# Evolution of Extreme Rainfall and Temperature Indices in the Nakambé Watershed at the Bagré Outflow (Burkina Faso)

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**Abstract**

Climate change is now a global phenomenon with serious implications for many countries. Like other countries in sub-Saharan Africa, Burkina Faso is also vulnerable to the extreme effects of climate change, although few studies have been carried out, even though several vital sectors, such as agriculture and the livestock, forestry are strongly affected. The objective of this work is to study the evolution of rainfall and temperature extremes in the Nakambé watershed at the synoptic stations of Ouagadougou, Ouahigouya and Pô. ClimPACT2 was used to calculate the extreme rainfall and temperature indices. The results show that cumulative rainfall above the 95th percentile (R95p) increases by 147.2 mm and 141.3 mm respectively in Ouahigouya and Ouagadougou. However, in Pô, a slight downward trend in the index (-0.17 mm) was observed. Cumulative extremely wet rainfall (R99p) is increasing at all stations. The frequencies of cold nights (TN10p) and cold days (TX10p) are decreasing while those of warm nights (TN90p) and warm days (TX90p) are increasing. The application of break detection tests to rainfall indices shows breaks in the time series. The PETTITT, HUBERT and LEE and HEGHINIAN tests show a break in 2008 for the PRCPTOT index in Ouagadougou with an excess of 20.8% from 2009 to 2018. With these same tests, a break is detected in 2006 in Ouahigouya on the same index followed by a 29.5% surplus.

**Keywords:** Extreme rainfall, extreme temperature, ClimPACT 2, watershed, Nakambé

## 1. Introduction

The effects of climate change caused by increasing global greenhouse gas emissions are being felt more acutely in many parts of the world. One of the obvious effects of global warming is the recurrence and intensity of extreme weather events including droughts and floods, (Thiombiano, 2010). Consequently, in the face of the variability faced by the climate on a global scale, the evolution of the current rainfall situation in sub-Saharan African countries is quite heterogeneous, with areas with local surpluses, sometimes causing floods, and areas with marked rainfall deficits, creating significant water stress in the agricultural system; (Mahé and *al.*, 2010; Paturel and *al*., 2010; Noufé and *al*., 2011). Drought leads to severe hydrological imbalances that are detrimental to land resource production systems.

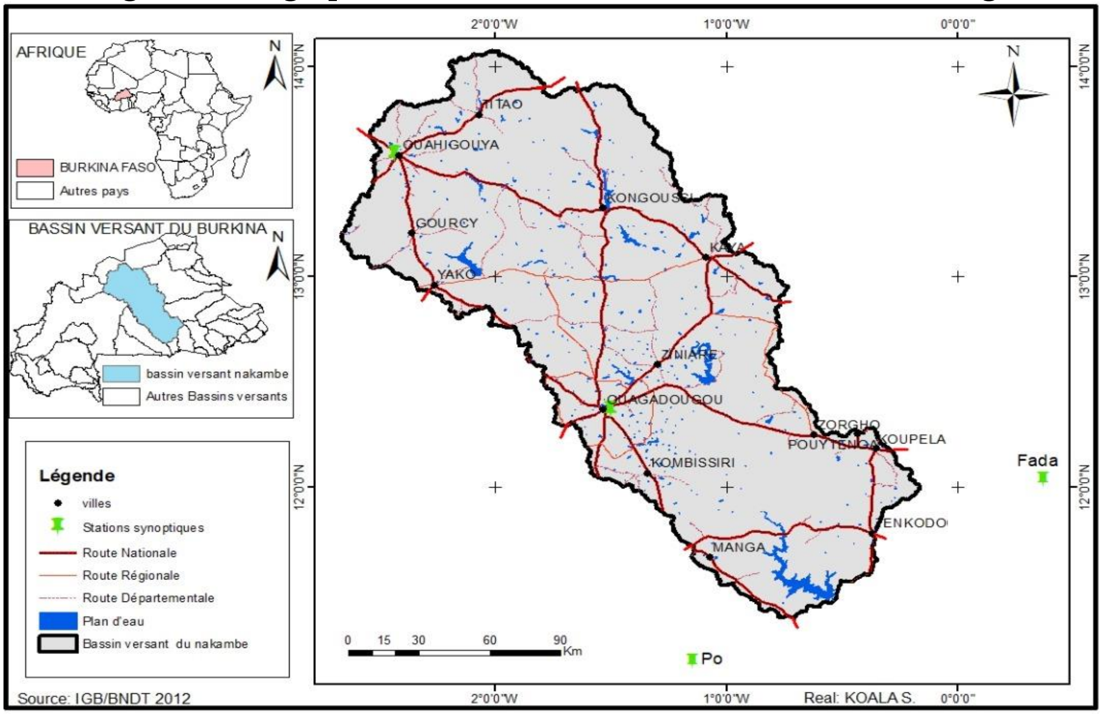
Burkina Faso, located in this part of Africa, is not immune to these climatic hazards. Like other Sahelian countries in the intertropical zone, Burkina Faso is confronted with these extreme situations, the consequences of which are disastrous for the country's main economic sectors such as agriculture, livestock, forestry, etc.

The objective of this study is to characterise the evolution of rainfall and temperature extremes in three synoptic stations, Ouahigouya, Ouagadougou and Pô, from different climatic zones using data from daily reference series. Sectors such as agriculture, health and water resources need information on the evolution of climate extremes, as they impact their activities. However, this information is often buried in meteorological data in a form that experts in those fields cannot use in a easy way. The ClimPACT 2 software makes it possible to extract this information while explaining the evolution of these phenomena in an explicit manner. This software was used in the present study to calculate the extreme indices.

In the broad outline of this work, the indices (rainfall and temperature) will first be calculated and then tested to detect possible breaks based on the tests proposed by the Khronostat 1.01 software. This work is a contribution to a better understanding of climate change in the Nakambé watershed. Indeed, global warming combined with increased rainfall variability and the resurgence of extreme phenomena (drought, floods) is already having significant impacts on natural and human systems. Consequently, without appropriate adaptation measures, agro-silvicultural and fisheries systems will be seriously weakened. It is therefore important to understand the evolution of extremes at the local level for planning appropriate adaptation measures (Aguilar and *al.*, 2009; Bedoum and *al.*, 2017).

The study focuses on the Nakambé sub-catchment in Burkina Faso, located between longitudes 0°10' East and 2°43' West and between 10°58' and 14°08' North latitude with a total area of 35.370 $km^2$ at the outlet of the Bagré dam. Map 1 shows the location of the catchment area on the scale of Burkina Faso.

**Figure 1: Geographical location of the Nakambé watershed in Bagré**




## 2. Materials and methods

### *2.1. Data used*

The extreme climate event or extreme climate phenomenon represents the tails of distribution (Abdelnour and *al.*, 2005), i.e., meteorological anomalies with low probabilities of occurrence. For this study, the data used to calculate the indices of climatic extremes are daily precipitation and temperature data for the period 1988 to 2018, i.e., thirty-one (31) years. They come from the National Meteorological Agency of Burkina Faso (NAMA). The rainfall and temperature series of three synoptic stations were used: the synoptic stations of Ouahigouya (13.58°E; -2.43°N), Ouagadougou (12.35°E; -1.5167°N) and Pô (11.15°E; -1.15°N).

### *2.2. Software used*

The analysis of rainfall extremes required the calculation of climate indices. Indeed, in order to characterise the frequency, intensity and duration of extreme climatic events, the indices of climatic extremes calculated by ClimPACT, based on RClimDex (Zhang and Yang, 2007), were recommended by the World Meteorological Organisation/ET-SCI. ClimPACT calculates more than 60 indices covering agriculture, water resources, health and other indices under development. It is open source software coded in R. It reads weather data (precipitation, daily minimum and maximum temperatures) and calculates the frequency, duration and magnitude of various climate extremes relevant to the health, agriculture and water sectors at monthly and annual time scales. In addition, the IRD's KhronoStat 1.01 software was used to detect breaks in the chronicles of the indices used.

*2.3 Quality control*

The ClimPACT 2 Master programme accessible from the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) website was used to calculate the indices under the R version 3.6.1 environment. ClimPACT has a quality control feature that provides diagnostic graphs to help the user detect erroneous values in the input weather data. However, prior to quality control by the software, missing data (for precipitation) is replaced by (-99.9). For the data collected from NAMA, at all three stations no major deficiencies were detected over the study period.

*2.4. Choice and calculation of indices*

There are several types of climate indices in the literature. In this work, those recommended by the WMO and the international scientific community were used. The use of indices for the detection of climate change has the advantage that trends can be easily compared between different regions belonging to different climate zones. In addition, indices of climate extremes are easily understandable and manageable for socio-economic climate impact studies (Christensen and *al.*, 2002, Balliet and *al.* 2016). Table 1 summarises the indices used in this work. To determine the level of significance of a trend, Student's t-statistic is used to test the hypotheses. The trend is qualified as significant if the probability p (p-value) of the t-test applied to the regression slope is less than 0.05. It is not significant if the probability p (p-value) of the t-test applied to the regression slope is exceeds the threshold of 0.05.

Table 1: Indices used in the analysis of extreme weather events

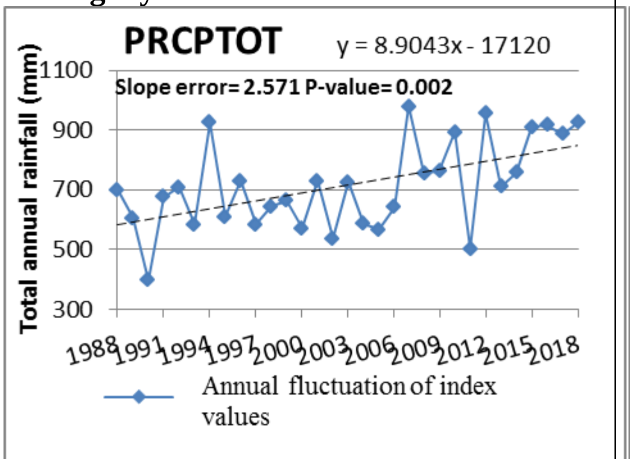
| **Identification** | **Index name** | **Definition** | **Unit** |
|---|---|---|---|
| **Extreme precipitation** | | | |
| **PRCPTOT** | Annual Precipitation | Total annual precipitation | [mm] |
| **R95p** | Intense rainfull | Rainfull≥ 95th percentile calculated over the period 1988-2018 | [mm] |
| **R99p** | Extreme rainfull | Rainfull≥ 99th percentile calculated over the period 1988-2018 | [mm] |
| **Temperature (heat and cold) extremes** | | | |
| **TN10p** | Cold nights | Percentage of days with TN<10th percentile | % |
| **TN90p** | Warm nights | Percentage of nights with TN>90th percentile | % |
| **TX10p** | Cold days | Percentage of days with TX<10th percentile | % |
| **TX90p** | Hot days | Percentage of days where TX>90th percentile | % |

## 3. Results

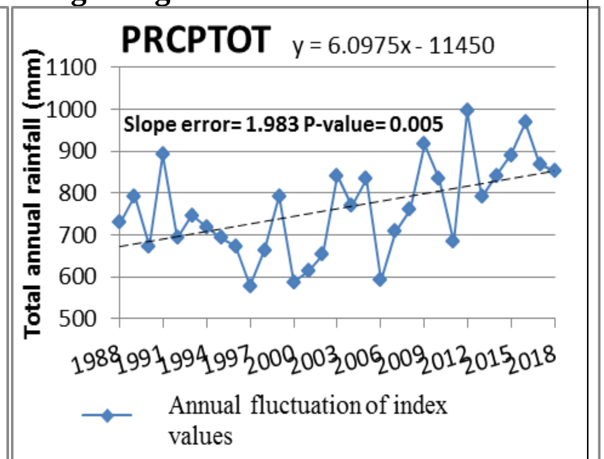
The methodology adopted led to the following results presented in the tables:

### *3.1. Calculation of rainfall and temperature indices*

**Ouahigouya**




**Ouagadougou**




**Pô**

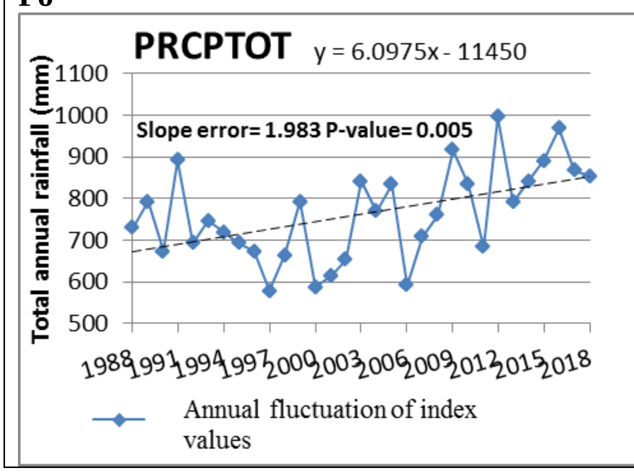



Figure 2**:** Annual Precipitation Totals Index PRCPTOT
**Source:** NAMA (2020)

From the analysis of this figure, in general the trend of annual rainfall totals is increasing in the three stations. At the Ouahigouya station, the general trend is an increase of 8.9043 mm of water per year, i.e., an increase of 276.03 mm of water over the 31-year period, i.e. an increase rate of 1.24% per year. The average over the 31 years is 714.82 mm. Rainfall increases by 89.04 mm per decade.

In Ouagadougou the trend is upward as indicated by the equation of the trend line which is positive and increases by 6.09 mm of water/year or 189.02 mm of water over the study period

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considered. Over the whole 31 years there is an increase of 0.79% per year. The average rainfall over the 31 years is 762.89 mm.
As for the Po station, the general trend curve is quasi-stable, increasing slightly and the annual increase is 1.01 mm of water corresponding to an increase of 31.49 mm of water from 1988 to 2018, giving an increase rate of 0.09% per year.

- **Very wet days (R95p) and extremely wet days (R99p) indices**

The R95p index is the cumulative precipitation above the 95 percentile. It was calculated at all three stations. At Ouahigouya, the trend in this index shows an increase of 4.6847 mm/year. In ten years the index has increased by 44.87 mm/year, i.e. by 147.2257 mm in 31 years. The index is statistically highly significant with a P-value of 0.008. The years with the most intense rainfall during the period in question are 2007 (309 mm), 2015 (292.4 mm) and 1994 (251 mm). At the Ouagadougou station, the index increases by 4.5607 mm/year with a total increase of 141.3817 mm over the study period. The most intense rainfall was recorded in 2017 (417.7 mm), 2012 (372.8 mm) and 2009 (317.5 mm). In Po, however, there is a slight decrease in the trend of intense rainfall. Indeed, the trend line has a value of -0.0055, i.e. a decrease of -0.1705 mm over the 31 years. In Ouagadougou and in Po, the index is not significant. The years 1991, 1994 and 2010 show the highest values with 449.4 mm, 419.1 mm and 419.2 mm respectively. The indices for extremely wet days (R99p) are increasing at all three synoptic stations. The index shows an increase of 0.73 mm/year in Ouahigouya, 2.2 mm/year in Ouagadougou and 0.04 mm/year in Pô. The years with the highest rainfall were recorded in 2007 (153 mm) and 2017 (171 mm) in Ouahigouya; in 2009 (261.3 mm) in Ouagadougou and 1994 (214.9 mm) in Pô. In Ouahigouya, the majority of years (18 years) did not record any days of extreme humidity. This was also the case at the other stations, i.e. 15 years in Ouagadougou and 17 years in Pô. However, the index is not statistically significant in the three stations.

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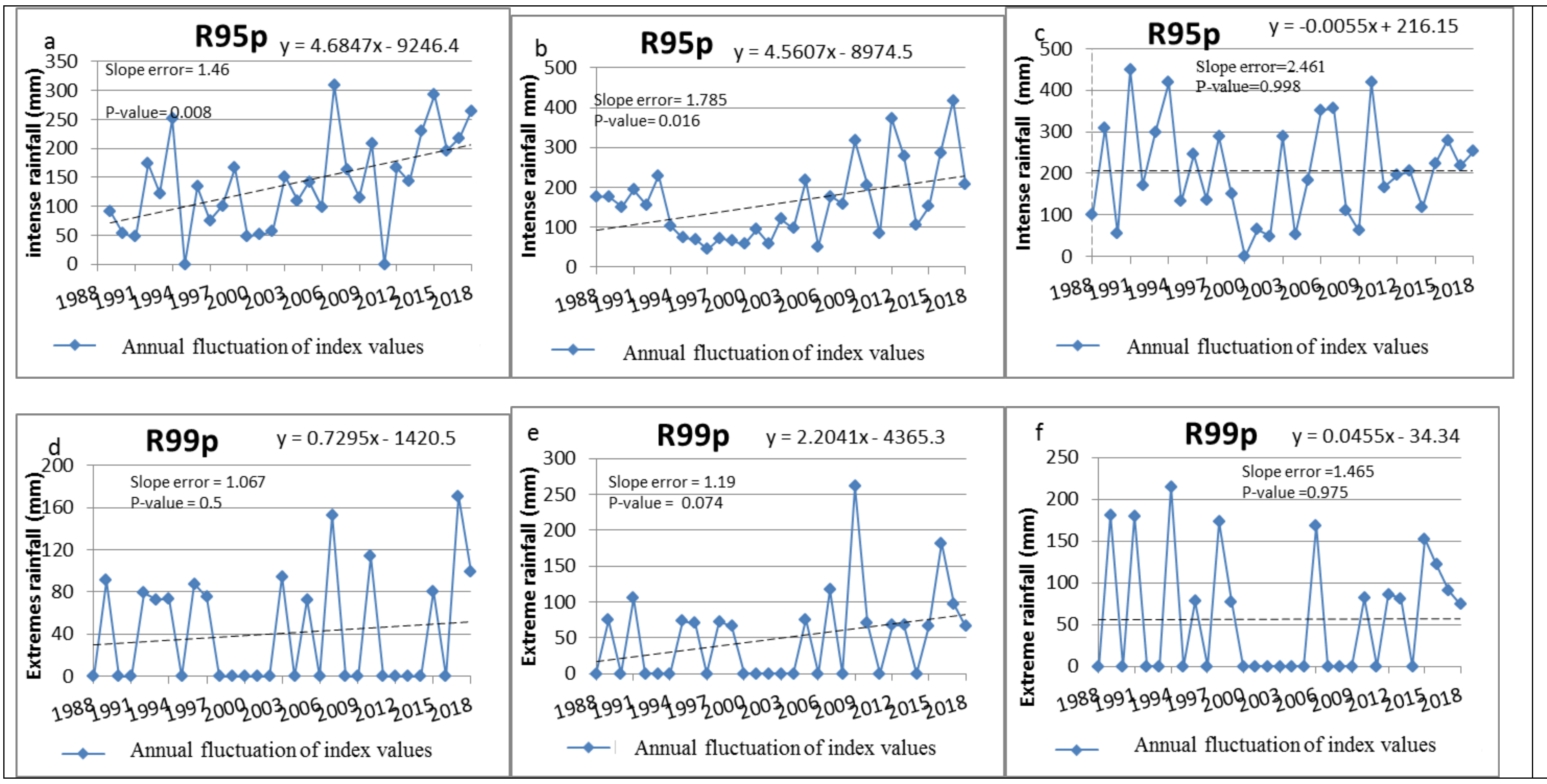


**Figure 3: Annual variation of intense rainfall index values (R95p) at Ouahigouya (a), Ouagadougou (b) and Pô (c) stations and extreme rainfall (R99p) at Ouahigouya (d), Ouagadougou (e) and Pô (f)**

- **Index of cold nights (TN10P), hot nights (TN90P) and index of cold days (TX10p) and hot days (TX90p)**

Figures 4 and 5 below illustrate the interannual evolution of the thermometric indices. The TN10P index, which determines cold nights, indicates the percentage of the number of nights where the minimum temperature is below the 10th percentile in a year. The downward trend in the TN10P index over the period 1988-2018 is observed in all the stations covered by the study. In Ouahigouya, the year 1994 recorded the highest percentage of cold nights, i.e. 21.91%, compared to 4.34% for 2016, the lowest value. In Ouagadougou the highest value was recorded in 1989 corresponding to 20.71% of cold nights in that year. In Po, the year with the highest percentage of cold nights was 2000 with 18.82%.

The TN90P index, defined as the percentage of nights in a year with a maximum temperature value above the 90th percentile, indicates a hot night. The TN90P index shows a slight increase at all weather stations. The value of the slope at the Ouahigouya station is 0.2696, at the Ouagadougou station it is 0.3969 and 0.3689 at the Pô station. The highest percentage of warm nights for the period was recorded in 2015 at Pô (24.86%) compared to 1.06% in 1992 at the same station and is the year with the lowest number of warm nights.

The percentage of days where the maximum temperature is below the 10th percentile determined by the TX10P index is called cold days. In all stations the observation shows a general decrease in the percentage of cold days. Indeed, the trend lines are decreasing with negative values. This decrease is -0.1646% per year at the Ouahigouya station, -0.2383% per year at Ouagadougou and -0.2462% per year at Pô.

The year 1994 with 20.62% cold days in Ouahigouya is the highest in the whole time series. The decrease is more remarkable in the southern part of the basin at the Pô station as cold days decrease by -7.63% over the 3 decades concerned.

The TX90P index determines the warm days and is defined as a percentage of days where the maximum temperature is above the 90th percentile. The general trend of hot days is increasing at all stations. The increase in hot days is 3.45% in the north, 11.44% in the centre and 6.43% in the south of the catchment over the 31 years. These data show that during the last three decades the centre of the catchment has recorded the highest number of hot days. This situation could be explained by the pollution linked to the use of a large number of machines due to demographic pressure.

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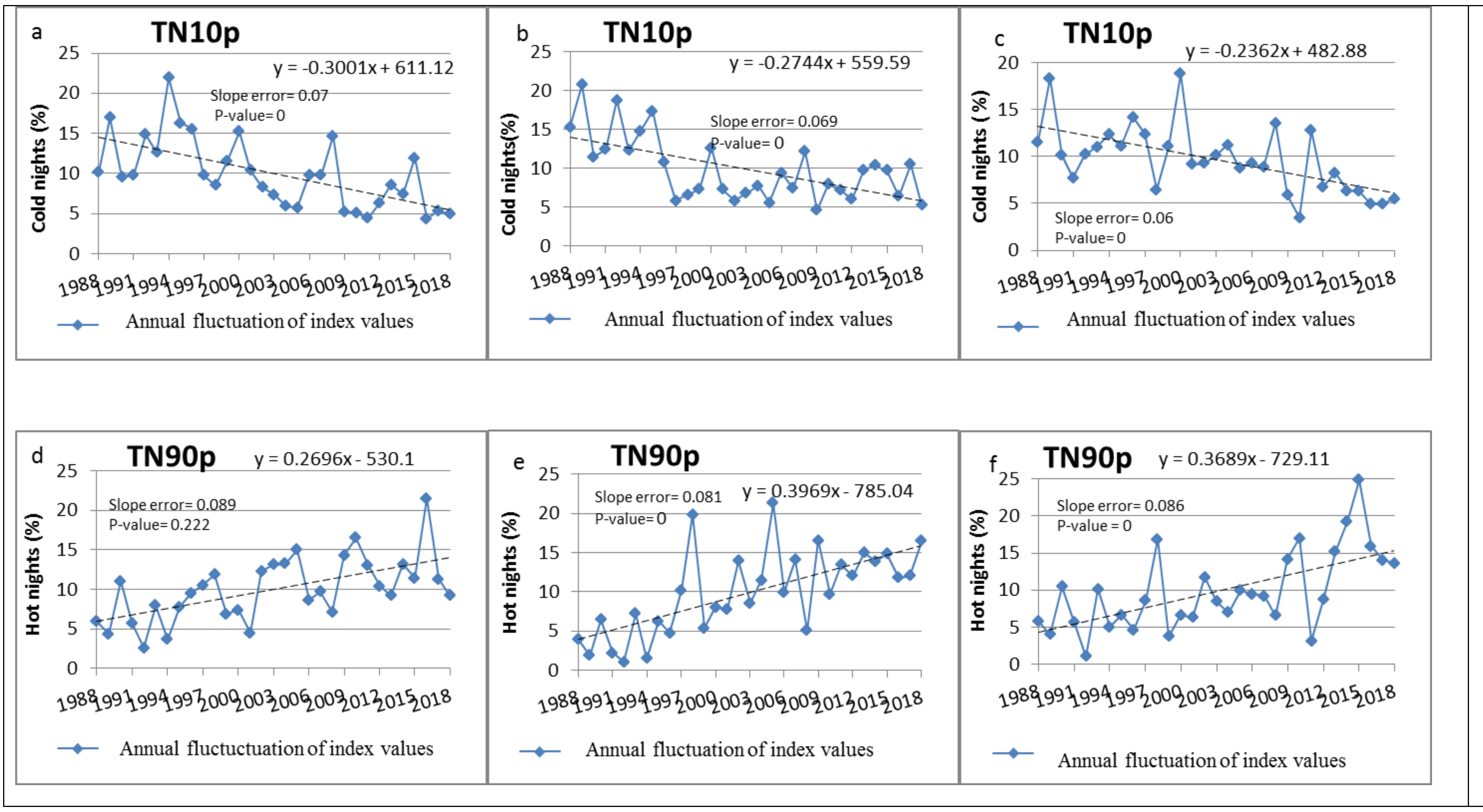


**Figure 4: Annual variation of cold night index values TN10p at Ouahigouya (a), Ouagadougou (b) and Pô (c) and hot night index values TN90p at Ouahigouya (d), Ouagadougou (e) and Pô (f)**

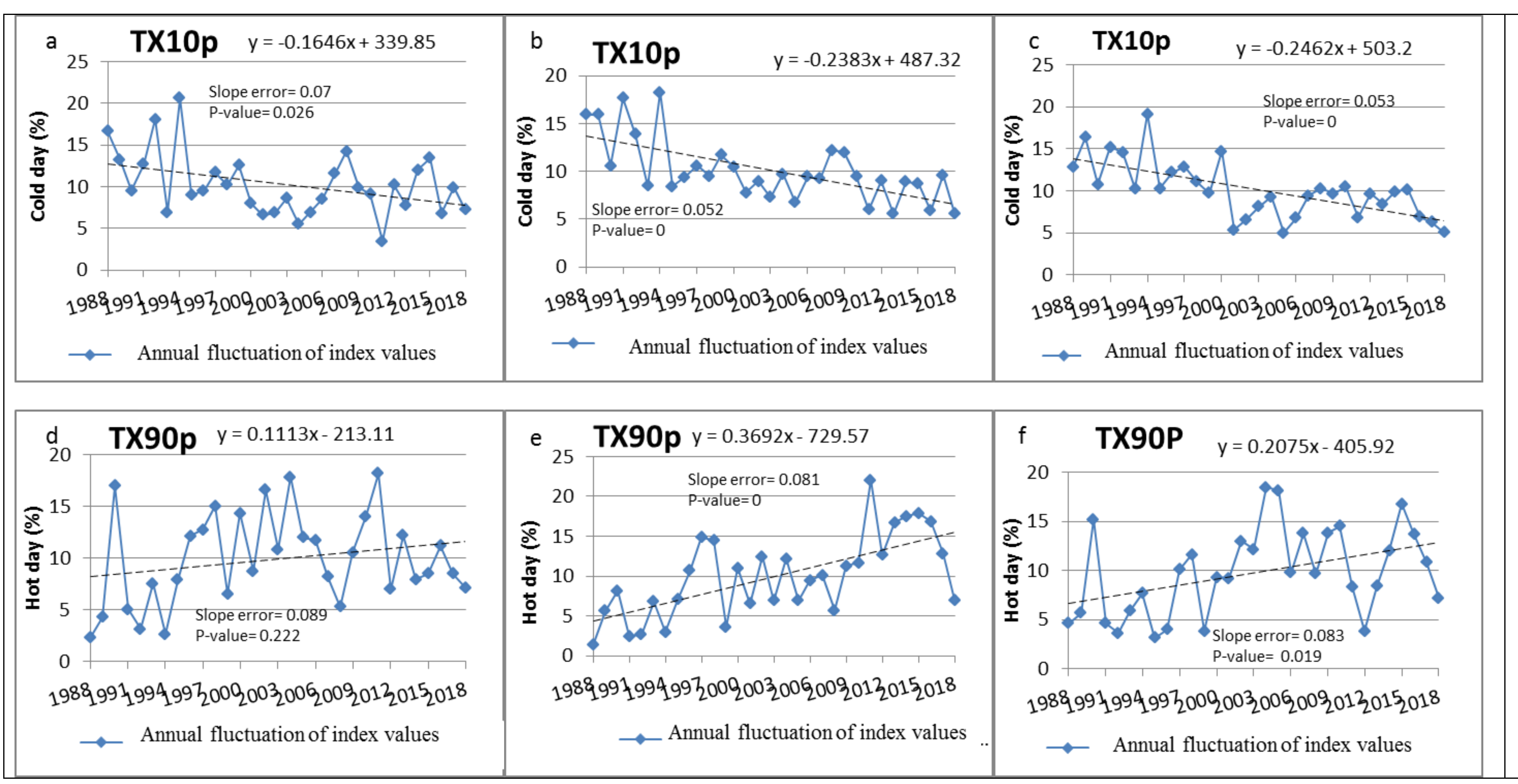


**Figure 5: Annual variation of the frequency of cold days (TX10p) at Ouahigouya (a), Ouagadougou (b) and Pô (c) and hot days (TX90p) at Ouahigouya (d), Ouagadougou (e) and Pô (f)**

*3.1. Time series analysis*

The Khronostat 1.01 software of the Institut for Development Research (IDR) was analysed to test the indices used, with a view to detecting a possible break linked to non-stationarity.

3.2.1 Application of break detection tests to indices of climate extremes

A "break" can be defined by a change in the probability law of the random variables whose successive realisations define the time series studied (Abdelhamid and al. 2015). To detect breaks within the time series in this study, the application of three tests (PETTITT, HUBERT's segmentation and LEE and HEGHINIAN's Bayesian method) was necessary to test the indices of each station. Tables 2 and 3 summarise the results of the different tests. At the Po station, no breaks were detected on the three rainfall indices.

3.2.2. Results of the tests applied to the indices

Table 2: Ouagadougou station

| Station : Ouagadougou | Indexes | Break according to tests | | | Break according to HUBERT | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Serie 1 | | Serie 2 | | variation |
| | | PETTITT | HUBERT | LEE and HEGHINIAN | Mean before break | Ecartype1 | Mean after break | Ecartype 2 | (%) |
| | PRCPTOT | 2008 | 2008 | 2008 | 715.552 | 86.963 | 864.400 | 89.176 | 20.8 |
| | R95p | 2006 | 2008 | 2006 | 121.319 | 59.079 | 243.090 | 110.828 | +100 |

Table 2 presents the results of three tests applied to the different indexes. Their application to the Ouagadougou station shows breaks on two indices. NS' indicates the insignificance of the index according to the proposed test.

Table 3: Ouahigouya station

| Station : Ouahigouya | Indexes | Break according to tests | | | Break according to HUBERT | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Serie 1 | | Serie 2 | | variation |
| | | PETTITT | HUBERT | LEE and HEGHINIAN | Mean before break | Ecartype1 | Mean after break | Ecartype 2 | (%) |
| | PRCPTOT | 2006 | 2006 | 2006 | 641.926 | 4.057 | 830.242 | 136.610 | 29.5 |
| | R95p | 2006 | 2013 | 2013 | 121.738 | 72.071 | 241.240 | 38.114 | |
| | R99p | NS | 2016 | NS | 35.259 | 46.895 | 136.100 | 50.912 | |

Also in Ouahigouya, all three indices show breaks.

## 4. Discussion

The analysis of the evolution of extreme rainfall from 1988 to 2018 in the Nakambé watershed at Bagré reveals overall variability and irregularity of rainfall in time and space. However, this spatio-temporal variability is very pronounced in the stations located in the north and centre of the basin, while the southern part of the basin is less exposed. This variability, which translates into increases and decreases in rainfall, is likely to have a negative impact on agricultural production, as most crops are linked to rainfall, especially its frequency and spatial distribution (Atcheremi and al. 2018). At a small scale, the index study (PRCPTOT) showed the increase in total annual rainfall over the last three decades. However, these results do not corroborate with those found by New and al. (2006) in their study on the evolution of daily weather extremes over southern and western Africa which showed that the regions experienced a decrease in total annual rainfall (PRCPTOT) and number of rainy days. Balliet and al. (2016) found similar results at the Gagnoa station with a decrease of 3.18 mm of water per year from 1961 to 2010 in the PRCPTOT index. Furthermore, the same station (Gagnoa) that was recently studied is marked by an increase in the index in its last phase: a first phase (1961-1976) marked by a decrease in annual accumulations, the second phase (1977-1997) is quasi-stationary; the third phase (1998-2016) records an increase in accumulations, (Atcheremi and al. 2018). A similar study conducted by Abdelhamid and al. (2015) in the Saïss plain in Morocco from 1978 to 2014 showed that the wet period only started from 2009 until 2014 in this area. In our study, the sub-period 1988-2008 recorded a decrease in its rainfall totals and the increase only started from the years 2009 onwards according to the results of the break detection tests. This explains the discrepancy between our results and those of New and al. (2006) since the increase starts in 2009 while their study ended in 2006. These results, which show an increase in total rainfall, could be the beginning of a return to wetter conditions as reported by Ozer and al. (2003) in Niger and confirmed in some West African countries, notably Senegal (Sarr and al. 2013) and Burkina Faso (Lodoun and al. 2013), and better explain the increase in flooding in this part of Africa in recent years.

The analysis of the index of intense rainfall (R95p) and extreme rainfall (R99p) shows increasing trends, except for the Pô station with a decrease and only for the intense rainfall. The trends are not significant and these results are in agreement with those obtained in northern Benin by Hountondji and Ozer, (2011). However, the upward trend of R95p and R99p indexes is to be noted the origin of floods in the western part of the African continent. In Burkina Faso, floods have become recurrent from the 2000s onwards in the city of Ouagadougou, the country's capital, (Hangnon and al. 2015). The most tangible example is the flood of 1 September 2009 in Ouagadougou with 263.4 mm of rain falling in the space of 12 hours, whereas the annual rainfall average is around 800 to 900 mm. Moreover, at the Ouagadougou station, the Hubert segmentation test detected a break in the R95p index in 2008 with a rate of variation that was almost doubled. However, it should be noted that these floods, although caused by extreme levels of rainfall, are part of a climatic cycle that has already caused similar floods in previous years and during a recent period. Like the drought, the overabundance of rain in some places is accompanied by problems. In agriculture, crops are sometimes ruined by floods, (Benoit, 2008); there is also the disappearance of animals due to flooding in the livestock sector. With regard to hydro-agricultural structures, the torrential rains have led to the deterioration of dykes and spillways, the washing away of earth and vegetation causing premature silting of the basin, and the deterioration or even destruction of the irrigation network.

The analysis of the thermometric indices shows the temperature trends in the catchment area. Over the 31-year period, a slight decrease in the frequency of cold nights (TN10p) is observed at all three stations. Also, a decrease in the frequency of cold days (TX10P) is seen over the same period justifying the increase in the frequencies of warm nights (TN90P) and warm days (TX90p) observed over the period 1988 to 2018 at the three stations. These results are similar to those found at the Ouagadougou and Ouahigouya stations by Bambara et al. (2018), over the period 1956 to 2015. Indeed, the evolution of temperatures results in a decrease in the frequency of cool nights: 101 days to 86 days over the period 1956-1985 and of cool days: 76 days to 67 days and an increase in the frequency of warm nights: 61 days to 95 days and warm days: 68 days to 77 days at the Ouagadougou synoptic station. In Ouahigouya, the observation is the same: overall, the heat is increasing and the coolness is less frequent. The temperature trend is generally upwards. Similarly, Karimou and al (2015) found similar results in south-eastern Niger, with cold nights tending to decrease, hot days, hot nights and heat that is increasing. These results were confirmed by the work of Goubanova, (2007) on the Mediterranean basin and Paturel and al. on the Bani in Niger (2014).

The decrease in rainfall, drought and the increase in temperature lead to a decrease in water resources in the regions of Burkina Faso. This lack is manifested by the great difficulty in obtaining water in both quality and quantity for the population and for the agroforestry production system, resulting in a food deficit. All in all, heat stress weakens yields. For Karl and al (2009), any increase in the variability of water supply will affect plant growth and reduce yields.

Statistical tests applied to the different indices indicate breaks with increasing trends reflecting the non-stationarity of the indices. At the Po station, the statistical tests did not detect any significant breaks in the different indices. However, the absence of a break in a rainfall series does not mean that there is no variation in the level of rainfall over time, but that this variation, if it exists, remains insignificant (Lubès and al. 1994, Fossou and al. 2015). This condition makes us understand that at the Po station in the south of the catchment area, extreme climatic phenomena have less effect than in its northern and central part.

**Conclusion**

The analysis of the evolution of precipitation indices during the period 1988 to 2018 has highlighted a general increase in rainfall totals as well as the increase and frequency of intense and very intense rainfall in the Nakambé basin. This decrease is accompanied by an increase in temperature indices during this same period. Indeed, the frequency of cold night and day temperatures decreased while that of hot nights and hot days increased. These data reflect the observed climatic disturbances and the frequency of extreme events in recent decades, namely floods and droughts, mainly in the Ouagadougou and Ouahigouya areas. Even if the floods that occurred in Ouagadougou are the result of unplanned urban growth, they are nevertheless the result of a local climatic disturbance, namely the frequency and intensity of extreme rainfall. These extreme situations jeopardize the exploitation of watershed resources through a reduction or excess of water resources available for agricultural activities. In Burkina Faso, 80% of the population lives from agriculture and livestock. It is one of the developing countries in the world. The Climate change threatens people's livelihoods and increases hunger. The main impacts of climate change on agriculture are loss of crops and productivity, water scarcity and land degradation, increased pest and disease outbreaks, and increased conflict over natural resources. The most frequent climatic scenarios that lead to livestock decapitalization are drought leading to a lack of grazing and a decrease in agricultural production, floods and strong winds, as well as "heat stroke. In addition, the strong variation in climatic factors such as temperature, rainfall, hygrometry and winds causes a significant decrease in pastoral resources, with the corollary of a considerable decrease in animal productivity. However, in urban areas, without being only linked to climatic hazards, floods can be due to the absence of road works (sewerage works) in housing estates and during development operations and this constitutes a real handicap for the preservation of housing infrastructures. It leads to the stagnation of rainwater and domestic sewage in the streets, a source of flooding in the neighborhoods, with the degradation of the roads and even their disappearance.

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