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Analysis of Rainfalls in Niger during the Period 2008-2024

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Abstract: The global reheating observed in these last years is followed with a change of rainfalls bunches at the global and regional area. The floods frequency increasing, dangerously impacts the socio-economic activities of several countries throughout the world. Indeed, for Niger as a country located in West Africa where the majority of the population existence depends on the agricultural and pastoral activities, this change of rainfalls bunches may have unwanted consequences. The aim of this work is to analyze the evolution and trend of rainfall in Niger during the period 2008-2024 compared to the period 1971-2000 characterized by episodes of drought. To achieve the objective of this work, annual data of rainfalls and the number of rainy days from four meteorological stations representative of the four major climatic zones of Niger are used. These are the station of Agadez (in Sahelian zone), the station of Tahoua (in mid Sahelian and Saharan zone), the station of Niamey (in Sahelian zone) and the station of Gaya (in mid Sahelian and Sudden zone). Thus, the standardized index of Lamb (1982) and the least squares method are respectively used to analyze the variability of the interannual rainfalls and their tendency. The results obtained show a significant improvement in rainfall in the four climatic zones compared to the period from 1971 to 2000, and especially in the Nigerien Sahara where 88.2% of the years were wet. The latitudinal gradient South-North of the rainfalls has known an upgrading going from 1 mm/km during the period of 1971-2000 to 1.26 mm/km during the period of 2008-2024. Our results also show that this improvement in rainfall is linked to heavy rainfall events which are the cause of floods observed mainly during wet years (2010, 2012, 2013, 2017, 2019 and 2024). Finally, the results show that, excepting the Sahel-Niger, the other climatic zones are experiencing an increasing trend in rainfall.
Therefore, in the face of current climate change, West African countries must mobilize to put in place a strategy to mitigate the consequences of heavy rainfall.

Key words: Climatic change, precipitations, floods, Niger.

1. Introduction

The global reheating has worldly and locally modified in a considerable way the climatic system. Rainfalls are one of the most touched pluviometry parameters with the climate change [1]. The rain is an essential element for countries' economic and populations development. In West-Africa, rainfalls are conditioned by the bunch of the MOA (Monsoon West African) [2]. In the Sahel, the rain gauge has been characterized by two well-known periods: The 1950-1969 period that has known a succession of humid years and the period of 1970-1993 marked by a persistency of dry years. After the droughts of the years 70s and 80s, West African countries, and mainly those of the Sahel zone, undergo, a comeback of rainfalls with massive rains and devastating floods [3]. From 1970 to 2000, Niger has known a drastic decreasing of annual cumulations of rainfalls in comparison to the humid period of 1931-1960 [4-6]. After the dryness of 1970s, the rainfalls in Niger are seen improved in the earlier 21th century [7, 8]. But this improvement is followed by a modification in the rainy days number per season with a rainy events intensification principally during the years seen as highly humid. According Yacoubou et al. [9], during the comeback of the rainfalls, the correlation between the cumulative annual precipitations and the number of rainy days has not been much significative and this

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seems to depend on some events of high intensity observed overall during August.

These strong rainy events cause generally floods constituting the main natural disasters that face Niger these recent years [10]. In Niger, the floods rise has been demonstrated in all over the country by Fiorillo et al. [11] in analyzing the official collected data by the government regarding the damages recorded from 1998 to 2017. The floods consequences are of environmental and human characteristics. They consequences are then characterized by the lost in human life and in materials, the occupation of arable spaces and the destroying of economic infrastructures [12]. Throughout this study, it is about to study first the interannual variability of rainfalls in the four climatic zones for the period going from 2008 to 2024 and secondly to analyze their evolution in comparison to the period between 1971 to 2000. This will allow to find the tendency of the rain gauge that should in turn serve of a means of shaping the evolution of the rain precipitation system in the goal to prevent the future situation.

2. Presentation of the Zone to Study

The concern of this study is the evolution of the rain precipitation system in Niger, a Sahelian country located between the latitudes 11°37 N and 23°33 N and between the longitudes 0° E and 16° E. More than 2/3 of the space of Niger is situated in the highest and hottest desert of the world that is the Sahara. The climate in Niger is characterized by four climatic zones with a negative gradient of rainfalls from South to North. Four representative stations are concerned by this study. It is about the station of Agadez located in the Sahara zone (see the yellow color), the station of Tahoua located in the center of the mid Sahelian-Saharan zone (see the orange color), the station of Niamey located in the Sahelian zone (in green color) and the station of Gaya located in the mid Sahelian-sudden zone (in blue color) (see Figure 1).

The rainfalls in Niger have unimodal character with a pic during August all along the four climatic zones (see Figure 2) and the duration of the raining season diminishes with the higher latitudes.

3. Data and Methodology

Data used in this work are as reminder, those from the four meteorological stations that are the one of Agadez, of Tahoua, of Niamey and of Gaya. These data are the annual data of DMN (Direction de la Météorologie Nationale) published in monthly newsletters. The interannual variability of rainfalls is studied through the annual cumulation of Pi and the rainy days number Ni for a given year i. These two parameters are calculated using the following formulas:

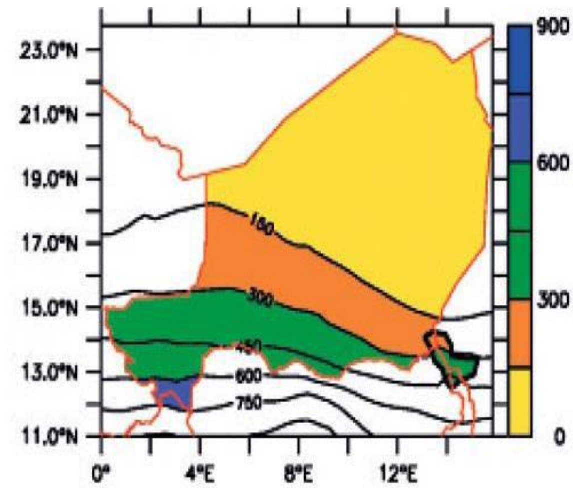

Fig. 1 The different climatic zones in Niger.

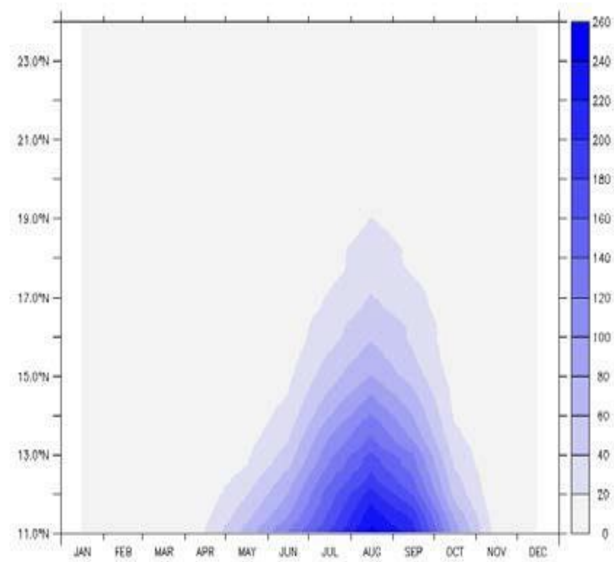

Fig. 2 The distribution of rainfalls per season.

Cj stands for the monthly cumulation of the month j (June, July, August, September).

stands for the number of the rainy days in the month j (June, July, August, September).

The correlation between the rainfalls annual cumulation and the number of the rainy days is analyzed through the coefficient of correlation known as linear R and is calculated in the below formula:

: The average of annual cumulation from the period 2008-2024.

The evolution of rainfalls along the period 2008-2924 against the one of 1971-2000 is analyzed through Lamb's standardized index of rainfalls [13], Isp calculated with the following formula:

with: the climate average along the period 1971-2000; the standard deviation of the series.

The annual rainfalls cumulation is the most used indicator to describe the evolution for long term duration. In most studies, the annual abnormalities of rainfalls are estimated in calculating an index of standardized rainfalls (I_{SP}) [14]. The I_{SP} allows to distinguish superior and inferior years with the climatologic average and to define relevant characteristics of rains using the interannual and decade variability. The lower squares method is employed to analyze the rainfalls tendency along the period 2008-2924 through the coefficient of the slope.

A positive coefficient valor indicates an increasing tendency and a negative valor stands of a decreasing tendency. This coefficient is calculated with the formula below:

4. Findings

4.1 Interannual Variability of Rains with the Station of Agadez

The station of Agadez is featured by the Saharan zone with low rainfalls annual cumulation with an average of 122.5 mm along the period 1971-2000. The Figure 3 presents variations in annual cumulation of rainfalls for the period 2004-2024. It also presents the correspondent number in rainy days.

The histogram shows a significative interannual variability in pluviometry cumulation for the period 2008-2024 at the station of Agadez. The average in annual cumulation along this period is 173 mm. A significative rise of rainfalls can be noticed with a gap of 40.5 mm of rains in using a comparison between the averages in annul cumulations of the two periods (1971-2000 and 2008-2024). The number in rainy days is also highly variable along the period of 2008-2024. All along the raining season period that

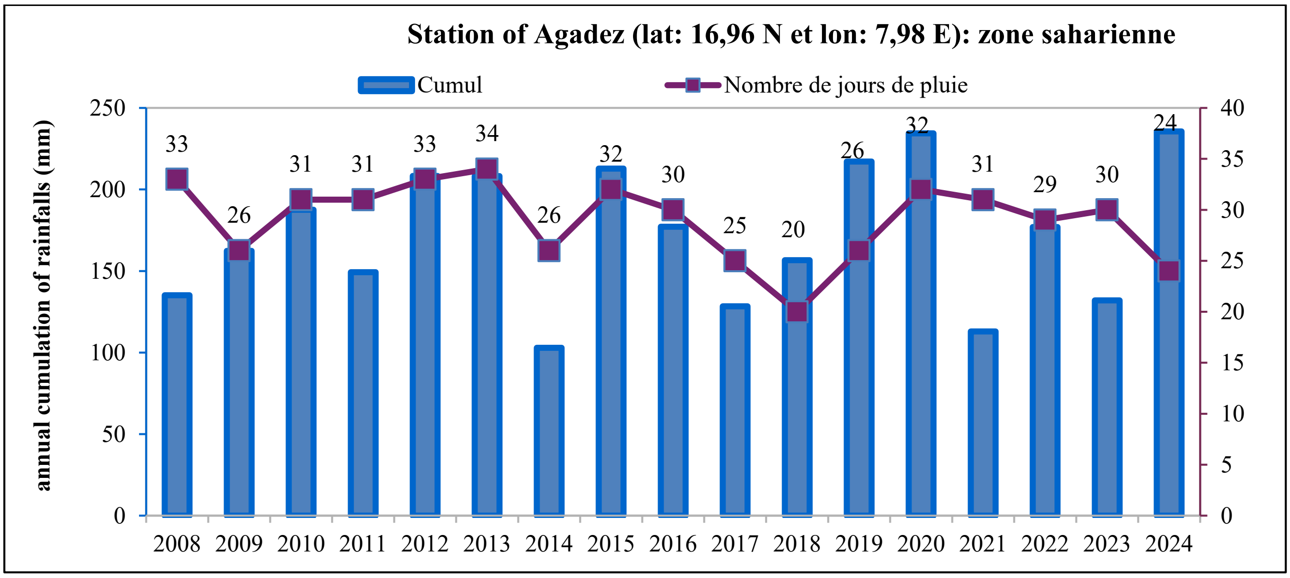

Fig. 3 Interannual variability of annual cumulation and the number of rainy days recorded at the station of Agadez.

lasts three months (July-August-September), the number of the rainy days varies between 20 days (with 156.6 mm) and 34 days (with 208.2 mm) whereas the annual cumulation varies between 102.9 mm in 2014 (recorded in 26 days) and 235.6 mm in 2024 (recorded within 24 days). These high remarks show that the cumulations in the pluviometry are considerable aleatory in comparison to the number of rainy days in the Saharan zone. This finding is justified by the low coefficient of linear correlation (R1 = 0.21) that is found between the two parameters (the cumulation and the number of rainy days).

4.2 Interannual Variability of Rains with the Station of Tahoua

The region of Tahoua is located between the Saharan zone in North and in the Sahelian zone in South and is characterized with a semi-dry tropical climate. Along the period of 1971-2000, the annual average in rainfalls cumulation at the station of Tahoua is 314 mm. The Figure 4 presents the annual rainfalls cumulation during the period 2008-2024 and also those corresponding with the number of rainy days.

At the station of Tahoua (Figure 4), the annual cumulation is also characterized by an interannual variability. Indeed, along the period 1971-2000, the cumulative average is 314 mm while along the period 2008-2024, the cumulations vary between 681 mm versus 245 mm for the year 2013 that has recorded the lowest pluviometry cumulation. That corresponds to a gap of 436 mm. The number of annual rainy days is also variable. It wavers between 30 and 51 days along the period of 2008-2024 with a raining season that lasts around four months (June, July, August and September). The least rainy year (245 mm) has recorded 39 rainy days and the must rainy year (681 mm), 38 rainy days. Therefore, with a difference of one rainy day, it is to note a gap of 256 mm of rain. This gap might be caused by some strong rainy events. The correlation coefficient between the annual cumulation and the number of rainy days is not only negative but also low (R2 = -0.03). The annual cumulation of rainfalls and the number of rainy days in the Sahelian- Saharan zone of Niger weakly grow in the opposite way and the average in annual cumulation along that period is 379 mm. The annual cumulation in the Sahelian-Saharan zone along that period does not depend on the number of rainy days.

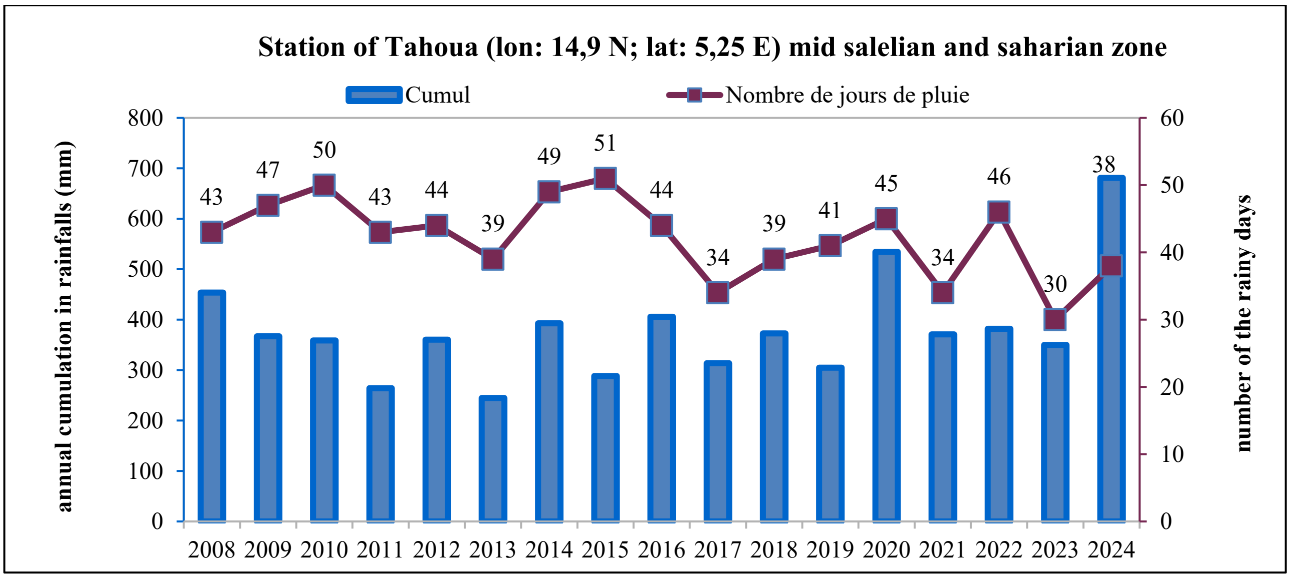

Fig. 4 Interannual variability of annual cumulation and of the number of rainy days at the station of Tahoua.

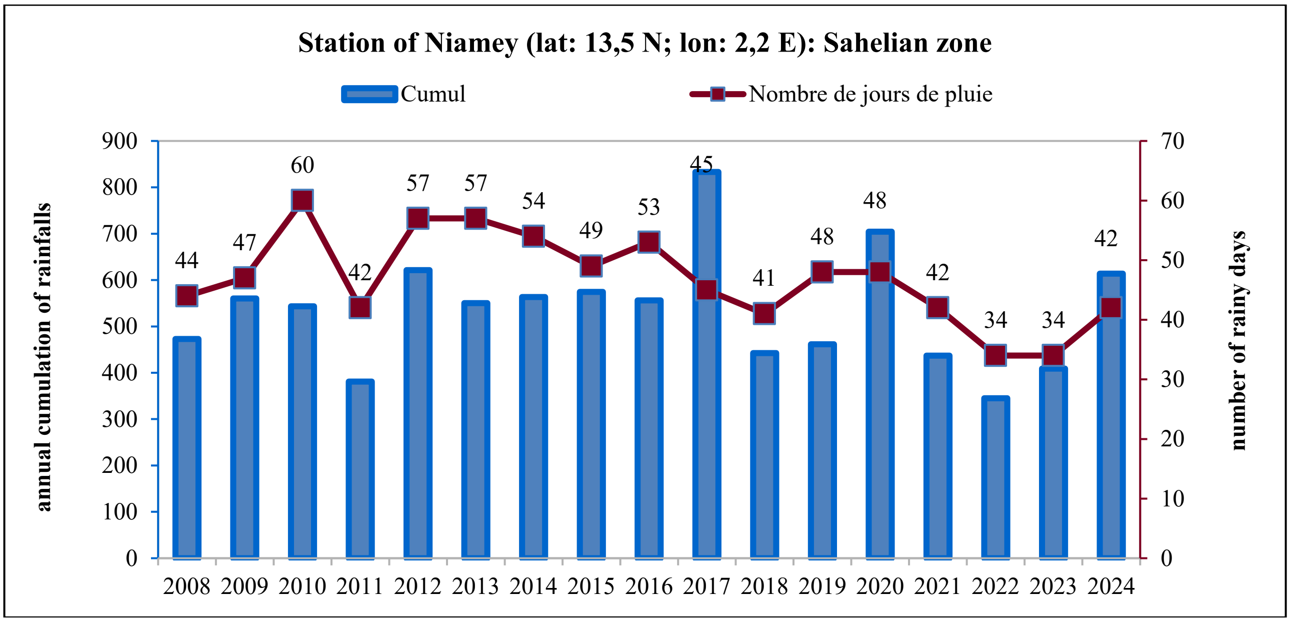

Fig. 5 Interannual variability of annual cumulations and the number of rainy days at the station of Niamey.

4.3 The Interannual Variability of Rains at the Station of Niamey

Along the period 1971-2000, the average in annual cumulation at the station of Niamey is 484 mm. The variation of the interannual cumulation of rainfalls and the one in the number of rainy days at the station of Niamey which is characterized by the Sahelian zone during the period 2008-2024 are illustrated by the Figure 5. The cumulative average in annual rainfalls along that period is 533.2 mm. Thus, an addition of 45 mm of rain is observed between the cumulative averages of rainfalls of the two periods (1971-2000 and 2008-2024).

The recorded results at this station also show a considerable interannual variability of rainfalls as the annual cumulations vary between 345 mm (the lowest rainy year) with 34 rainy days and 833 mm (the highest rainy year) with 45 rainy days. Regarding the number of rainy days, the shortest duration is 34 days versus the largest that is 60 days. It is surprising to notice here that despite the record of 60 rainy days, the year 2010 has not been the rainiest year of the period and the least rainy year has the little number of rainy days as if the annual cumulation is linked to the number of rainy days. In the station of Niamey, the correlation coefficient between the annual cumulation and the number of rainy days is R3 = 0.47.

4.4 Interannual Variability of Rains at the Station of Gaya

The station of Gaya is situated at the extreme South of the country in the Sahelian-sudden zone. It is the more wetted area during rainy seasons. The average in annual cumulation is 763 mm along the period 1971-2000 while the one of the periods 2008-2024 is 894 mm so as to say an average increase of 131 mm between the two periods. During the period 2008-2024, the station of Gaya has recorded annual cumulations varying from 649 mm (in the least rainy day) to 1,279 mm (in the rainiest year). The annual average along the is 894 mm per year (Figure 6). Regarding the number of the rainy days, a variation between 58 and 80 days was recorded. The year 2011 with less rainy days (58) has recorded 811.4 mm and the year 2018 with 80 rainy days has recorded 1,194 mm. The rainiest year (2024), with 1,279 mm recorded within only 62 rainy days. The correlation between the annual cumulation and the number of the rainy days is not much significative at the station of Gaya where R4 = 0.47.

4.5 Analysis of Rainfalls Evolution along the Period 2008-2024 versus the Period 1971-2000

The Figure 7 shows through the standardized index of rainfalls a significative improvement of rainfalls along the period 2008-2024 in opposite to the period 1971-2000 at all stations characterizing the four climatic zones of Niger. Indeed, along the period 2008-2024, at the station of Agadez, 88.2% of the years have recorded a cumulation higher than the climatic average of the period 1971-2000 that is 122.5 mm. That means the rainfalls have known much improvement in the desertic zone. For the station of Tahoua (Sahelian-Saharan zone), the one of Niamey (Sahelian zone) and the one of Gaya (Sahelian-Sudden zone), the percentages rainy years during the period 1971-2000 are respectively 76.4%, 58.8% and 76.4%. But the station of Niamey is particularized by a tendency toward lowness mainly from the year 2018 with a little period of seven (7) years of dryness followed with two (2) humid years separated by three (3) successive dry years. The station of Gaya is particularized on its part by strong annual cumulation during the last decade of the period 2008-2024.

The rainfalls improvements at all stations are followed by the apparition of extremely humid years where the standardized index of rainfalls is superior than 1.5. For the stations of Tahoua and Niamey, the frequency of the apparition of extremely humid years is 11.76% so as to comprehend that there one extremely humid year during each decade. At the station of Gaya, this frequency is around 30%, that means three (3) years over ten (10). At the station of Agadez, the frequency of the apparition of these events is more important with 41% that corresponds to four (4) extremely humid years within each decade.

Regarding the dry years, a year is called extremely dry for an index inferior to -1. Along the period 2008-2024, only the station of Niamey (Sahelian zone) presents only one deficient year with an index corresponding to -1.13. Thus, rainfalls improvement in Niger has reduced the intensity of dryness years. However, this situation does not exclude the events of portions of long duration of dryness during the raining season and can negatively affect the agricultural, sylvicultural and pastoral activities.

The table below presents linear tendency coefficients and the coefficient of R determination at each station.

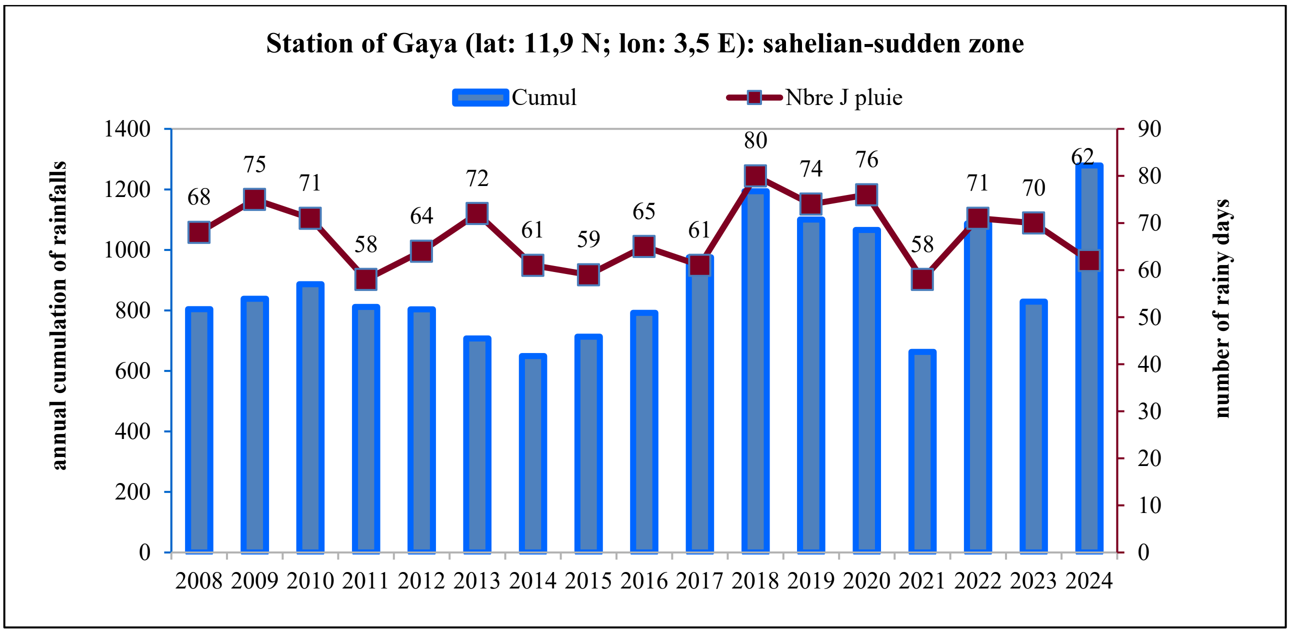

Fig. 6 Interannual variability of annual cumulations and the number of rainy days at the station of Gaya.

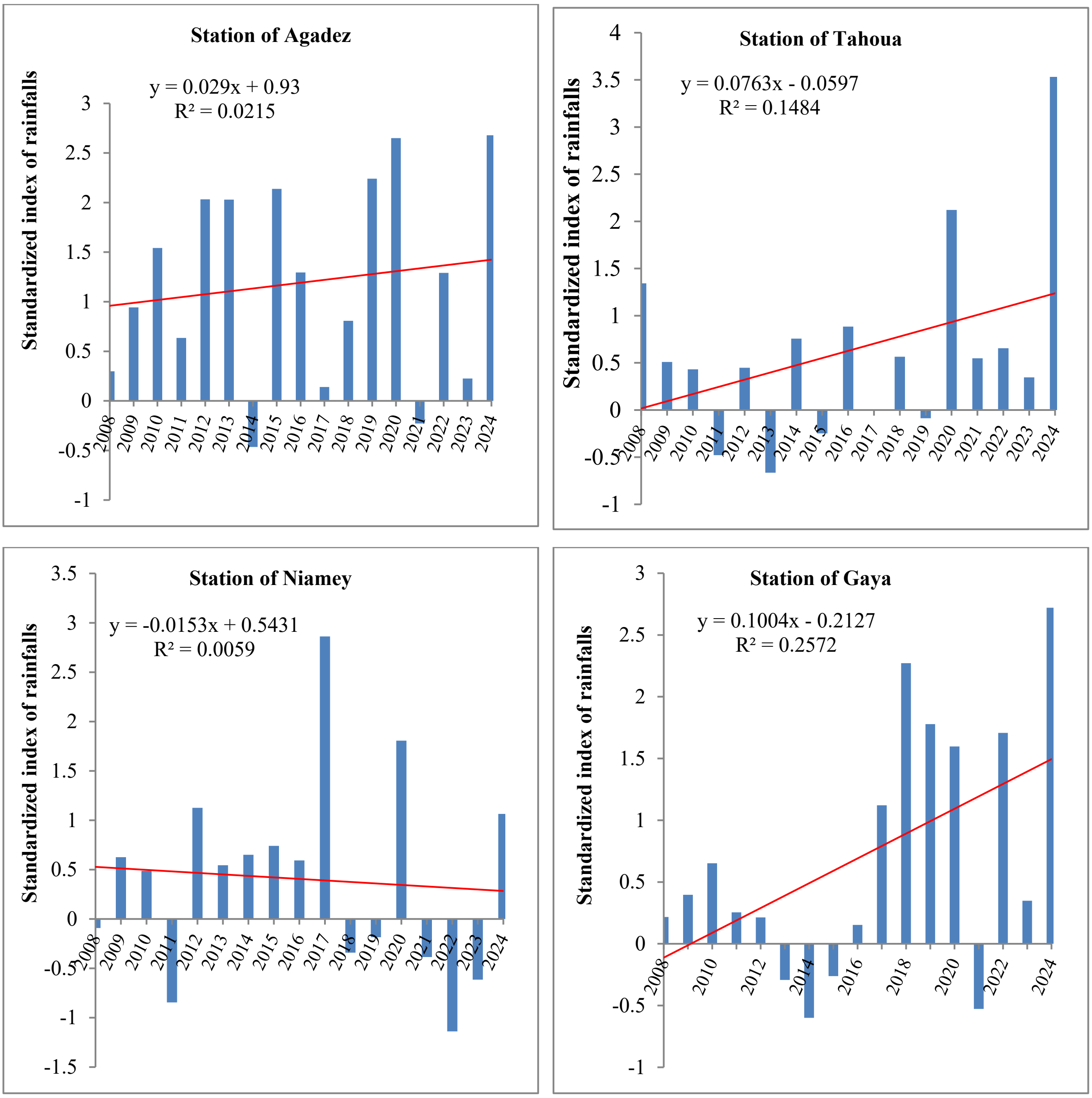

Fig. 7 Interannual variability of annual cumulation of rainfalls during the period 2008-2024 in rapport to the climatic average 1971-2000 and the pluviometry tendency.

Table 1 The tendency coefficients and determination.

	Saharan zone (Agadez)	Sahelian-Saharan zone (Tahoua)	Sahelian zone (Niamey)	Sahelian-Sudden (Gaya)
Coefficient of the tendency ()	0.029	0.076	-0.015	0.10
Coefficient of determination (R)	0.144	0.384	0.07	0.51

Reading this table offers the information that only the Sahelian zone presents a negative coefficient of tendency during the period 2008-2024 that is caused by an interruption from 2017 with a five (5) successive deficient years. The station of Gaya presents the best coefficient of rainfalls increasing tendency. It is then deductible that rainfalls will be improved in the Sahel and the Sahara and extremely deficient years are possible to be observed in the future.

5. Discussion

Our results show that at all the four stations (Agadez, Niamey, Tahoua and Gaya), there is a persistence of interannual variability of rainfalls with some humid and dry years. The gap between the two extreme years (the rainiest year and the least rainy year) is 133.6.1 mm, 436.1 mm, 488.2 mm and 629.7 mm in respective distribution to the station of Agadez, of Tahoua, of Niamey and of Gaya. Rainfalls recorded following the stations are: Agadez (133,6.1 mm), Tahoua (436.1 mm), Niamey (488.2 mm) and Gaya (629.7 mm). This symbolises a strong temporal variability of rainfalls at each climatic zone. According to Bolakonga and Ozer [15] and Hassane [16], the rainfalls fluctuations manifest not only in the quantity of rain per year but also through the daily length of rains. These rains are also marked by a considerable spatial variability along the period 2008-2024. In fact, the averages in rainfalls cumulations are 172.8 mm at Agadez, 379.1 mm at Tahoua, 533.5 mm at Niamey and 894.1 mm at Gaya. Thus, rainfalls vary from South in North direction with a negative gradient that is -1.26 mm/km between the latitude 11°53 N and the latitude 16°58 N. This gradient neatly ameliorates in rapport to the gradient -1 mm/km given by Taupin [17] regarding the Sahelian zone for the period 1990.

As the movement of the ITF from South toward North, the raining season then takes progressively place from the station of Gaya to the station of Agadez with different durations that also diminish from South in North direction. Therefore, the recorded number of rainy days at each station depends on the duration of the raining season. That is why along the period 2008-2024, the averages in the number of the rainy days are 29 days in Agadez, 42 days in Tahoua, 46 days in Niamey and 67 days in Gaya.

The comparison of the number of rainy days shows that the correlation with the rainfalls cumulation is very weak in Agadez and Tahoua with respective coefficient of correlation R1 = 0.21 and R2 = -0.03. The coefficient of relation is 0.47 in Niamey and Gaya. Therefore, the annual cumulation does not depend on the number of rainy events but rather on the intensification of the extreme events like demonstrated by Panthou [18] through a window going from 10° W to 5° E and from 10° N to 15° N. The results of the present study also show unchange in the intensification of certain rainy events in Niger along the period 2008-2024 versus the period 1990-2000 where the variability of the interannual seasonal cumulations in Niger depends only on the interannual variability of the number of events according to Ali [14].

Like shown by the obtained results at the four stations characterized by the climatic zones of Niger knows an improvement in rainfalls. Thus, the percentages of humid years at the stations of Agadez, Tahoua, Niamey and Gaya are respectively 88.2%, 76.4%, 58.8% and 76.4%. But because of bad rainfalls distribution in time, it is noticeable that some extremely rainy events are responsible of floods [19-21]. In Niger, the floods are ranked in second position of natural catastrophes after the dryness [10]. Niamey, the capital of Niger has been touched by a series of floods in 2010, 2012, 2013, 2017 and 2019 with heavy consequences on the socio-economic life of the population [22]. In referring on the obtained results in this study, these years of flooding respectively have the values of the standardized rainfalls index: 0.43, 1.12, 0.54, 2.86 and -0.18 and have recorded 60, 57, 57, 45 and 48 rainy days. Nonetheless, the year 2019 is even declared deficient versus to the period 1971-2000 but Niamey city has known a flooding. Thus, these floods are caused by strong rainy events with an increasing intensity and frequency all along the worldwide like demonstrated by Dunn et al. [23].

6. Conclusion and Perspectives

The objective of this study is to analyze the rainfalls evolution in Niger during the period 2008-2024 under the effects of climate changes. In a first phase of this work, an analysis of the distribution of interannual cumulations of rainfalls and the number of the rainy days is done during the period 2008-2024 at the four climatic zones of Niger that are as reminder: the Sahelian-Sudden zone, the Sahelian zone, the Sahelian-Saharan zone and the Saharan zone.

In the second phase, a comparison of pluviometry cumulations of this period to the climatic average of the period 1971-2000 known as a period of drought in the Sahel is accomplished. The third phase of this work has consisted in analyzing the evolution of the spatial-temporal annual cumulations at the four climatic zones above-mentioned.

The results of the study show a considerable interannual variability of rainfalls cumulations and of the numbers of rainy days. These two pluviometry parameters explicate an independency between the annual cumulation and the number of rainy events. During the period 2008-2024, it happened not only an improvement of rainfalls in Niger in comparison to the period 1971-2000 but also with the gradient South-North of pluviometry cumulations. However, this improvement spatial-temporal of rainfalls with an increasing tendency does not exclude some years of droughts. It is nonetheless possible to observe a decrease of their apparition frequency.

The change in the regime of rainfalls is perceived these last years by the population throughout strong rainy events that are responsible of floods. These represent a natural disaster for Niger with heavy socio-economic and environmental consequences.

On the other hand, this study on the evolution of rainfalls in Niger emerges a paradox linked to the climate change. Indeed, it has been admitted global reheating which was at the origin of droughts during the period 1971-2000 and the advancement of the desert toward south. Today, with the climate reheating, an improvement of rains in Niger is most noticeable in the zone of Sahara-Niger. If the reheating would persist until in 2100, it would be interesting to study the future evolution of rainfalls and their impacts on the Sahara zone of Niger with data of projection.

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