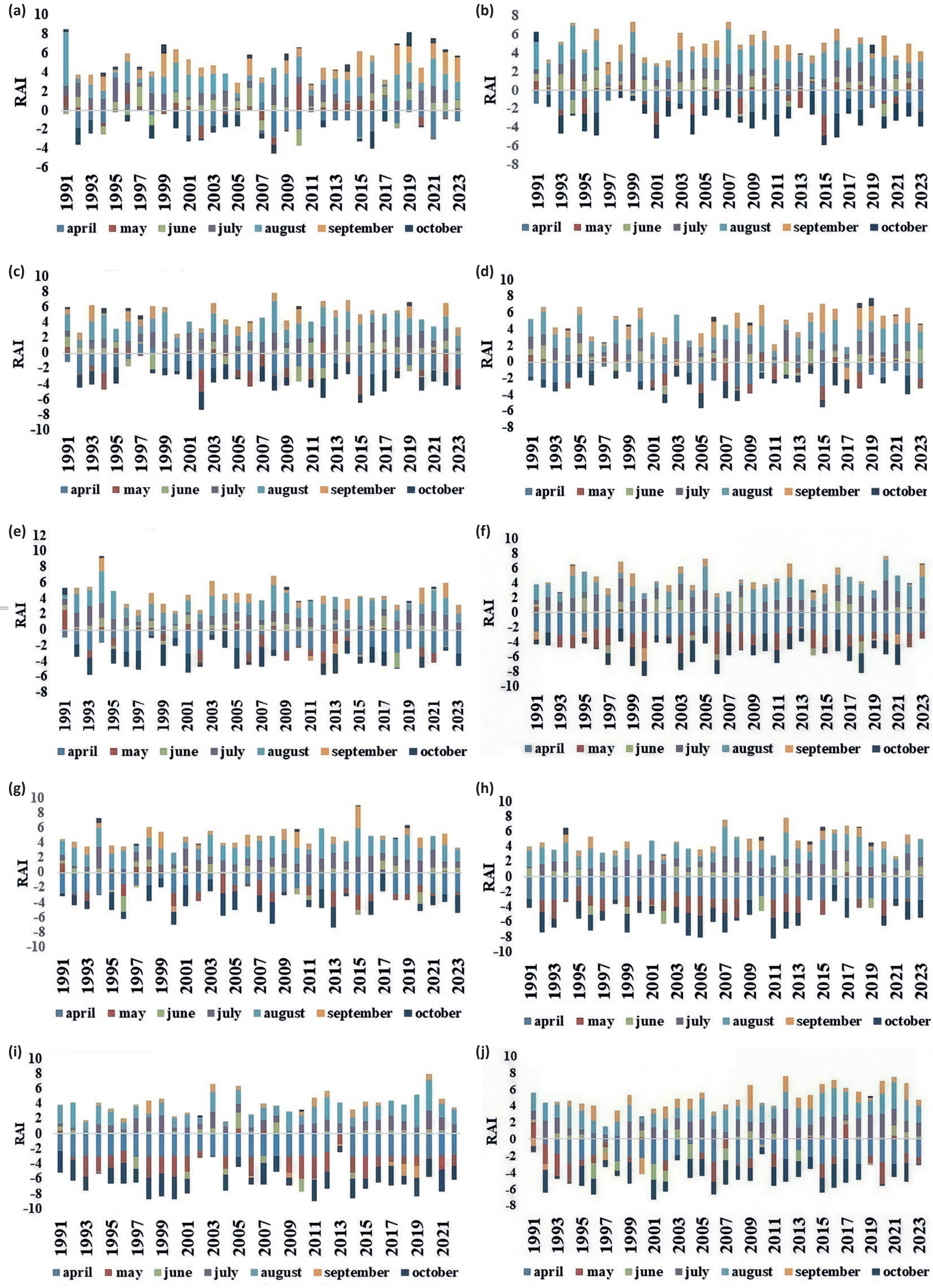

Fig. 11 Change in annual RAI values over the period 1991–2023. Gaoua station (a), Po station (b), Boromo station (c), Bobo station (d), Fada station (e), Bogande station (f), Dedougou station (g), Ouahigouya station (h), Dori station (i), Ouagadougou station (j).

south, which was in a wet phase. The decade 2011–2023 was therefore the wettest in the country. This situation reduced the dry phases during this period.

3.1.3 Spatial distribution of RAI in Burkina Faso between 1991 and 2023 during the post-rainy season

The post-rainy season covers two months, namely September and October. Fig. 8 shows that September is still a wet month, although humidity levels are lower. Minimum RAIs vary between 0.14 and 0.20, while maximum RAIs range from 1.54 to 1.40 (Fig. 9). Fig. 9a-c show that September experiences slightly wet periods. However, the decade 2011–2023 (Fig. 9d) experiences a wet phase. This reveals a slightly wet to wet situation.

However, October experiences a period of drought (Fig.10). Between 1991 and 2023 (Fig. 10a), arid, desert, and hot areas (Bsh) are affected by moderate to very severe drought. Fig. 10b-d show that this trend was also observed during the decades 1991–2000, 2001–2010, and 2011–2023.This situation shows a shortening of the post-rainy season period, as this period corresponds to a precipitation deficit, leading to recurring pockets of drought. The southern part of the country is less affected, as droughts there are moderate and mild. This reflects a slightly longer post-rainy season period in this part of the country.

3.2 Temporal changes and spatial trends in RAI values from 1991 to 2023 in Burkina Faso

The evolution and spatial trend make it possible to identify the years in which drought occurred. It is therefore important to analyze them.

3.2.1 Temporal and variability changes in RAI, RSI values from 1991 to 2023 in Burkina Faso

Fig. 11 shows the monthly evolution of RAI values over the period 1991–2023. This evolution fluctuates both in stations located in the arid, desert, hot climate zone and in the arid, steppe, hot climate zone and the tropical, savanna zone.

Fig. 11 shows three phases (alternating long ascending and descending phases) at the stations of Gaoua, Po, Boromo, and Bobo-Dioulasso. In contrast, the other stations show constant variability, with very short upward and downward phases throughout the period 1991–2023. This situation shows that the stations of Gaoua, Po, Boromo, and Bobo-Dioulasso experience very wet phases and significant droughts. However, the other stations experience less pronounced droughts and wet phases over the period 1991–2023. Furthermore, the RAI is also associated with seasonal variability in precipitation over the period 1991–2023 (Fig. 12).

Fig. 12 shows that there are two types of seasonal precipitation variability: average seasonal variability and high seasonal variability. Average seasonal variability is observed at stations located in the AW zone (RAI ranging from 0.80 to 0.99), while high seasonal variability is observed in the Bsh and Bwh zones (RAI ranging from 1.00 to 1.19 for 90% of stations) in Burkina Faso (Fig. 13). The Dori station is an exception, as its RSI ranges between 1 and ≥ 1.20. It should be noted that this station covers both the Bsh and Bwh zones.

Fig. 13 shows that average seasonal variability, with RSIs between 0.80 and 0.99, is characterised by long dry seasons. However, high seasonal variability is characterised by rainfall of less than three months (Bwh zone) and less than one or two months (Sh zone). Thus, both zones (Bsh and Bwh) generally experience high or very high RSI. This inevitably implies rainfall concentrated over a few months and long dry periods.

3.2.2 Spatial trends in RAI values from 1991 to 2023 in Burkina Faso

Fig. 14 shows that no trend was observed for the months of April and May, with the exception of the Fada station, which experienced an upward trend over the period 1991–2023.

During the rainy season (June, July and August), June shows no trend (Fig. 15). This situation reveals

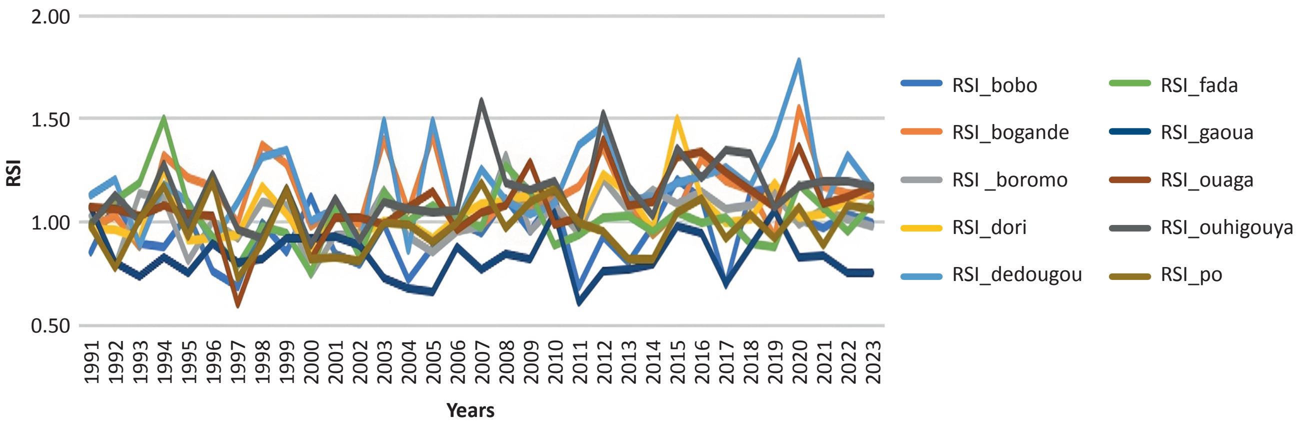

Fig. 12 Seasonal precipitation evolution in Burkina Faso between 1991 and 2023.

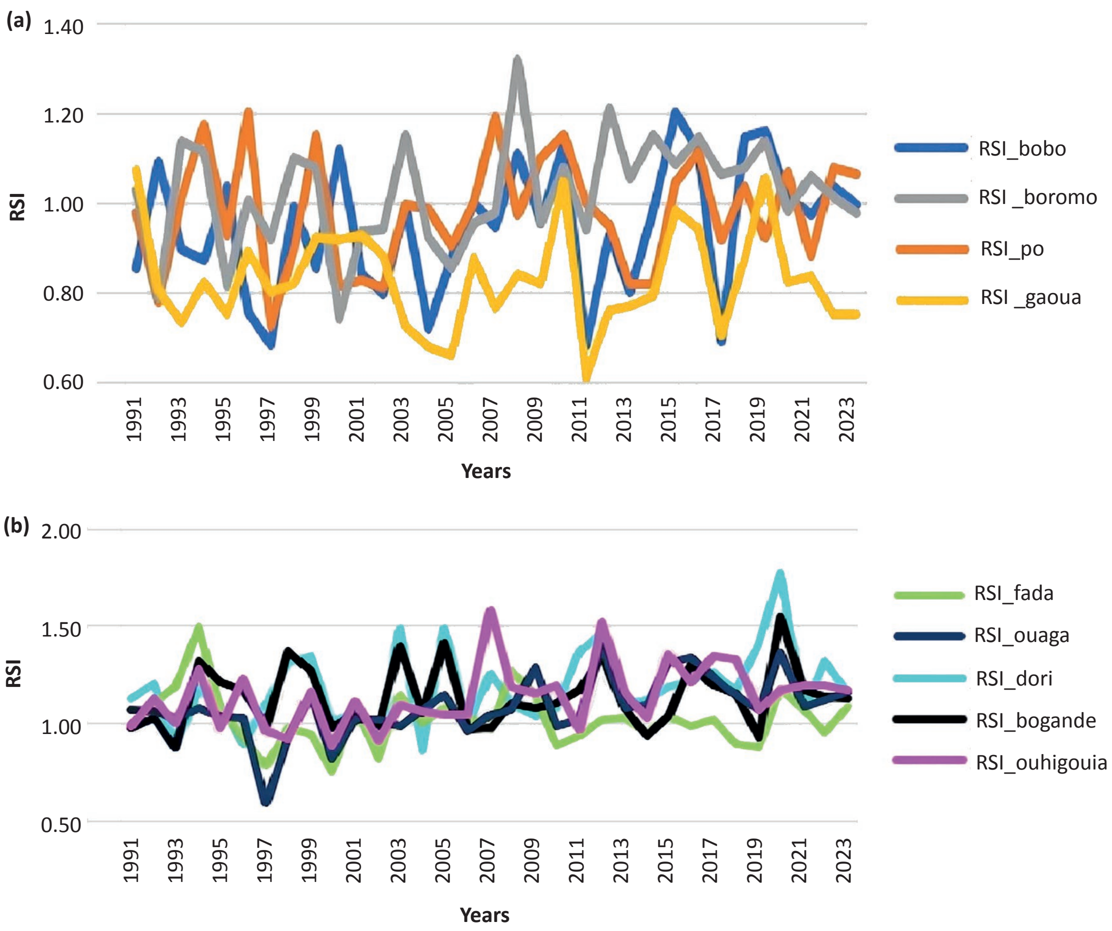

Fig. 13 Differentiated evolution of RSI between zones Aw (a) and Bsh, Bwh (b) from 1991 to 2023.

that June experienced little rainfall during this period. In contrast, July and August are marked by heavy rainfall. However, in August, only the Bsh zone experienced an upward trend, resulting in increased rainfall. This is consistent with the results of the PCD and PCP indices, which show heavy rainfall in the Bsh zone compared to the Aw zone.

Fig. 15 also shows that July and August exhibit trends. At the Dori, Ouagadougou, Dedougou, and Boromo stations, an upward trend was observed, with high significance for the Ouagadougou station and

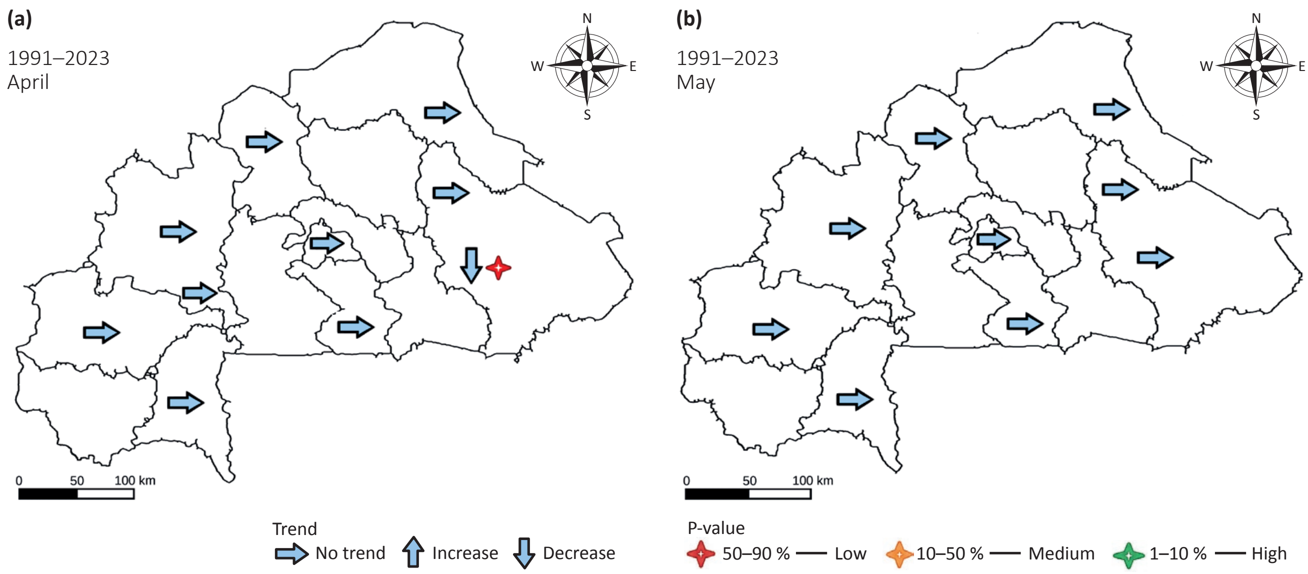

Fig. 14 Trend in RAI values during the rainy preseason over the period 1991–2023.

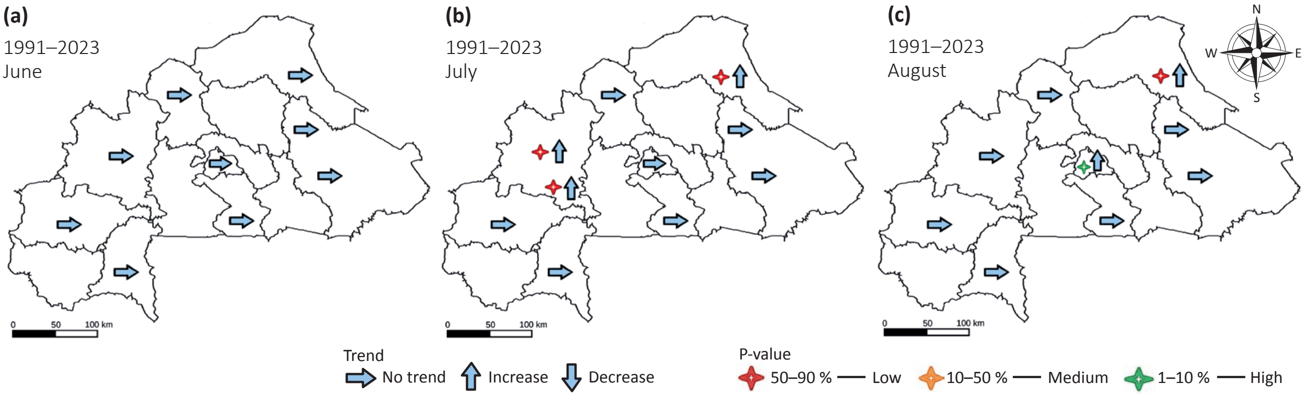

Fig. 15 Trend in RAI values during the rainy season over the period 1991–2023.

low significance for the other stations for the month of July. For August, the trend is upward at the Dori and Ouagadougou stations. This confirms the wet trend in July and August, which are the wettest months in Burkina Faso.

During the post-rainy season, trends are upward in September and no trend is observed in October. The upward trends observed in September are moderate for the Bobo and Gaoua stations, high for the Ouagadougou station, and low for the Dori station (Fig. 16).

3.2.3 Decadal spatial trends in RAI values from 1991 to 2023 in Burkina Faso

Fig. 17 shows that the ten-year trend in RAI is unclear. Indeed, upward trends were recorded in the decade 1991–2000, particularly at the Ouahigouya and Dédougou stations in April. In the tropical savannah zone, a downward trend was observed at the Bobo-Dioulasso station over the period 2011–2023. However, no clear trend was observed in May over the decades 1991–2000, 2001–2010 and 2011–2023.

During the rainy season, ten-year trends are also highly variable over the period 1991–2023. In fact, there is no clear trend in June, with the exception of the decade 1991–2000, when an upward trend was observed at the Boromo station. In July, arid, desert and hot areas experienced an upward trend in the decades 1991–2000, 2001–2010 and 2011–2023. In contrast, a downward trend was observed at the Fada N'Gourma station during the decade 1991–2000. Fig. 18 summarises the details of the decadal trends below.

For the post-rainy season, an upward trend was observed during the decades 1991–2000 and 2001–2010 at the Po, Bobo-Dioulasso and Ouahigouya stations, with a significant p-value ranging from low to medium (Fig. 19). However, during October, no clear trend was observed, except for the period 1991–2000, when a downward trend was observed, with an average p-value significance.

The analysis of drought in Burkina Faso, conducted using the RAI, revealed numerous absence of significant regular trends during the period concerned, as

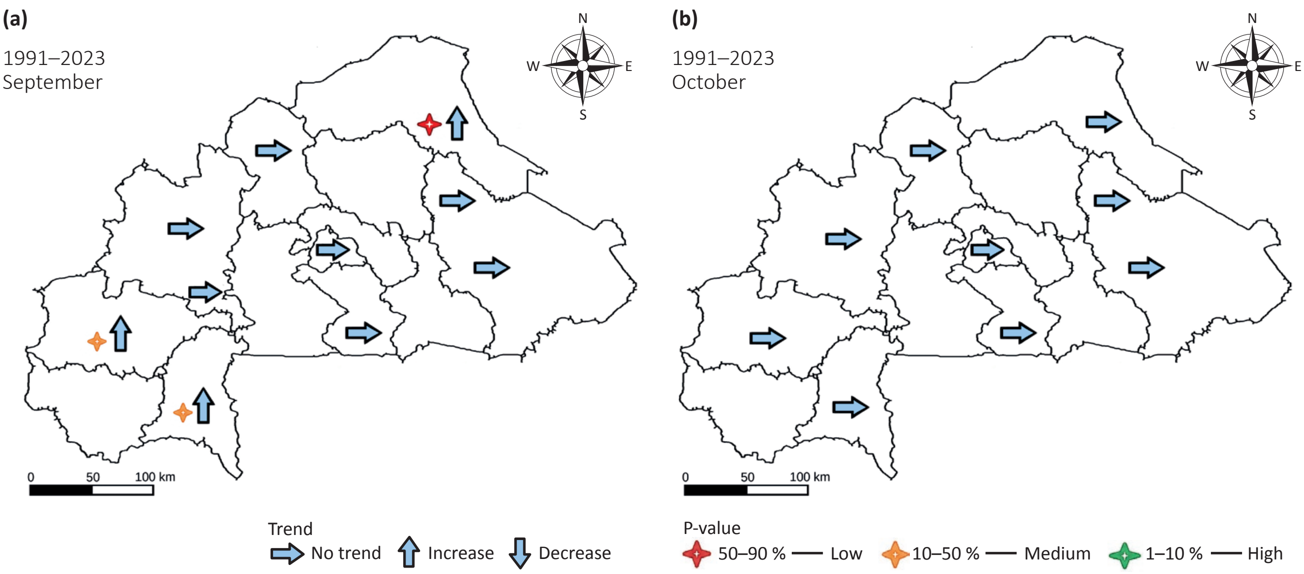

Fig. 16 Spatial trends in monthly RAI values from September to October.

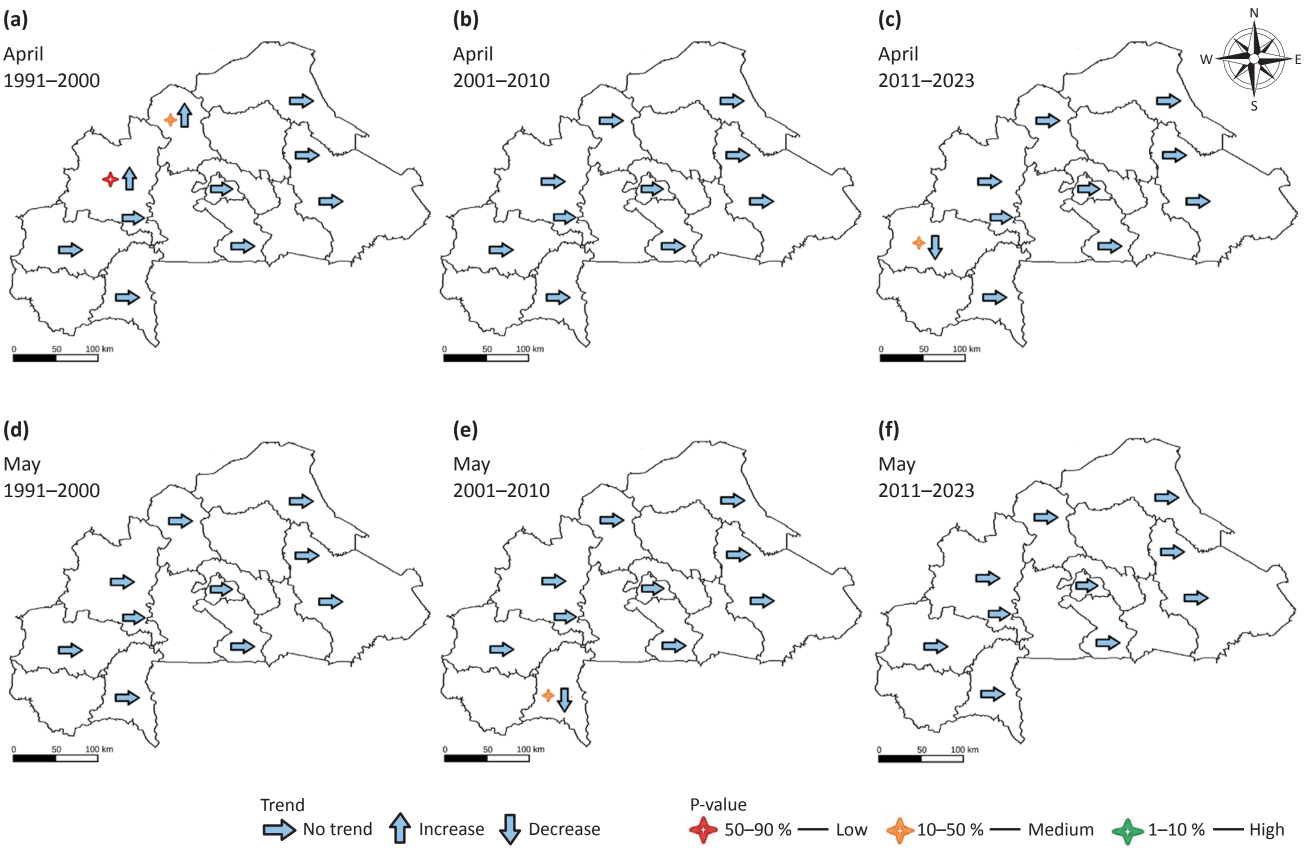

Fig. 17 Ten-year trend in RAI values during the pre-rainy season.

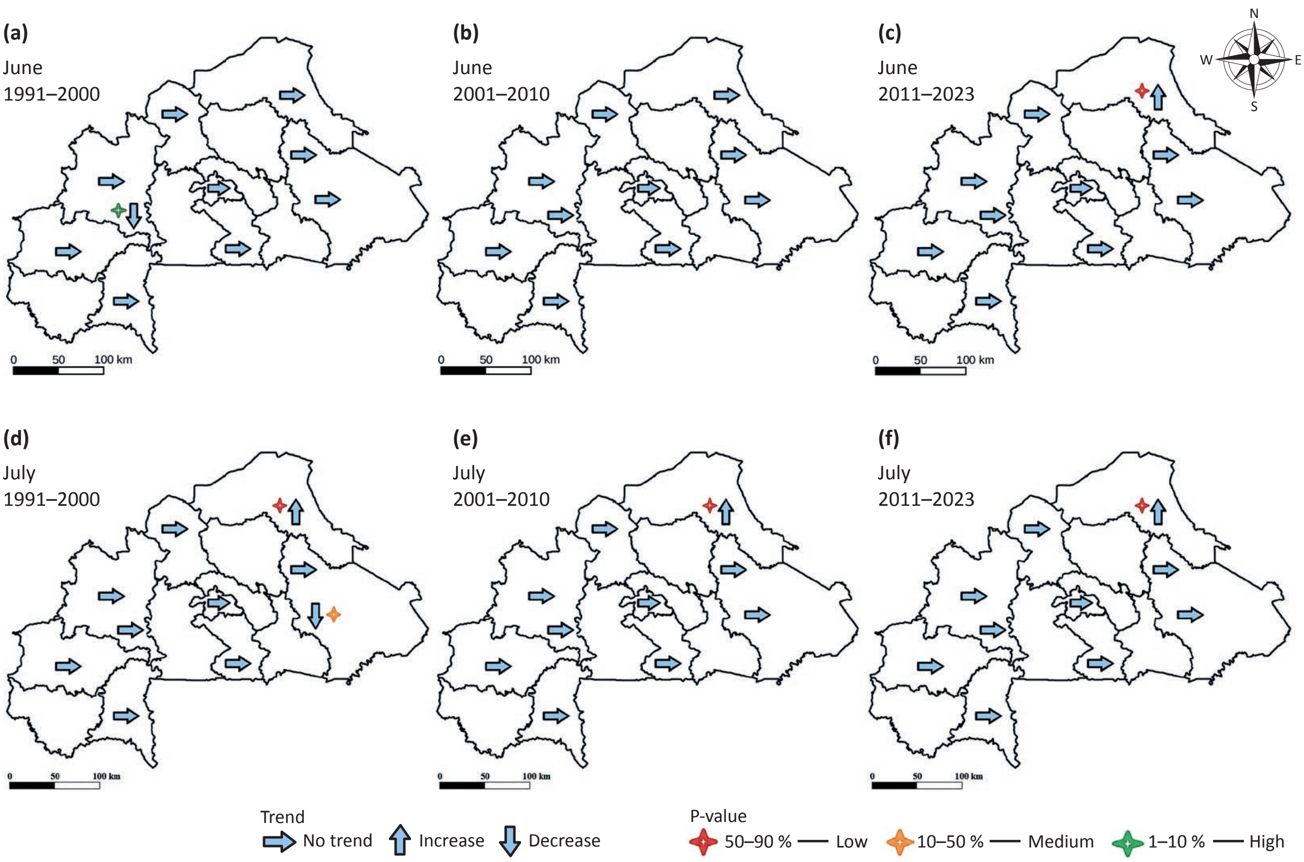

Fig. 18 Trend decadal in RAI values during the rainy season (June–July).

illustrated by the results of the Spearman test presented in Fig. 17, 18 and 19. This result reflects the highly variable nature of the Sahelian rainfall regime, particularly in Burkina Faso, which is characterised by high interannual variability and pronounced sensitivity to fluctuations in the West African monsoon. Indeed, rainfall in Burkina Faso is highly dependent on the position and intensity of the Intertropical Convergence Zone (ITCZ). This variability generates significant fluctuations in meteorological drought over time. Thus, the absence of a monotonic trend does not reflect stable rainfall conditions, but highlights the high variability of IWR in the country.

4. Discussion

4.1 Distribution and evolution of drought in Burkina Faso and Africa

Drought is a meteorological phenomenon characterised by an abnormal lack of precipitation. It causes difficulties in the supply of water (Abdela et al. 2023). Various analytical methodologies are employed to evaluate the complexity of this phenomenon. Drought indices, as defined by Katipoğlu et al. (2022), are useful indicators of arid conditions. The parameters used to calculate these indices allow meteorological,

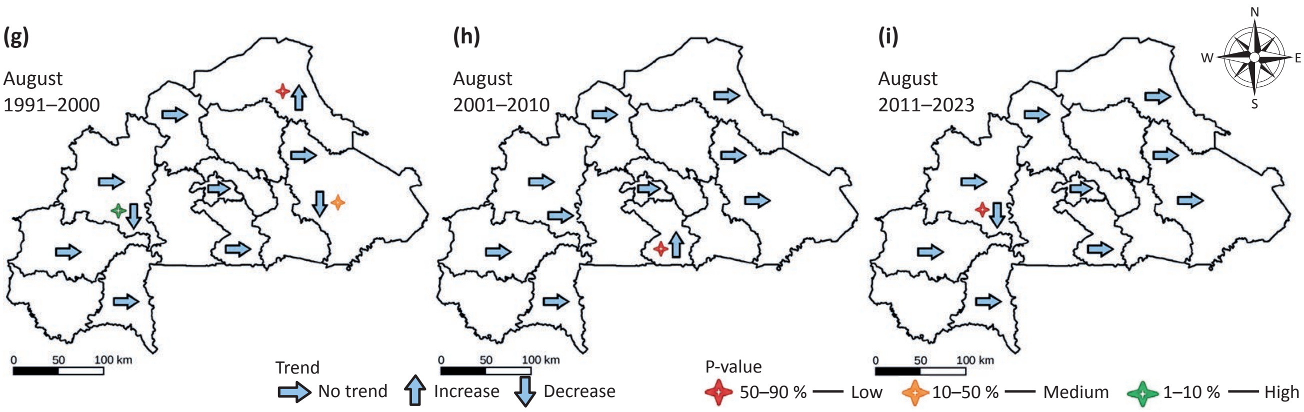

Fig. 18 Trend decadal in RAI values during the rainy season (June–July).

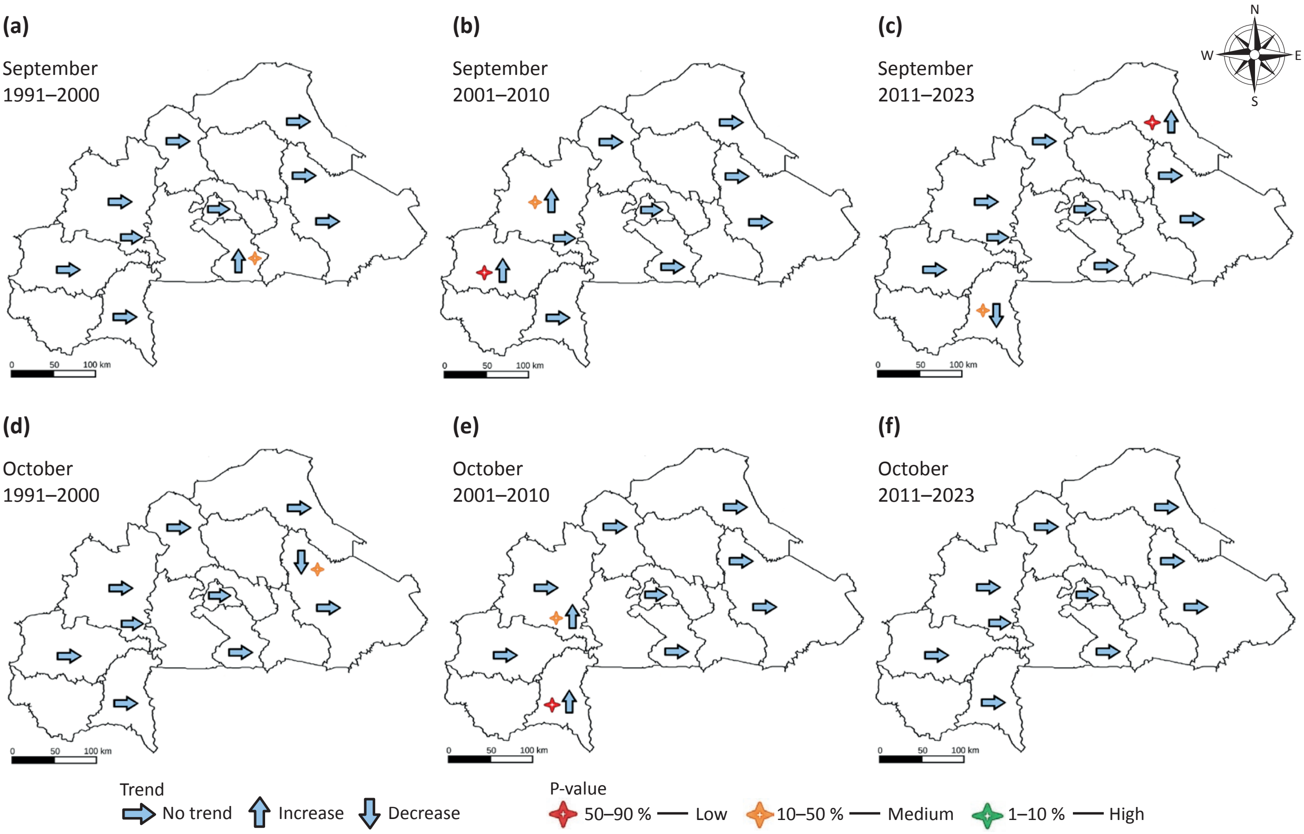

Fig. 19 Ten-year trend in RAI values over the post-rainy season period.

hydrological and climatic events to be interpreted (Patra 2020; Robleh et al. 2024). The RAI (Rainfall Index) is a meteorological index used to detect meteorological droughts.

Analysis of drought in Burkina Faso using the RAI index reveals that the pre- and post-wet seasons are the most affected periods. These two periods correspond, respectively, to hot arid and desert climate zones, as well as hot arid and steppe climate zones. This has an impact on the occurrence of dry periods at the beginning and end of the rainy season. Indeed, as Yaméogo (2024) points out, dry periods have been observed at the beginning of the rainy season, particularly at the Boromo station. However, at the Gaoua station, dry periods decrease at the beginning and end of the rainy season (Yaméogo 2024). This indicates that drought levels are higher at the beginning of the rainy season than at the end. Another study conducted in the Mouhoun basin, in southwestern Burkina Faso, confirms our findings. Indeed, Bontogho et al. 2023, found that droughts were moderate to mild (RAI values were low or very low), particularly at the Boromo, Gaoua, and Bobo-Dioulasso stations over the period 1985–2011. The work of Tefera et al. (2025) on Ghana and Burkina Faso reveals points of convergence. The authors note that the months of March, April, and May have negative SPI values, especially in northern Burkina Faso. In the Niger Basin in Nigeria, Okpara and Tarhule (2015) also note an increase in droughts in April, May, and October over the period 1950–2001. Conversely, July and August see few negative SPI values. This shows the spatial dynamics of drought from month to month and season to season.

The rainy season (June, July, and August) in the study area also experiences slight drought in June, especially in the central part of the country. However, the other two months (July and August) experience a wet or even very wet phase. Another study conducted by Yaméogo (2025c) in the Mouhoun-Comoé basin shows, however, that the wet phases of the rainy season, i.e., July and August, are accompanied by very wet periods, with phases of drought during the decades 1994–2004 and 2005–2014. This confirms the very wet phase during the rainy season (particularly in July and August).

The study shows that no clear trend was observed during the pre- and post-rainy seasons. However, the rainy season as a whole saw an upward trend in wet phases, revealing a wet phase over the period 2011–2023. This study is confirmed by Yaméogo and Rouamba (2023), who show that periods of flooding in Burkina Faso occurred between 2000 and 2020. In the Niger Basin, variable trends alternating between wet and dry phases were observed over the period 1970–2008 (Oloruntade et al. 2017). In the southern Niger basin (NSB), a sub-basin of the Niger basin, variable trends alternating between wet phases and periods of drought were observed between 1970 and 2008 (Oloruntade et al. 2017). In Niger, Moussa et al. (2025) also note an alternation of wet and dry phases, with an upward trend in wet phases over the period 2001–2022. This reflects high SPI variability across Niger. Other studies conducted in northern Nigeria (Dasat et al. 2021), Mali (Sanogo et al. 2023), and Ghana (Incoom et al. 2020) reveal high variability in drought indices. Ogunrinde et al. (2025) find that, in addition to the variability of drought indices, they show an upward trend over the period 1960–2018.

4.2 The consequences of drought and agriculture

Drought is a climatic phenomenon with major consequences for agriculture, particularly in regions such as Burkina Faso. The rainfall anomaly index (RAI) takes into account positive anomalies (marked by excess water) and negative anomalies (marked by water stress). As a result, the various crops grown in Burkina Faso (maize, rice, millet and sorghum) are subject to both water stress and excess water. This situation could lead to production problems in different climatic zones. However, the lack of agricultural statistics on yields makes it impossible to assess the effects of drought on agricultural production. Nevertheless, Tab. 4 below shows that Burkina Faso is facing both water stress caused by severe water shortages and excess water (wet phase), which could affect cereal cultivation in the country (Tab. 4).

This table shows that the water stress caused by these anomalies has negative consequences for cereal crops in Burkina Faso, a Sahelian country in West

Tab. 4 Risks posed by water stress to cereal crops in Burkina Faso.

Zone	Annual rainfall	Cereal produced	Probable critical phase (high risk if drought)	Relative risk level (RAI)	Decade affected	Period
Arid, desert, hot (Bwh)	300–600 mm	Sorghum, Millet	Germination/start of vegetation, flowering Maturation (grain) if rainfall is insufficient	Moderately dry (−1.99 to −1)	2011–2023	Start of the rainy season (especially in May) End of the rainy season (especially in October)
Arid, steppe, hot (Bsh)	600–900 mm	Sorghum, Millet, Maize	Flowering, grain filling	High (maize more vulnerable) (slightly dry–moderately dry)	2011–2023	Start of the rainy season (especially in May)
Tropical, savannah (Aw)	900–1200 mm	Sorghum, Millet, Maize	Less critical, but late stress/end of season	Moderate to high (depending on rainfall variability)	2011–2023	End of the rainy season (especially in October)

Source: Gano et al. (2022); Serme et al. (2018); Shrestha et al. (2023) and the results of the study.

Tab. 5 The main effects of very wet periods accompanied by flooding.

Cereals	Main consequences of flooding/excess water	Authors	Study scale
Millet	Root stress, seedling rot, loss of germination, reduced yield	Müller et al. (2023)	Burkina Faso
Sorghum	Total losses in 33% of flooded plots; sorghum among the most affected crops	Müller et al. (2023)	Burkina Faso
Maize	Root stress, poor aeration, mortality, very likely total loss or reduced yield.	Benjamin et al. (2025)	Africa
Rice (rainfed/ irrigated)	For rice, uncontrolled excess water or prolonged submersion causes serious damage (root asphyxia, stress).	Benjamin et al. (2025); Atanga and Tankpa (2021)	Africa, Ghana

Africa. The month of May (pre-rainy season) in the decade 2011–2023 was moderately dry at the beginning and end of the rainy season in zones Bwh, Bsh and Aw, which affects cereals, especially during the germination and ripening periods. Other studies point to disruption of agricultural activities in Bangladesh (Kamruzzaman et al. 2018b).

The wet and very wet periods, which occur between July and September, have an impact on cereal crops. The study by Yaméogo and Rouamba (2023) reveals that these periods are marked by flooding throughout the country, particularly between 2000 and 2020. This situation shows that August and September, considered to be periods at risk of flooding, are very wet periods. Cereals could therefore be affected. Several studies on Burkina Faso and Africa reveal that maize, rice and sorghum crops are affected by flooding resulting from these very wet periods (Tab. 5).

5. Conclusion

Drought is an extreme phenomenon that has a detrimental effect on agricultural activities. Recording this information is, therefore, an essential part of managing the agricultural calendar. In Burkina Faso's semi-arid climate, it is crucial that the national authorities are aware of meteorological drought in order to prepare the agricultural population, 80% of whom work in rain-fed agriculture, more effectively. In order to understand the monthly spatial distribution of drought in Burkina Faso, RAI analysis is a relevant tool. The study reveals a north-south gradient in the spatial distribution of droughts, both during the pre-rainy season (April and May) and during the post-rainy season. It should be noted, however, that the rainy season, which runs from June to August, experiences a marked wet period, particularly in July and August. The BWh and BSh zones are affected by these very wet phases. In June, a slight wet phase was observed in the central region of the country, while a wet phase was recorded in the east. These disturbances had a significant impact on the timing of sowing periods during the pre-rainy season in Burkina Faso. In addition, observations revealed that crops are exposed to particularly wet weather in July and August, which could affect their development during the growth and ripening phases. This can result in suboptimal harvests during this season. Sudden interruptions to rainfall during the post-rainy season, particularly in October, can lead to significant losses in agricultural production in regions characterised by arid, desert and hot climates, as well as in steppe and arid areas. Consequently, it is imperative that improved seeds developed by research institutes take this factor into account to provide seeds adapted to the new conditions.

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References

Abara, M., Budiastuti, S. (2020): Drought frequency, severity, and duration monitoring based on climate change in southern and southeastern Ethiopia. IOP Conference Series: Earth and Environmental Science 477(1): 012011, https://doi.org/10.1088/1755-1315/477/1/012011.

Abbas, A. K. (2024): Drought Assessment based on Rainfall Anomaly Index (RAI) across Erbil-Iraq. Polytechnic Journal 14(1): 10, https://doi.org/10.59341/2707-7799.1827.

Abdela, K. A., Fantabil, A., Muleta, D., Yohannes, T., Jonah, K. (2023): Bibliographic review on drought and water level articles. Discover Water 3(1): 17, https://doi.org/10.1007/s43832-023-00038-w.

Alwan, I. A., Ziboon, A. R. T., Khalaf, A. G. (2018): Comparison of nine meteorological drought indices over middle euphrates region during period from 1988 to 2017. International Journal of Engineering and Technology 7(4.20), 602–607, https://doi.org/10.14419/ijet.v7i4.20.27400.

Ahmad, I., Tang, D., Wang, T., Wang, M., Wagan, B. (2015): Precipitation Trends over Time Using Mann-Kendall and Spearman's rho Tests in Swat River Basin, Pakistan. Advances in Meteorology 2015(1): 431860, https://doi.org/10.1155/2015/431860.

Al-Hasani, B., Abdellatif, M., Carnacina, I., Harris, C., Al-Quraishi, A. M. F., Al-Shammari, M. M. (2025): Forecasting Evaporation Trends Amid Climate Change for Sustainable Water Management in Semi-Arid Regions. Water 17(7): 1039, https://doi.org/10.3390/w17071039.

Ananias, D. R. S., Liska, G. R., Beijo, L. A., Liska, G. J. R., de Menezes, F. S. (2021): The assessment of annual rainfall field by applying different interpolation methods in the state of Rio Grande do Sul, Brazil. SN Applied Sciences 3(7): 687, https://doi.org/10.1007/s42452-021-04679-1.

Atanga, R. A., Tankpa, V. (2021): Climate change, flood disaster risk and food security nexus in Northern Ghana. Frontiers in Sustainable Food Systems 5: 706721, https://doi.org/10.3389/fsufs.2021.706721.

Attiogbé, A. A. C., Bessah, E., Quansah, E., Nehren, U., Agodzo, S. K. (2025): Spatial analysis of drought vulnerability in cocoa agroforestry systems across the Ghana-Togo border. Geomatics, Natural Hazards and Risk 16(1): 2467406, https://doi.org/10.1080/19475705.2025.2467406.

Barry, A. A., Caesar, J., Klein Tank, A. M. G., Aguilar, E., McSweeney, C., Cyrille, A. M., Nikiema, M. P., Narcisse, K. B., Sima, F., Stafford, G., Touray, L. M., Ayilari-Naa, J. A., Mendes, C. L., Tounkara, M., Gar-Glahn, E. V. S., Coulibaly, M. S., Dieh, M. F., Mouhaimouni, M., Oyegade, J. A., Sambou, E. and Laogbessi, E. T. (2018): West Africa climate extremes and climate change indices. International Journal of Climatology 38, e921–e938, https://doi.org/10.1002/joc.5420.

Benjamin, J., Idowu, O., Babalola, O. K., Oziegbe, E. V., Oyedokun, D. O., Raheem, J., Adebayo, A. (2025): Status of cereal production in Africa: insights from abiotic stressors in a changing climate – a short review. Discover Agriculture 3(1): 115, https://doi.org/10.1007/s44279-025-00291-8.

Biswas, B., Karmegam, D. (2023): Long-term spatio-temporal analysis and trends of precipitation over semi-arid region of Rajasthan. Meteorology and Atmospheric Physics 135: 53, https://doi.org/10.1007/s00703-023-00991-0.

Bontogho, T. N. P. E., Kansole, M. M. R., Yaméogo, B. T., Kabore, M., Kientaga, R. (2023): Rainfall Anomaly Index over Mouhoun Basin in Southwestern Burkina Faso. International Journal of Environmental & Agriculture Research (IJOEAR) 9(6), 1–7, https://doi.org/10.5281/zenodo.8094679.

Bouregaa, T. (2023): Change point detection and trend analysis of drought over Algeria from 1901 to 2018. Arabian Journal of Geosciences 16(3), 168, https://doi.org/10.1007/s12517-022-11174-3.

Castellanos, M., García, M. Á., Pérez, I. A., Sánchez, M. L., Pardo, N., Fernández-Duque, B. (2021): Measuring temperature trends in the Mediterranean basin. Journal of Atmospheric and Solar-Terrestrial Physics 222: 105713, https://doi.org/10.1016/j.jastp.2021.105713.

Cook, B. I., Mankin, J. S., Marvel, K., Williams, A. P., Smerdon, J. E., Anchukaitis, K. J. (2020): Twenty-First Century Drought Projections in the CMIP6 Forcing Scenarios. Earth's Future 8(6): e2019EF001461, https://doi.org/10.1029/2019EF001461.

Dai, A. (2013): Increasing drought under global warming in observations and models. Nature climate change 3, 52–58, https://doi.org/10.1038/nclimate1633.

Dasat, G. L., Ajayi, D. D., Aremu, A. (2021): Spatio-Temporal Analysis of Drought over the Guinean-Sudano Ecological Zone, Northern Nigeria (6)6, 151–166, https://dx.doi.org/10.25046/aj060620.

Machiwal, D., Jha, M. K. (2008): Comparative evaluation of statistical tests for time series analysis: application to hydrological time series. Hydrological Sciences Journal 53(2), 353–366, https://doi.org/10.1623/hysj.53.2.353.

Doukoro, D., Abbey, G. A., Kalifa, T. (2022): Drought Monitoring and Assessment of Climate Parameters Variability in Koutiala and San Districts, Mali. American Journal of Climate Change 11(3), 230–249, https://dx.doi.org/10.4236/ajcc.2022.113011.

Esit, M., Çelik, R., Akbas, E. (2023): Long-term meteorological and hydrological drought characteristics on the lower Tigris-Euphrates basin, Türkiye: relation, impact and trend. Environmental Earth Sciences 82: 491, https://doi.org/10.1007/s12665-023-11182-w.

Fang, Z., Morales, A. B., Wang, Y., Lombardo, L. (2025): Climate change has increased rainfall-induced landslide damages in central China. International Journal of Disaster Risk Reduction 119: 105320, https://doi.org/10.1016/j.ijdrr.2025.105320.

IPCC (2021): Climate change widespread, rapid, and intensifying. Available online: https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/ (accessed on 15 December 2025).

Kheloufi Attou, A., Baba-Hamed, K., Bouanani, A. (2025): Developing a method to model extreme rainfall events using drought indices in northern Algeria under climate change. H2Open Journal 8(5), 313–335, https://doi.org/10.2166/h2oj.2025.003.

Fowé, T., Yonaba, R., Mounirou, L. A., Ouédraogo, E., Ibrahim, B., Niang, D., Yacouba, H. (2023): From meteorological to hydrological drought: a case study using standardized indices in the Nakanbe River Basin, Burkina Faso. Natural Hazards 119, 1941–1965, https://doi.org/10.1007/s11069-023-06194-5.

Katipoğlu, O. M., Acar, R., Şenocak, S., Şengül, S. (2022): Assessment of meteorological drought trends in the Euphrates Basin, Turkey. Arabian Journal of Geosciences 15: 555, https://doi.org/10.1007/s12517-021-08482-5.

Gano, B., Dembele, J. S. B., Sine, B., Diouf, D., Audebert, A. (2022): Agro-physiological responses of 10 West African sorghum varieties to early water deficit assessed by UAV and ground phenotyping. In: Kane, N. A., Foncéka, D., Dalton, T. J. (Eds.), Crop Adaptation and Improvement for Drought-Prone Environments; New Prairie Press: Manhattan, pp. 188–237. Available online: https://publications.cirad.fr/une_notice.php?dk=604057 (accessed on 15 December 2025).

Guhathakurta, P., Saji, E. (2013): Detecting changes in rainfall pattern and seasonality index vis-à-vis increasing water scarcity in Maharashtra. Journal of Earth System Science 122, 639–649, https://doi.org/10.1007/s12040-013-0294-y.

Kamruzzaman, M., Rahman, A. S., Ahmed, M. S., Kabir, M. E., Mazumder, Q. H., Rahman, M. S., Jahan, C. S. (2018a): Spatio-temporal analysis of climatic variables in the western part of Bangladesh. Environment, Development and Sustainability 20, 89–108, https://doi.org/10.1007/s10668-016-9872-x.

Kamruzzaman, M., Kabir, M. E., Rahman, A. S., Jahan, C. S., Mazumder, Q. H., Rahman, M. S. (2018b): Modeling of agricultural drought risk pattern using Markov chain and GIS in the western part of Bangladesh. Environment, development and sustainability 20, 569–588, https://doi.org/10.1007/s10668-016-9898-0.

Khalil, A. (2022): Space-time characterization of droughts in the Mae Klong River Basin, Thailand, using rainfall anomaly index. Water Supply 22(9), 7352–7374, https://doi.org/10.2166/ws.2022.306.

Keyantash, J., Dracup, J. A. (2002): The quantification of drought: an evaluation of drought indices. Bulletin of the American Meteorological Society 83(8), 1167–1180, https://doi.org/10.1175/1520-0477-83.8.1167.

Kour, R., Patel, N., Krishna, A. P. (2016): Climate and hydrological models to assess the impact of climate change on hydrological regime: a review. Arabian Journal of Geosciences 9: 544, https://doi.org/10.1007/s12517-016-2561-0.

Incoom, A. B. M., Adjei, K. A., Odai, S. N. (2020): Rainfall variabilities and droughts in the Savannah zone of Ghana from 1960–2015. Scientific African 10: e00571, https://doi.org/10.1016/j.sciaf.2020.e00571.

Haied, N., Foufou, A., Chaab, S., Azlaoui, M., Khadri, S., Benzahia, K., Benzahia, I. (2017): Drought assessment and monitoring using meteorological indices in a semi-arid region. Energy Procedia 119, 518–529, https://doi.org/10.1016/j.egypro.2017.07.064.

Hänsel, S., Schucknecht, A., Matschullat, J. (2016): The Modified Rainfall Anomaly Index (mRAI) – Is this an alternative to the Standardised Precipitation Index (SPI) in evaluating future extreme precipitation characteristics? Theoretical and Applied Climatology 123, 827–844, https://doi.org/10.1007/s00704-015-1389-y.

Harisuseno, D. (2020): Comparative study of meteorological and hydrological drought characteristics in the Pekalen River basin, East Java, Indonesia. Journal of Water and Land Development 45(IV–VI), 29–41, https://doi.org/10.24425/jwld.2020.133043.

Hosseinizadeh, A., SeyedKaboli, H., Zareie, H., Akhondali, A., Farjad, B. (2015): Impact of climate change on the severity, duration, and frequency of drought in a semi-arid agricultural basin. Geoenvironmental Disasters 2: 23, https://doi.org/10.1186/s40677-015-0031-8.

Jayanta, D., Tapash, M., Piu, S., Kumar, B. S. (2020): Variability and trends of rainfall using non-parametric approaches: a case study of semi-arid area. MAUSAM 71(1), 33–44, https://doi.org/10.54302/mausam.v71i1.4.

Lee, J. H., Kim, C. J. (2013): A multimodel assessment of the climate change effect on the drought severity–duration–frequency relationship. Hydrological Processes 27(19), 2800–2813, https://doi.org/10.1002/hyp.9390.

Lelieveld, J., Proestos, Y., Hadjinicolaou, P., Tanarhte, M., Tyrlis, E., Zittis, G. (2016): Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. Climatic Change 137, 245–260, https://doi.org/10.1007/s10584-016-1665-6.

León-Muñoz, J., Aguayo, R., Corredor-Acosta, A., Tapia, F. J., Iriarte, J. L., Reid, B., Soto, D. (2024): Hydrographic shifts in coastal waters reflect climate-driven changes in hydrological regimes across Northwestern Patagonia. Scientific Reports 14(1): 20632, https://doi.org/10.1038/s41598-024-71008-y.

Lim Kam Sian, K. T., Zhi, X., Ayugi, B. O., Onyutha, C., Shilenje, Z. W., Ongoma, V. (2023): Meteorological drought variability over Africa from multisource datasets. Atmosphere 14(6): 1052, https://doi.org/10.3390/atmos14061052.

Luppichini, M., Bini, M., Barsanti, M., Giannecchini, R., Zanchetta, G. (2022): Seasonal rainfall trends of a key Mediterranean area in relation to large-scale atmospheric circulation: How does current global change affect the rainfall regime? Journal of Hydrology 612, Part B: 128233, https://doi.org/10.1016/j.jhydrol.2022.128233.

Ly, S., Charles, C., Degré, A. (2011): Geostatistical Interpolation of Daily Rainfall at Catchment Scale: The Use of Several Variogram Models in the Ourthe and Ambleve Catchments, Belgium. Hydrology and Earth System Science 15(7), 2259–2274, https://doi.org/10.5194/hess-15-2259-2011.

Maleika, W. (2020): Inverse distance weighting method optimization in the process of digital terrain model creation based on data collected from a multibeam echosounder. Applied Geomatics 12(4), 397–407, https://doi.org/10.1007/s12518-020-00307-6.

Minea, I., Boicu, D., Negm, A., Zelenakova, M., Demirci, M. (2025): Impact of climate changes on groundwater resources. Frontiers in Environmental Science 13: 1557374, https://doi.org/10.3389/fenvs.2025.1557374.

Mouhamed, L., Traore, S. B., Alhassane, A., Sarr, B. (2013): Evolution of some observed climate extremes in the West African Sahel. Weather and Climate Extremes 1, 19–25, https://doi.org/10.1016/j.wace.2013.07.005.

Mohamed, M. A. E. H., Moursy, F. I., Darrag, M. H., El-Mahdy, M. E. S. (2023): Assessment of long-term trends and mapping of drought events in Tunisia. Scientific African 21: e01766, https://doi.org/10.1016/j.sciaf.2023.e01766.

Mohammed, E. A., Zhi, X., Abdela, K. A. (2025): Extreme weather patterns in Ethiopia: analyzing extreme temperature and precipitation variability. Atmosphere 16(2): 133, https://doi.org/10.3390/atmos16020133.

Montaseri, M., Amirataee, B., Nawaz, R. (2017): A Monte Carlo simulation-based approach to evaluate the performance of three meteorological drought indices in northwest of Iran. Water Resources Management 31(4), 1323–1342, https://doi.org/10.1007/s11269-017-1580-2.

Moussa, I. D., Kona, K. A., Hamidine, I., Adagoye, B. A., Madja, R. B., Idrissa, I. (2025): Tendance climatique actuelle dans l'aire de distribution potentielle actuelle de Boscia senegalensis (Pers.) Lam. ex Poir. dans la région de Zinder. Afrique Science 26(6), 19–30. Available online: https://www.afriquescience.net/article.php?nid=1806&&code=Vol.26,%20N%C2%B06%20(2025)&id=2 acc (accessed on 15 December 2025).

Mukherjee, S., Mishra, A., Trenberth, K. E. (2018): Climate change and drought: a perspective on drought indices. Current Climate Change Reports 4, 145–163, https://doi.org/10.1007/s40641-018-0098-x.

Müller, C., Ouédraogo, W. A., Schwarz, M., Barteit, S., Sauerborn, R. (2023): The effects of climate change-induced flooding on harvest failure in Burkina Faso: case study. Frontiers in Public Health 11: 1166913, https://doi.org/10.3389/fpubh.2023.1166913.

Ngaina, J., Mutai, B. (2013): Observational evidence of climate change on extreme events over East Africa. Global Meteorology 2(1): e2, https://doi.org/10.4081/gm.2013.e2.

Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R. A., Carrao, H., Feyen, L. (2018): Global Changes in Drought Conditions Under Different Levels of Warming.

Geophysical Research Letters 45(7), 3285–3296, https://doi.org/10.1002/2017GL076521.
Nicholson, S. E. (2013): The West African Sahel: A Review of Recent Studies on the Rainfall Regime and Its Interannual Variability. International Scholarly Research Notices 2013(1): 453521, https://doi.org/10.1155/2013/453521.
Ndehedehe, C. E., Awange, J. L., Corner, R. J., Kuhn, M., Okwuashi, O. (2016a): On the potentials of multiple climate variables in assessing the spatio-temporal characteristics of hydrological droughts over the Volta Basin. Science of The Total Environment 557–558, 819–837, https://doi.org/10.1016/j.scitotenv.2016.03.004.
Ndehedehe, C. E., Agutu, N. O., Okwuashi, O., Ferreira, V. G. (2016b): Spatio-temporal variability of droughts and terrestrial water storage over Lake Chad Basin using independent component analysis. Journal of Hydrology 540, 106–128, https://doi.org/10.1016/j.jhydrol.2016.05.068.
Noureldeen, N., Mao, K., Mohmmed, A., Yuan, Z., Yang, Y. (2020): Spatiotemporal Drought Assessment over Sahelian Countries from 1985 to 2015. Journal of Meteorological Research 34, 760–774, https://doi.org/10.1007/s13351-020-9178-7.
Ntoumos, A., Hadjinicolaou, P., Zittis, G., Proestos, Y., Lelieveld, J. (2022): Projected Air Temperature Extremes and Maximum Heat Conditions Over the Middle-East-North Africa (MENA) Region. Earth Systems and Environment 6, 343–359, https://doi.org/10.1007/s41748-022-00297-y.
Sadiq, A. A., Suleman, M., Mohammed, U. (2020): An estimation of rainfall anomaly index and its impact on crop production in Yola and environs. African Journal of Environment and Natural Science Research 3(4), 35–53. Available online: https://abjournals.org/ajensr/papers/volume-3/issue-4/an-estimation-of-rainfall-anomaly-index-and-its-impact-on-crop-production-in-yola-and-environs/ (accessed on 10 September 2025).
Sanogo, A., Owusu, P., Kabange, R., Djire, B., Donkoh, R., Dia, N. (2023): Meteorological Drought Detection and Forecast Using Standardized Precipitation Index and Univariate Distribution Models: Case Study of Bamako, Mali. Journal of Geoscience and Environment Protection 11(7), 30–55, https://doi.org/10.4236/gep.2023.117003.
Sawadogo, B. (2022): Drought Impacts on the Crop Sector and Adaptation Options in Burkina Faso: A Gender-Focused Computable General Equilibrium Analysis. Sustainability 14(23): 15637, https://doi.org/10.3390/su142315637.
Serme, I., Ouattara, K., Bandaogo, A. A., Wortmann, C. (2018): Pearl Millet and Sorghum Yield Response to Fertilizer in the Sahel of Burkina Faso. Journal of Agricultural Studies 6(1), 176–188, https://doi.org/10.5296/jas.v6i1.12384.
Şener, E., Davraz, A. (2024): Comparison of drought indices in the analysis of temporal and spatial changes of climatic drought events: a case study in the Egirdir Lake basin (Isparta/Turkey). Natural Hazards 120(14), 12817–12849, https://doi.org/10.1007/s11069-024-06711-0.
Setianto, A., Triandini, T. (2013): Comparison of Kriging and Inverse Distance Weighted (IDW) Interpolation Methods in Lineament Extraction and Analysis. Journal of Applied Geology 5(1), 21–29, https://doi.org/10.22146/jag.7204.
Sharma, M. A., Singh, J. B. (2010): Use of probability distribution in rainfall analysis. New York Science Journal 3(9), 40–49. Available online: https://www.researchgate.net/publication/304109360_Use_of_probability_distribution_in_rainfall_analysis (accessed on 6 November 2025).
Silva, F. J. B. C. D., Azevedo, J. R. G. D. (2020): Temporal trend of drought and aridity indices in semi-arid pernambucano to determine susceptibility to desertification. Brazilian Journal of Water Resources 25: e32, https://doi.org/10.1590/2318-0331.252020190145.
Shrestha, N., Hu, H., Shrestha, K., Doust, A. N. (2023): Pearl millet response to drought: A review. Frontiers in Plant Science 14: 1059574, https://doi.org/10.3389/fpls.2023.1059574.
Simsek, O., Şenol, H. İ., Keskiner, A. D. (2025): Examination of area-based trend and drought characteristics of drought classes in the context of climate change. Natural Hazards 121, 15707–1573, https://doi.org/10.1007/s11069-025-07412-y.
Shibru, M., Opere, A., Omondi, P., Gichaba, M. (2023): Understanding physical climate risks and their implication for community adaptation in the borana zone of southern Ethiopia using mixed-methods research. Scientific Reports 13: 6916, https://doi.org/10.1038/s41598-023-34005-1.
Sneyers, R. (1990): On the Statistical Analysis of Series of Observations. Technical Note No. 143, WMO No. 415; World Meteorological Organization: Geneva, 192 p. Available online: https://www.cabidigitallibrary.org/doi/full/10.5555/19912451385 (accessed on 24 July 2025).
Soren, D. D. L., Karmegam, D., Biswas, B. (2025): Variability of Gridded Rainfall Data, Time Series Trend Analysis and Rainfall Forecasting of Mayurakshi Basin of Eastern India. Pure and Applied Geophysics 182, 4451–4472, https://doi.org/10.1007/s00024-025-03817-9.
Sousa, P. M., Trigo, R. M., Aizpurua, P., Nieto, R., Gimeno, L., Garcia-Herrera, R. (2011): Trends and extremes of drought indices throughout the 20th century in the Mediterranean. Natural Hazards and Earth System Sciences 11(1), 33–51, https://doi.org/10.5194/nhess-11-33-2011.
Spinoni, J., Naumann, G., Carrao, H., Barbosa, P., Vogt, J. (2014): World drought frequency, duration, and severity for 1951–2010. International Journal of Climatology 34(8), 2792–2804, https://doi.org/10.1002/joc.3875.
Sylla, M. B., Nikiema, P. M., Gibba, P., Kebe, I., Klutse, N. A. B. (2016): Climate Change over West Africa: Recent Trends and Future Projections. In: Yaro, J., Hesselberg, J. (Eds.), Adaptation to Climate Change and Variability in Rural West Africa; Springer: Cham, https://doi.org/10.1007/978-3-319-31499-0_3.
Raziei, T. (2021): Revisiting the Rainfall Anomaly Index to serve as a Simplified Standardized Precipitation Index. Journal of Hydrology 602: 126761, https://doi.org/10.1016/j.jhydrol.2021.126761.
Robleh, H. B., Yuce, M. I., Esit, M., Deger, I. H. (2024): Meteorological drought monitoring in Kızılırmak basin,

Türkiye. Environmental Earth Sciences 83: 265, https://doi.org/10.1007/s12665-024-11550-0.

Quiring, S. M. (2009): Monitoring Drought: An Evaluation of Meteorological Drought Indices, Geography Compass 3(1), 64–88, https://doi.org/10.1111/j.1749-8198.2008.00207.x.

Panday, D. P., Agarwal, V., Kumar, M. (2025): Statistical variability of precipitation and the detection approaches. In: Water Sustainability and Hydrological Extremes; Elsevier, pp. 77–88, https://doi.org/10.1016/B978-0-443-21499-8.00005-2.

Patra, P. (2020): Comparative Analysis of Multi-temporal Drought Indices Using Monthly Precipitation Data: A Study in the Southwestern Part of West Bengal, India. In: Sahdev, S., Singh, R., Kumar, M. (Eds.), Geoecology of Landscape Dynamics. Advances in Geographical and Environmental Sciences; Springer: Singapore, https://doi.org/10.1007/978-981-15-2097-6_11.

Perera, A., Ranasinghe, T., Gunathilake, M., Rathnayake, U. (2020): Comparison of Different Analyzing Techniques in Identifying Rainfall Trends for Colombo, Sri Lanka. Advances in Meteorology 2020(1): 8844052, https://doi.org/10.1155/2020/8844052.

Oloruntade, A. J., Mohammad, T. A., Ghazali, A. H., Wayayok, A. (2017): Analysis of meteorological and hydrological droughts in the Niger-South Basin, Nigeria. Global and Planetary Change 155, 225–233, https://doi.org/10.1016/j.gloplacha.2017.05.002.

Ogunrinde, A. T., Adigun, P., Xue, X., Koji, D., Jing, Q. (2025): Spatiotemporal analysis of drought patterns and trends across Africa: a multi-scale SPEI approach (1960–2018). International Journal of Digital Earth 18(1): 2447342, https://doi.org/10.1080/17538947.2024.2447342.

Okpara, J. N., Tarhule, A. (2015): Evaluation of drought indices in the Niger Basin, West Africa. Journal of Geography and Earth Sciences 3(2), 1–32, http://dx.doi.org/10.15640/jges.v3n2a1.

Oubaha, A., Ongoma, V., Ait Hssaine, B., Bouchaou, L., Chehbouni, A. (2025): Multiscale assessment of drought spatiotemporal dynamics over the Mediterranean region: a case study of Morocco. Journal of Hydrology 661, Part C: 133723, https://doi.org/10.1016/j.jhydrol.2025.133723.

Vijith, H., Dodge-Wan, D. (2021): Statistical Trend Characteristics of Rainfall in the Baram River Basin (Malaysian Borneo). Papers in Applied Geography 7(2), 131–160, https://doi.org/10.1080/23754931.2020.1847728.

Tefera, M. L., Seddaiu, G., Carletti, A., Awada, H. (2025): Rainfall variability and drought in West Africa: challenges and implications for rainfed agriculture. Theoretical and Applied Climatology 156: 41, https://doi.org/10.1007/s00704-024-05251-8.

Traore, S., Owiyo, T. (2013): Dirty droughts causing loss and damage in Northern Burkina Faso. International Journal of Global Warming 5(4), 498–513, https://doi.org/10.1504/IJGW.2013.057288.

Tegegne, G., Alemayehu, S., Dejene, S. W., Gebre, L., Zeleke, T. T., Tesfaye, L., Abdulhamid, N. (2025): Next-Generation Drought Intensity–Duration–Frequency Curves for Early Warning Systems in Ethiopia's Pastoral Region. Climate 13(2): 31, https://doi.org/10.3390/cli13020031.

Tsakiris, G., Loukas, A., Pangalou, D., Vangelis, H., Tigkas, D., Rossi, G., Cancelliere, A. (2007): Drought characterization. In: Iglesias, A., Moneo, M., López-Francos, A. (Eds.), Drought Management Guidelines Technical Annex; CIHEAM/EC MEDA Water: Zaragoza, pp. 85–102. Available online: http://om.ciheam.org/om/pdf/b58/00800535.pdf (accessed on 24 January 2026).

Todaro, V., D'Oria, M., Secci, D., Zanini, A., Tanda, M. G. (2022): Climate Change over the Mediterranean Region: Local Temperature and Precipitation Variations at Five Pilot Sites. Water 14(16): 2499, https://doi.org/10.3390/w14162499.

Tuğrul, T., Hinis, M. A. (2024): Trend analysis of hydrological and meteorological drought in Apa Dam, Türkiye. Environmental Earth Sciences 83: 502, https://doi.org/10.1007/s12665-024-11791-z.

Van Rooy, M. P. (1965): A Rainfall Anomaly Index Independent of Time and Space, Notos. Weather Bureau South Africa 14, 43–48. Available online: https://www.sid.ir/En/Journal/ViewPaper.aspx?ID=215820 (accessed on 24 January 2026).

Zeng, Z., Wu, W., Li, Y., Huang, C., Zhang, X., Peñuelas, J., Ge, Q. (2023): Increasing meteorological drought under climate change reduces terrestrial ecosystem productivity and carbon storage. One Earth 6(10), 1326–1339, https://doi.org/10.1016/j.oneear.2023.09.007.

Wanders, N., Wada, Y., Van Lanen, H. A. J. (2015): Global hydrological droughts in the 21st century under a changing hydrological regime. Earth System Dynamics 6(1), 1–15, https://doi.org/10.5194/esd-6-1-2015.

Waghmare, P. T., Panhalkar, S. S., Pawar, D. S. (2022): Drought Assessment of Eastern Satara District of Maharashtra using Rainfall Anomaly Index. Disaster Advances 15(8), 29–34, http://dx.doi.org/10.25303/1508da029034.

Walsh, R. P. D., Lawler, D. M. (1981): Rainfall Seasonality: Description, Spatial Patterns and Change Through Time. Weather 36(7), 201–208, https://doi.org/10.1002/j.1477-8696.1981.tb05400.x.

Yaméogo, J. (2024): Changes in the seasonal cycles of extreme temperatures in the Sudano-Sahelian domain in West Africa: a case study from Burkina Faso. Meteorology Hydrology and Water Management 12(2), 1–25, https://doi.org/10.26491/mhwm/194451.

Yaméogo, J., Rouamba, S. (2023): Climatic disasters in Burkina Faso from 1960 to 2020: Occurrence, Spatiotemporal dynamics and Socio-environmental consequences. African Journal on Land Policy and Geospatial Sciences 6(5), 1022–1043. Available online: https://revues.imist.ma/index.php/AJLP-GS/article/view/43074 (accessed on 20 January 2026).

Yaméogo, J. (2025a): Annual rainfall trends in the Burkina Faso Sahel: a comparative analysis between Mann-Kendall and innovative trend method (ITM). Discover Applied Sciences 7: 221, https://doi.org/10.1007/s42452-025-06675-1.

Yaméogo, J. (2025b): Trends and prediction of extreme precipitation indices in three cities of Burkina Faso using non-parametric statistics and the Holt-Winters smoothing method. Meteorology Hydrology and Water Management 13(1), 74–103, https://doi.org/10.26491/mhwm/209088.

Yaméogo, J. (2024): The Evolution of the Onset and the Cessation of the Rainy Season in Burkina Faso: A Comparative Study of Two Climatic Conditions. IIARD International Journal of Geography & Environmental

Management (IJGEM) 10(2), 22–31. Available online: https://hal.science/hal-04490335v1 (accessed on 20 January 2026).

Yaméogo, J., Koala, S., Rouamba, S., Yanogo, P. I. (2026): Spatial distribution and temporal trends in precipitation concentration indices over Burkina Faso from 1993 to 2023. Discover Environment 4: 54, https://doi.org/10.1007/s44274-026-00564-z.

Yaméogo, J. (2025c): Spatio-temporal analysis of drought trends recorded during the wettest months in the Mouhoun-Comoé basin in Burkina Faso (Africa): An analysis using z-score and linear regression. Geographica Pannonica 29(2), 65–83, https://doi.org/10.5937/gp29-56313.

Yue, S., Pilon, P., Cavadias, G. (2002): Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. Journal of hydrology 259(1–4), 254–271, https://doi.org/10.1016/S0022-1694(01)00594-7.