Rising Flooding in Garoua: Impacts of Hydro Morphological, Humans Factors and Proposed Solutions from 1940 to 2022 (Cameroon)

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Abstract: *This analysis is part of the context of climate change and their impacts in the locality of Garoua, aims to fully understand the extreme hydro morphological dynamics in order to better manage the risks and disasters linked to floods. It is about identifying and anticipating the effects of climate change on floods in order to protect vulnerable communities. This strengthens the resilience of ecosystems and populations in the face of environmental crises. Several recent events bear witness to the recurrence of floods. In 2022, unprecedented floods received approximately 1.3 million people in Chad, resulting in the displacement of more than 350,000 people and the submersion of a million hectares of planting, according to the World Bank data (Armand Mouko Boudombo, 2024). In 2024, these floods caused 341 deaths and affected nearly 1.5 million people throughout the country, according to the United Nations Bureau for the Coordination of Humanitarian Affairs (Jeune Afrique, 2024). In the Cameroon Far North region, cities like Yagoua were seriously affected by repeated floods, especially in 2024, where torrential rains resulted in a dozen deaths and significant damage (Africanews, 2024). Garoua, in 2012, the floods caused significant damage. The bubble and Bibemiré districts were particularly affected due to the waters of the Benue. A primary school has been engulfed by waters, and about twenty homes have been collapsed, leaving many homeless (Cameroon-Info, 2012). To add to this, the years 1988, 1991, 1994, 1996, 1999, 2009, 2010, 2014 and 2019 recorded strong precipitation in Garoua causing considerable consequences. Thus, combined factors such as: seasonal variability, El Niño and Niña episodes, plant cover, urbanization, and inadequate choice explain the all-out frequency of these floods in the city of Garoua? It was then that in an analysis that is both diachronic synchronic, we also used: in relation to normal, away from average, ten -year and five -year sequential averages and the rain. The study reveals that the floods in the city of Garoua not only are caused by natural and anthropogenic factors but also that these are accompanied by devastating consequences not only on civilian populations, society, on infrastructures, on food resources, but also on the economy. Although strategies such as the construction of dikes and the flooding emergency project have been implemented, their efficiency remains limited. The study offers additional adaptation measures, such as the construction of sheltered neighborhoods and the implementation of fast alert systems, in order to better anticipate and manage floods. This article thus spreads an efficiency contribution to the management of risk and hydro meteorological disasters. It is a tool for the protection of civilian populations in the face of the impact of climate change.*
Keywords*: Precipitation, El Niño, La Niña, implications, resurgence, floods, Garoua*

Introduction

The city of Garoua is increasingly affected by climate change, leading to dramatic consequences on rainfall patterns and flood frequency. This study, focusing on the city of Garoua, provides an in-depth analysis of rainfall, El Niño and La Niña events, and their implications for the increase in flooding between 1940 and 2022. Indeed, climate variability, not only exacerbated by natural phenomena such as El Niño and La Niña, contributes to the destabilization of rainfall patterns but also increases the vulnerability of local communities to extreme events.

In this study, we explore the complex dynamics underlying these floods, highlighting not only the physical and environmental aspects, but also the socio-economic impacts on affected populations. We integrate quantitative rainfall data and historical observations to shed light on observed trends. The objective of this analysis is to provide practical recommendations for sustainable water resource management to strengthen the resilience of ecosystems and communities in the face of environmental crises. This article therefore aims to raise awareness and encourage concrete measures to protect populations increasingly exposed to devastating and merciless floods.

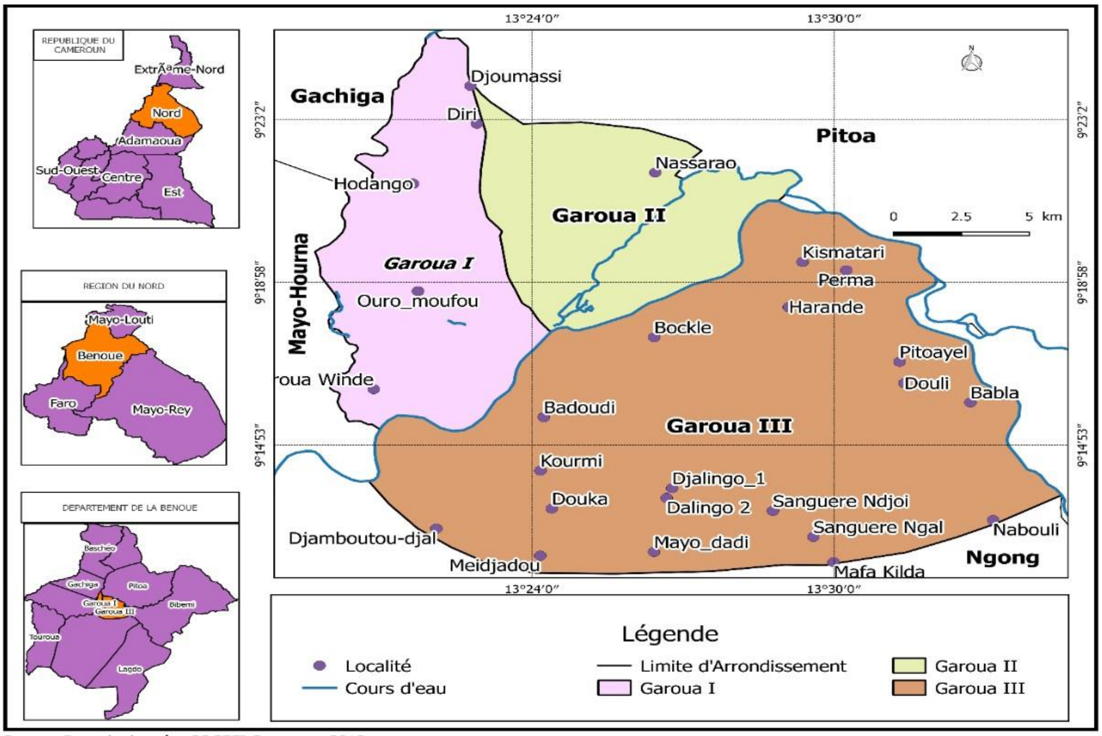
1. Presentation of the site, contextualization of the study and methodology

1.1 Presentation of the site

This presentation highlights the geomorphological, climatic and ecological characteristics of Garoua. The city of Garoua is divided into three districts namely Garoua I, Garoua II and Garoua III. It has been recognized as an urban community since 2008, it is the capital of the North Region of Cameroon and the department of Benue. Located at an average altitude of 289 m, it is between 9°18' North latitude and 13°24' East longitude. To this end, the relief of the locality consists of a floodplain at 181 m and a terrace at 195 m, on which the city has developed. The city is completely drained towards the West by the valleys of the Benue River and Mayo-Kebbi, receiving waters from the Adamawa Plateau and Mount Poli, located 150 and 50 km to the south respectively. Mena Marin et al (2024).

From a climatic point of view, Garoua benefits from a tropical Sudanian climate, with annual rainfall varying between 800 and 1000mm. April is the hottest month, with temperatures reaching between 40 and 45°C, while January is the coolest month, although temperatures remain high. The rainy season runs from April to October, peaking in August, while the dry season, from November to March, is particularly arid in January and February. Mena Marin et al (2024). The vegetation of Garoua is composed of Sudanian savannahs and dry open forests, accompanied by shrub savannahs. F. Normand (1992), the soils of this region present not only a varied sequence, ranging from tropical ferruginous soils with a sandy texture to alluvial soils with a salty texture but also with temporary hydromorphic.

Djangue Nankap Marlyse and the others in 2020, through their analysis on the mapping of the climatic and topographic factors of the information hazard in the locality of Garoua Cameroun that the existence of a division of the values of slopes and altitudes in several classes make it possible to explain this hazard of floods. Thus, they note that while the altitudes are between 125 and 200, 200 and 300m and 400m. The last class higher than 400m, the slopes of the slopes are between 0° and 4° ; 4° and 7° and 10°, and above 10°. Fig. 1presents the city of Garoua.



Source: Base de données SOGEFI Cameroun 2018 Réalisation:Yangne Houmbosso Claire Maximilienne, Février 2024

Figure 1: Location of the city of Garoua

1.2 Contextualization of the research

According to (Rémi Carayol, 2020). It is a paradox: where in the Sahel, a region made more and more arid by the advance of the desert, regularly faces devastating floods. Niamey has been particularly affected where several districts were flooded, notably those on the right bank, where the university is after the rupture of a dike on September 06, 2020, the authorities count 65 dead, 32000 collapsed houses, around 33000 victims and thousands of hectares of ravaged crops. Also following to(Reliefweb.int, 2022), in Nigeria flood have affected more than 4,4 million people across the country since July, with over 2,4 million people displaced, about half of them in Bayelsa State alone. 36 States and the federal capital territory have been affected. Flood have also damaged 650000 hectares of farmland, raising concerns of worsening hungers for millions of people amid already alarming food insecurity levels in country.

Subsequently, the Humanitarian Coalition, in 2022, related that Chad recorded devastating floods during the 2022 rainy season, causing large human and material damage where 800.00 people had been affected. In addition to the dead and the wounded, several hectares of fields have been destroyed, hundreds of cattle heads have been swallowed up, and bridges engulfed by the waters have stopped working. A total of 16 of 23 provinces were flooded. Finally, in Chad, floods also had serious consequences. In 2022, approximately 800,000 people were). By 2024, the number of affected people reached approximately 1.9 million, with more than 570 deaths and significant agricultural losses (Africa Center, 2025). Thus, flooding in the Sahel is a recurring phenomenon that requires special attention to strengthen the resilience of local communities to these extreme climatic events. In Ndjamena in 2024, the consequences of flooding are devastating. According to reports, torrential rains and the rising of the Chari and Logone rivers caused 576 deaths and affected 1.9 million people in the country, including many residents (World Bank, 2024). Areas such as Walia, Ngueli, and Kabé were submerged despite the construction of dikes (Mongabay, 2024). Adding to this, in Moundou, several houses, crops, and livestock were destroyed, leaving populations in a situation of increased vulnerability (UN, 2024). Preventative measures put in place helped limit the damage. However, challenges persist due to uncontrolled urbanization and inadequate infrastructure (Mongabay, 2024). The floods in Moundou in 2024 had devastating impacts. According to the IFRC (2024), Mandoul province, where Moundou is located, was among the hardest hit, with 267,408 people affected. Torrential rains and rising waters destroyed approximately 218,000 homes and damaged more than 342,000 others across the country. In this region, floods submerged farmland, destroying nearly 1.9 million hectares of crops and resulting in the loss of more than 72,000 livestock.

Particularly in Cameroon, the African Development Bank Group affirmed in 2022 the existence of countless areas that are affected by extreme weather events. This is for example the case of the floods in Douala in 2020 as revealed by Agence France Presse (2021), in Yaoundé more precisely at Kennedy Avenue and the Mfoundi market during the years 20182019, the floods in Maga in 2010 and 2012 according to Médecins sans frontières as well as in Yagoua in 2022 and 2024. Yangne Claire (2024). In addition, the floods in Kousséri, in the Far North region of Cameroon, had devastating consequences. As of 11 November 2024, more than 448,000 people have been affected by flooding, with more than 56,000 homes destroyed and tens of thousands of hectares of crops flooded, potentially worsening food insecurity (OCHA, 2024).

Garoua, the capital of Cameroon's North Region, is particularly vulnerable to these extreme weather events. Between 1940 and 2022, the city experienced a gradual increase in flooding, causing considerable human and material losses. These floods are often linked to abnormal rainfall, which can be amplified by climatic anomalies such as those observed during El Niño and La Niña events. For example, in 2012, major floods hit the region, according to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA, 2012), affecting more than 500,000 people and causing considerable damage.

The various disasters that have occurred in the city of Garoua underscore the ongoing dangers its residents face. Disasters in Garoua, particularly the floods of 2008 and July 2021, have caused considerable damage. In 2008, floods affected several neighborhoods such as Pitoaré, Doualaba, Bédi, and Nassarao, resulting in the deaths of nine people and significant material losses. The population was severely affected, with approximately 25,000 people affected and 1,000 rendered homeless, according to information from Nord Actu TV (Yangne Claire, 2024). In 2021, floods in Garoua had serious consequences. Heavy rain during the night of July 5-6 caused significant damage. Three people died as a result of this torrential rain accompanied by strong winds on July 7. The floods also affected 964 households in the Garoua III district (Actu Cameroun, 2021).

In 2012, the city was hit by disastrous floods, with tragic consequences for both human and infrastructure, with the destruction of homes and crops. This led to massive population displacement, as reported by the Xinhua news agency. Furthermore, a report by former Minister of Communication Issa Tchiroma indicated that many homes and crops had been wiped out, leaving behind many abandoned herds. Approximately 633 families were affected, resulting in nearly 6,500 displaced people, according to the Journal Investir au Cameroun of September 20, 2012 (Yangne Claire, 2024).

Variations in rainfall patterns, particularly El Niño and La Niña events, have significant impacts on the area's meteorological and hydrological conditions. For example, El Niño can bring periods of drought followed by torrential rains, while La Niña can intensify rainfall in some environments.

According to MATT Lineal (2022), La Niña is a weather pattern coinciding with colder than average waters in the Pacific Ocean, affecting global weather events and climate. During La Niña years (2020-2022, 2016, 2008_2009), normal weather patterns are disrupted, leading to intensified storm activity in some places and droughts in others. La Niña also contributes to a more active Atlantic hurricane season, which runs from June to November in South America, Peru, and Chile and above average rain in Brazil. La Niña contributes to flooding in eastern regions of Australia. In eastern regions of Australia; In Asia, in Asia, it drives above average rainfall. And in Africa, La Niña typically contributes to increased precipitations in southern Africa and drought in East Africa;

Following Marco Wolter (2024), El Niño, is a meteorological phenomenon that occurs every two and seven years, when the Pacific Ocean warms up while causing the increase in global climatic systems not only through peaks of heat, prolonged droughts but also by devastating floods. For example, in Africa, El Niño in 2024, countries like Kenya, Tanzania, Ethiopia and southern Africa were the most affected. Besides, the humanitarian organization Oxfam in 2024, had counted more than 20 million people confronted with hunger and malnutrition. A prominent example of El Niño is the one that occurred between 1997 and 1998, which caused approximately 21,000 human losses and material damage (OCHA, 2016).

For ActuCameroun (march 2018), following a torrential rain there occurred a drama in Tchollire in Mayo-Rey (North-Cameroon) or not only we recorded 03 deaths, 17 injured but also the perfect’s residence, the place des fetes and schools were destroyed. During the same year, actuCameroun (august 2018) testifies that the spectrum of devastating floods of 2012 (material loses, hectares of devastating flood crops and losses in human lives) haunt and still traumatized Garoua populations since the risks of floods are permanent much more in the Liddiré district where the populations live on the alert at theslightest thunderclap. It should be to remember the words of a resident of the Lidire district who testifies: here, we are each drop of rain, overwhelmed by the waters of the river, last year in August, the water invaded all our house including all the furniture.

Garoua's vulnerability is exacerbated by rapid urbanization, which has led to infrastructure degradation and inappropriate water resource management. Urban areas are often poorly planned to amplify extreme rainfall events. Inadequate drainage systems and illegal occupation of floodplains exacerbate the situation, making communities even more vulnerable to flooding. According to a UN report, Garoua's population increased by more than 50% between 2005 and 2015, putting additional pressure on existing infrastructure (UN-Habitat, 2016). Addressing these challenges requires the development of effective strategies for water resource management and flood prevention. An integrated approach that combines climate data, weather forecasts, and adaptation measures can help strengthen community resilience. Thus, studying rainfall, El Niño and La Niña events, and their implications for flooding in Garoua is necessary to understand the region's climate and environmental dynamics. This topic is important in discussions on environmental crisis management and the protection of vulnerable populations.

In short, the city of Garoua is facing extreme and complex hydro meteorological challenges (existence and influence of several acting parameters) faced by the populations of this geographical area. These communities, which traditionally derive their livelihood from fishing, agriculture and grazing, are today prey to multifaceted crises. Similarly, infrastructure, including residential houses, is also exposed to the fury of floods. The lasting impact of these floods exacerbates economic and social precariousness in an already vulnerable context. Families, often subject to poverty, now find themselves facing food insecurity due not only to the existence of various conflicts but also to the increasing frequency of forced displacements caused by these floods. The vulnerability of populations is accentuated as their hostile or even fragile ecosystem increasingly deteriorates.

1.3 Methodology

To analyse rainfall variability from 1940 to 2022, the methodology involves calculating mean rainfall, the deviation from mean index, and the rainfall index. It also uses isohyets and long-term trends to establish visual links between climate variations and flood frequency. This integrated approach provides a thorough understanding of the environmental impacts associated with rainfall fluctuations. To achieve this, the following operations have furnished this methodology.

a)-The average or normal (Pm)

$$P_m = \frac{\sum px}{n}$$

Where Pm: average precipitation during the period
Px: seasonal precipitation of year x
N: number of seasons

b)-The index of deviation from the mean (RN)

$$RN\ (\%) = \frac{px - pm}{pm} \times 100$$

c)- The ratio to the normal D = $RN = \frac{px - pm}{pm} \times 100$

If D = 0 constant period
D > 0 excess period
D < 0 deficit period

d)- The rainfall index $I_P = \frac{px}{pm}$

If IP = 1 season: constant or stable rainfall
IP < 1 season: loss-making
IP >1 wet season

e) - The cumulative balance sheet of deficits and surpluses

∑ (of deficits and surpluses) obtained from = $P_x - P_m$

f)-the equationfrom Trend

This equation is necessary for trend analysis.

g)-Calculation of five-year averages

$$mq = \frac{px1 + px2 + px3 + px4 + px5}{n}$$

h)- The calculation of ten-year averages.

$$md = \frac{px1 + px2 + px3 + px4 + px5 + ...px10}{n}$$

Also, to better control the flood risks in the city of Garoua, we carried out a comparative study of seasonal rainfall in the Adamaoua plateau with that of the Northern region in order to show the direct or even indirect involvement of the Adamaoua plateau in the flooding process in Garoua.

2. Natural and anthropogenic factors, real catalysts of flooding in Garoua

In Garoua, flooding results from both natural and anthropogenic factors. Heavy rainfall during the rainy season, along with rivers like the Benue, increases the risk of flooding. From an anthropogenic perspective, urbanization and soil sealing reduce water absorption capacity, while a lack of storm water management infrastructure exacerbates the situation. Furthermore, deforestation reduces water retention in the soil. To minimize flood risks, it is therefore important to implement mitigation strategies, such as building dikes and improving drainage systems.

2.1 Natural factors

Natural factors are essential elements that shape our planet and influence various aspects of human life and the environment. A region's climate determines biodiversity and growing seasons, while temperature and precipitation affect agriculture and water availability. Geography, including relief and soils, impacts vegetation types and natural resources, while ecosystems, with their biodiversity and food chains, maintain ecological balance. Water resources, both in terms of availability and quality, are vital for public health and agriculture. Natural phenomena, such as disasters and climate change, can cause human losses and economic damage.

2.1.1 Analysis and contribution of seasonal precipitation in the flood process

Table 1: Summary of averages, rainfall records and cumulative monthly rainfall balances in Garoua from 1940 to 2022

Month	jan	feb	March	april	may	June	July	august	seven	oct	nov	dec
General average (1940-2022) in mm	**0**	**0.14**	**2.62**	**40.67**	**136.76**	**139.95**	**182.95**	**222.22**	**199.29**	**72.47**	**2.05**	**0.03**
Average S1 (1940-1981) In mm	**0**	**0.3**	**3.6**	**41.9**	**164.3**	**135.4**	**170.2**	**219.4**	**203.5**	**72.6**	**2.3**	**0**
Average S2 (1982-2022) In mm	**0**	**0**	**1.6**	**39.4**	**108.6**	**144.6**	**196.1**	**237.3**	**195.0**	**72.4**	**1.8**	**0.1**
RPMAX S1 (1940-1981) in mm	**0**	**6.3**	**31.3**	**157.9**	**201.6**	**282.4**	**377.1**	**495.2**	**338.0**	**213.0**	**34.8**	**0**
RPMIN S1 (1982-2022) in mm	**0**	**0**	**0**	**0**	**4.1**	**0**	**0**	**30.4**	**82.5**	**4.1**	**0**	**0**
RPMAX S2 (1940-1981) in mm	**0**	**0**	**11.0**	**139.6**	**239.5**	**337.4**	**377.1**	**484.4**	**459.2**	**297.6**	**45.1**	**3.0**
RPMIN S2 (1982-2022) in mm	**0**	**0**	**0**	**0**	**39.1**	**27.6**	**109.3**	**96.8**	**56.4**	**0**	**0**	**0**
Number of dry months (1940-2022)	**0**	**41**	**34**	**13**	**16**	**6**	**4**	**4**	**11**	**32**	**32**	**42**
Number of wet months (1940-2022)	**0**	**2**	**13**	**30**	**27**	**37**	**39**	**39**	**32**	**11**	**11**	**1**
Cumulative balance in mm	**0**	**+0.28**	**+0.52**	**+0.61**	**+8.02**	**+0.19**	**+0.56**	**+0.69**	**+0.79**	**+0.53**	**+0.05**	**+0.55**

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: MENA Marin and YANGNE Claire, March 2025.

NB: MG= General Average; S1= Sequence 1; S2= Sequence 2; RPMAX= Maximum Rainfall Record; RPMIN= Minimum Rainfall Record.

Examining the climate data for monthly rainfall for the period 1940 to 2022 in **Table 1** highlights an asymmetrical distribution of rainfall in Garoua. First, the months of November, December, January, February, and March are distinguished by very low cumulative rainfall, often close to zero millimeter. This indicates a period of marked drought. On the other hand, from April onwards, average rainfall heights increase. For example, April records 40.67 mm, while May, June, and July show averages such as: 136.76 mm, 139.95 mm, and 182.95 mm, respectively. In addition, August, considered the wettest month, reaches an impressive cumulative rainfall of 222.22 mm.

This rainfall dynamic highlights the importance of the rainy season in the local climate of the city of Garoua. Indeed, August stands out as the wettest month of the year, with an average height of 222.22 mm, which is indicative of an intertropical convergence phenomenon that favours precipitation. On the other hand, the months of December, January and February are the driest because they often record 0 mm of precipitation. This disparity illustrates the marked seasonal variations in the locality, with periods of intense drought followed by very rainy months. Furthermore, the analysis of data over the two distinct periods, S1 (1940-1981) and S2 (1982-2022) reveals climatic variations. Some months, such as April, March, May, July, September, and November, show a downward trend in rainfall, which could be attributed to long-term climate changes or El Niño and La Niña climate oscillations. In contrast, the months of June, July, and August show increasing rainfall surpluses, suggesting an intensification of torrential rain events or a change in weather patterns. Furthermore, the variability of rainfall is highlighted by the extremes observed during this period. January and February record minimum and maximum rainfalls of 0 mm, illustrating extreme weather conditions. Conversely, other months, such as July and August, show fluctuations. For example, July displays a minimum of 74.2 mm and a maximum of 377.1 mm, while August varies from 89.7 mm to 495.2 mm. These fluctuations reflect a complex dynamic of rainfall where certain months can experience drastic deficits after having been abnormally surplus in the past, thus reflecting the climatic instability that exists in the city of Garoua.

Finally, cumulative balances reveal a wetter trend in some months, such as May (+1.4 mm), June (+1.2 mm), and September (+0.8 mm). However, other months appear to be drier, which could have significant impacts on agriculture and water resource management. The months of April, June, September, October, and December show signs of increased rainfall, suggesting a need for adaptation in agricultural practices and proactive water resource management.

In summary, analysis of climate data on rainfall in Garoua reveals a highly uneven rainfall distribution, marked by arid and humid months. These results highlight the importance of monitoring rainfall trends to anticipate impacts on the environment and human activities with a view to reducing the vulnerability of the city's population.

2.1.2 Trends in the months of the rainy seasons in Garoua from 1940 to 2022

2.1.2.1 Rainfall distribution for the months of April in Garoua from 1940 to 2022

Figure 2presents the evolution of rainfall in April in Garoua, covering the period from 1940 to 2022. This graph highlights a fluctuating rainfall dynamic. The average rainfall is 40.67 mm, with a slight decrease observed between the two sequences: (41.9 mm) from 1940 to 1981 and (39.4 mm) from 1982 to 2022. This observation reveals a trend of both deficit and surplus, with 13 months of deficit compared to 30 months of surplus. The recorded rainfall extremes highlight the irregularity of rainfall. Similarly, the linear trend line reflects a surplus period, which has implications for food security and the vulnerability of populations. However, although the month of April is characterized by the return of rains, the fact remains that the still insufficient rainfall is still marked by fluctuations.

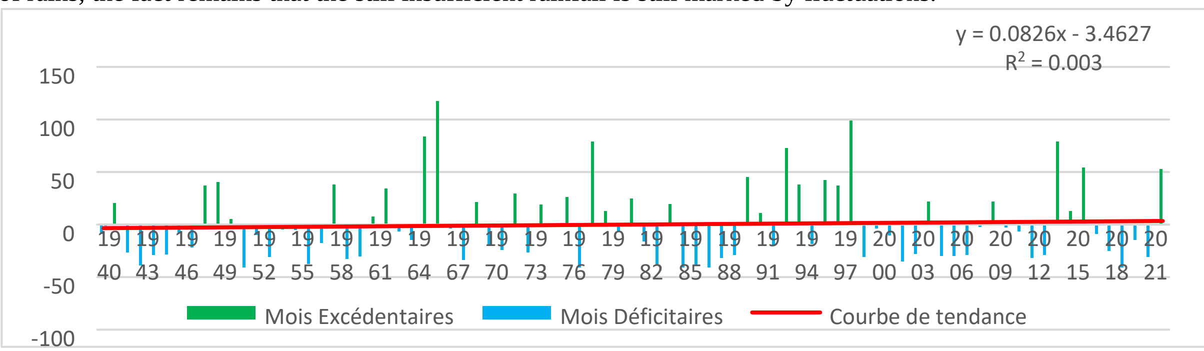


Figure 2: Increasingly excess evolution of April rainfall in Garoua from 1962 to 2022.

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.2.2 Rainfall distribution for the months of May in Garoua from 1940 to 2022

Figure 3 shows the evolution of the state of the precipitations of the months of May in Garoua from 1940 to 2022. To this end, it is important to note that the general average is 136.76mm. From **Table 1** we see that this average has varied because from 1940 to 1981 it is 164.3mm while from 1982 to 2022 the months of May record 108.6mm of rain. It is then that this analysis counts 16 months of deficit against 27 months of surplus. Thus, we can say that the months of May at the Garoua meteorological station are characterized by a rainfall recession. This is what Figure 3 highlights; it presents a decreasing trend curve.

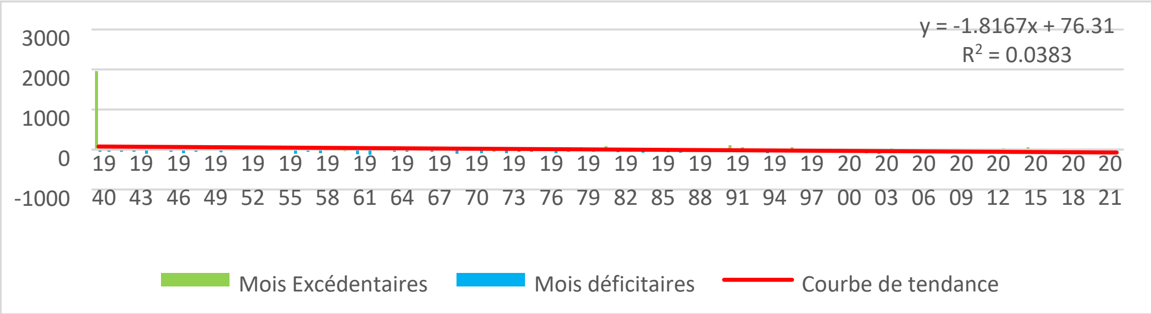


Figure 3: Decreasing evolution of rainfall in the months of May in Garoua from 1962 to 2022.
Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.2.3 Rainfall distribution for the months of June in Garoua from 1940 to 2022

Figure 4 illustrates the increasing rainfall trend for the months of June from 1940 to 2022 in Garoua. The general average of this distribution is 139.95mm. During the first sequence from 1940 to 1981, the average is estimated at 135.4mm with 6 months of deficit and 37 months of surplus while it increases during the second sequence from 1982 to 2022, it is estimated at 144.6mm hence the cumulative balance estimated at (+0.19mm). The trend curve of this rainfall distribution is increasing thus reflecting an increase in rainfall in the months of June.

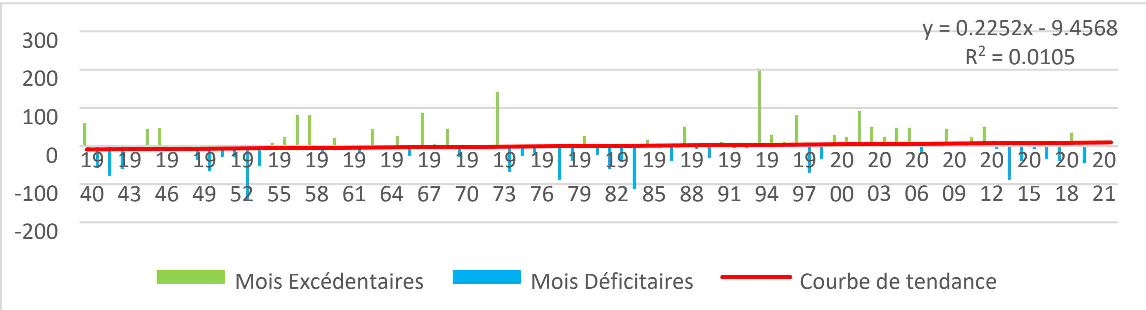


Figure 4: Excess rainfall trend in June in Garoua from 1962 to 2022.
Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.2.4 Rainfall distribution for the months of July in Garoua from 1940 to 2022

Given the elements highlighted in Table 1, the analysis of the evolution of rainfall for the months of July presents an average estimated at 182.95mm. However, we note an increase in rainfall because the average during the first period (1940-1981) is 170.2mm while the second period (1982-2022) is 196.1mm. This justifies the cumulative balance estimated at (+0.56mm) with an increasingly increasing trend curve. This rainfall distribution includes 4 arid months against 39 excess months. In view of the conclusions drawn from this analysis, **Figure 5** clearly illustrates the evolution of rainfall for these months during the period studied, which is also a source of heavy rainfall. This is the case of heavy rain observed on July 7, 2021 accompanied by strong winds which caused the death of three people in Garoua. This rain also caused significant material damage, notably by uprooting trees and blowing away roofs of houses and walls of schools (Actu Cameroun, 2021).

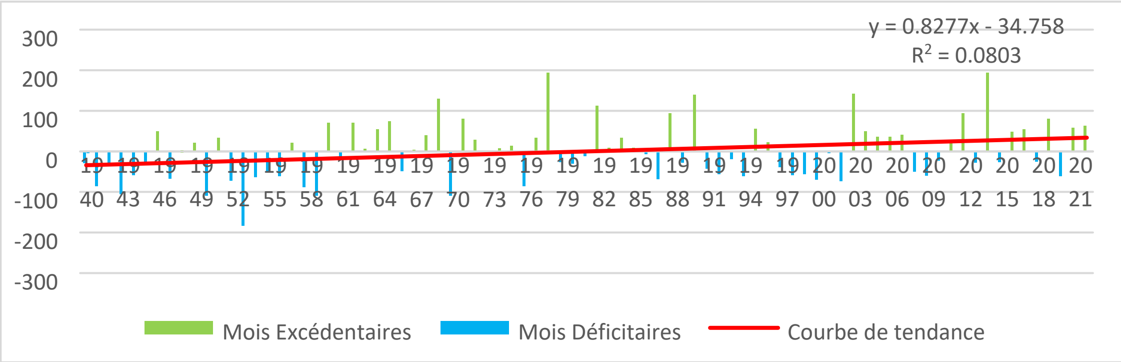


Figure 5: Increasingly excess evolution of July rainfall in Garoua from 1940 to 2022.
Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.2.5 Rainfall distribution for the months of August in Garoua from 1940 to 2022

Figure 6 shows the trend and evolution of rainfall in August in Garoua from 1940 to 2022. Taking into account the conclusions of the analyses carried out, we note that the general average for the months of August amounts to 222.2mm. Thus, this average has increased as it went from 219.4 mm between 1940 and 1981 to 237.3 mm from 1982 to 2022. The distribution of the months of August is marked by an increasing trend curve; it is therefore obvious that we arrive at a cumulative deficit balance estimated at (+0.69mm). To this end, the period studied (1940-2022) records 4 dry months against 39 wet months. It is important to note that the month of August at the Garoua meteorological station constitutes the peak of rainfall. This reflects the floods often observed. In August 2018, the population of Garoua faced devastating flooding, as witnessed by one resident who saw water invade his house, engulfing all his furniture (Actu Cameroun, 2018). To this end, the increase in rainfall during the month of August constitutes a major flood risk in the city of Garoua. The illustration below allows us to better understand the fluctuations during the month of August in Garoua.

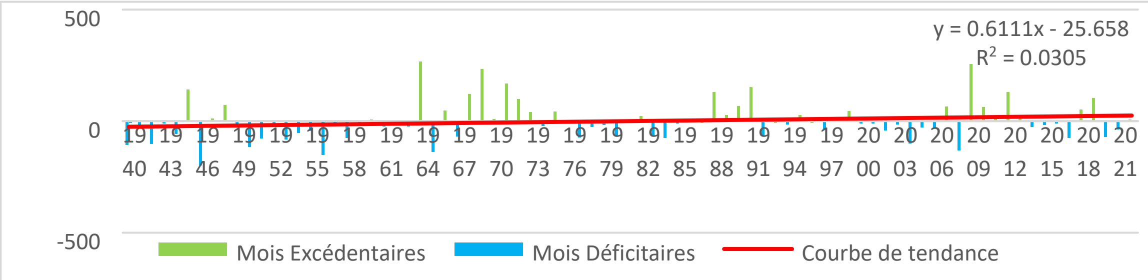


Figure 6: Increasingly excess trend in August rainfall in Garoua from 1940 to 2022.
Source**:** Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.2.6 The increasingly humid months of September in Garoua from 1940 to 2022

Looking at the analysis of September rainfall in Garoua from 1940 to 2022, we note an average of 199.29mm. We note that this average has decreased since between 1940 and 1981 we had 203.5mm of rainfall while from 1982 to 2022 the average decreased to 195.0mm. The months of September in Garoua are often faced with risks of flooding due to the heavy rains that fall. In the context of heavy rains that affected the North and Far North of Cameroon (WHO, 2012).The heavy rains are not only accompanied by the destruction of houses and crops but also impact the population of Garoua, which is mainly made up farmers and herders.

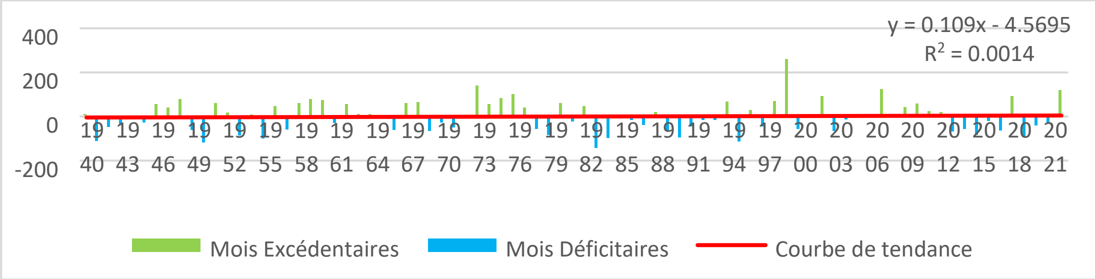


Figure 7: Slightly wet trend in September rainfall in Garoua from 1940 to 2022.
Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.2.7 Constant rainfall in the months of October in Garoua from 1940 to 2022

The trend of the evolution of the months of October as shown in Figure 8, presents a trend curve that increases slightly. In fact, the general average of the months of October amounts to 72.47 mm. During the period from 1940 to 1981 the average then estimated at 72.6 mm will be almost the same from 1982 to 2022 where it is estimated at 72.4 mm.

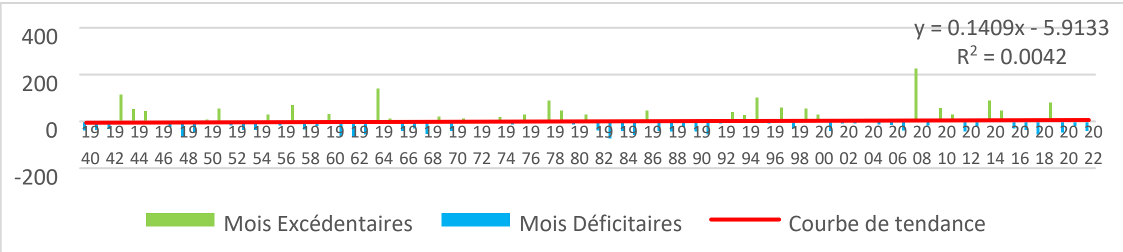


Figure 8: Increasing evolution of rainfall in the months of October in Garoua from 1940 to 2022.
Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

In summary, analysis of rainfall data in Garoua from 1940 to 2022 reveals fluctuating trends in monthly rainfall, with significant variations between different seasons. In April, the average rainfall is 40.67 mm, showing a slight decrease over the decades and an irregularity that complicates agricultural activities. In May, the average is 136.76 mm, with a decreasing trend and a prevalence of deficit months. June has an average of 139.95 mm, with an increasing trend, while July has an average of 182.95 mm, indicating an increase in rainfall. In August, rainfall reaches 222.2 mm, marking a peak often associated with flooding. September shows a decrease, ranging from 203.5 mm to 195.0 mm of rainfall, while October remains stable at around 72.47 mm.

2.1.3 Typology of the seasons

2.1.3.1 Case of dry seasons

This table presents a detailed analysis of rainfall and deviations from the average dry season in Garoua, spanning from 1940 to 2022, thus providing a perspective on climate variations over this period.

Table 2: Summary of heights and deviations from the average for dry seasons in Garoua from 1940 to 2022.

Years	Dry season heights	Average dry seasons	Deviations from the Average	Surpluses and Deficits	Years	Dry season heights	Average dry seasons	Deviations from the Average	Surpluses and Deficits
Years	Dry season heights	Average dry seasons	Deviations from the Average	Surpluses and Deficits	1982	0.0mm	4.85mm	-4.85 mm	DEF
1940	5.5mm	4.85mm	0.65mm	EX	1983	0.0mm	4.85mm	-4.85 mm	DEF
1941	52.2mm	4.85mm	47.35mm	EX	1984	0.0mm	4.85mm	-4.85 mm	DEF
1942	6.3mm	4.85mm	1.45mm	EX	1985	10.0mm	4.85mm	5.2 mm	EX
1943	0.9mm	4.85mm	-3.95mm	DEF	1986	0.3mm	4.85mm	-4.6 mm	DEF
1944	31.3mm	4.85mm	26.45mm	EX	1987	0.0mm	4.85mm	-4.85 mm	DEF

1945	0mm	4.85mm	-4.85mm	DEF	1988	0.0mm	4.85mm	-4.85 mm	DEF
1946	0mm	4.85mm	-4.85mm	DEF	1989	11.0mm	4.85mm	6.2 mm	EX
1947	5.7mm	4.85mm	0.85mm	EX	1990	1.0mm	4.85mm	-3.9 mm	DEF
1948	6.4mm	4.85mm	1.55mm	EX	1991	0.1mm	4.85mm	-4.8 mm	DEF
1949	0mm	4.85mm	-4.85mm	DEF	1992	45.1mm	4.85mm	40.3 mm	EX
1950	1mm	4.85mm	-3.85mm	DEF	1993	9.0mm	4.85mm	4.2 mm	EX
1951	0.2mm	4.85mm	-4.65mm	DEF	1994	0.0mm	4.85mm	-4.85 mm	DEF
1952	0mm	4.85mm	-4.85mm	DEF	1995	8.4mm	4.85mm	3.6 mm	EX
1953	7.7mm	4.85mm	2.85mm	EX	1996	9.6mm	4.85mm	4.8 mm	EX
1954	7.2mm	4.85mm	2.35mm	EX	1997	3.6mm	4.85mm	-1.3 mm	DEF
1955	0mm	4.85mm	-4.85mm	DEF	1998	0.0mm	4.85mm	-4.85 mm	DEF
1955	0mm	4.85mm	-4.85mm	DEF	1999	0.0mm	4.85mm	-4.85 mm	DEF
1956	20.4mm	4.85mm	15.55mm	EX	2000	0.0mm	4.85mm	-4.85 mm	DEF
1959	0.9mm	4.85mm	-3.95mm	DEF	2001	0.0mm	4.85mm	-4.85mm	DEF
1960	0.9mm	4.85mm	-3.95mm	DEF	2002	2.4mm	4.85mm	-2.5 mm	DEF
1961	0mm	4.85mm	-4.85mm	DEF	2003	0.0mm	4.85mm	-4.85 mm	DEF
1962	0mm	4.85mm	-4.85mm	DEF	2004	0.0mm	4.85mm	-4.85 mm	DEF
1963	0.0mm	4.85mm	-4.85mm	DEF	2005	0.0mm	4.85mm	-4.85 mm	DEF
1964	6.7mm	4.85mm	1.9mm	EX	2006	0.0mm	4.85mm	-4.85 mm	DEF
1965	0.0mm	4.85mm	-4.85mm	DEF	2007	0.0mm	4.85mm	-4.85 mm	DEF
1966	31.2mm	4.85mm	26.4mm	EX	2008	0.0mm	4.85mm	-4.85 mm	DEF
1967	0.0mm	4.85mm	-4.85mm	DEF	2009	0.0mm	4.85mm	-4.85 mm	DEF
1968	0.0mm	4.85mm	-4.85mm	DEF	2010	0.0mm	4.85mm	-4.85 mm	DEF
1969	4.3mm	4.85mm	-0.55mm	DEF	2011	0.0mm	4.85mm	-4.85 mm	DEF
1970	0.0mm	4.85mm	-4.85mm	DEF	2012	0.0mm	4.85mm	-4.85mm	DEF
1971	1.4mm	4.85mm	-3.5mm	DEF	2013	11.0mm	4.85mm	6.2mm	EX
1972	0.0mm	4.85mm	-4.85mm	DEF	2014	0.0mm	4.85mm	-4.85mm	DEF
1973	0.0mm	4.85mm	-4.85mm	DEF	2015	4.3mm	4.85mm	-0.5mm	DEF
1974	0.1mm	4.85mm	-4.75mm	DEF	2016	0mm	4.85mm	-4.85mm	DEF
1975	8.3mm	4.85mm	3.5mm	EX	2017	0mm	4.85mm	-4.85mm	DEF
1976	10.7mm	4.85mm	5.9mm	EX	2018	0mm	4.85mm	-4.85mm	DEF
1977	0.0mm	4.85mm	-4.85mm	DEF	2019	0mm	4.85mm	-4.85mm	DEF
1978	0.0mm	4.85mm	-4.85mm	DEF	2020	5.27mm	4.85mm	0.4mm	EX
1979	4.3mm	4.85mm	-0.5mm	DEF	2021	23.42mm	4.85mm	18.6mm	EX
1980	37.2mm	4.85mm	32.4mm	EX	2022	0.33mm	4.85mm	-4.5mm	DEF
1981	0.0mm	4.85mm	-4.85mm	DEF	-	-	-	-	-
S1 Balance Sheet (1940-1981): 14 dry seasons /42; or 33.33% 27 dry rainy seasons/42; or 64.28%					S2 report (1982-2022): 32 surplus dry seasons/41; or 70.04% 9 dry seasons in deficit/41; or 21.95%				

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: MENA Marin and YANGNE MENA Marin and YANGNE Claire, March 2025.

Table 2 presents a summary of rainfall amounts and deviations from the average for dry seasons in Garoua from 1940 to 2022. This table is therefore essential for understanding the evolution of rainfall patterns and their potential impacts on the local climate. Years with significant rainfall surpluses, such as 1941 (52.2 mm) and 1980 (37.2 mm), show values well above the average of 4.85 mm, indicating exceptionally wet dry seasons. Conversely, periods marked by deficits, such as 1981 and 1982, show zero amounts, highlighting extreme dry seasons without rainfall. Thus, the sequence (1940-1982) records 14 surplus dry seasons against 27 deficit dry seasons. The sequence (1982-2022) counts 32 arid dry seasons against 9 wet seasons.

2.1.3.2 Analysis of the rainy seasons in Garoua from 1940 to 2022

This table presents a detailed summary of rainfall heights and deviations from the average for the rainy seasons in Garoua from 1940 to 2022.

Table 3: Summary of heights and deviations from the average of the rainy seasons in Garoua from 1940 to 2022

Years	Dry season heights	Average dry seasons	Deviations from the Average	Surpluses and Deficits	Years	Dry season heights	Average dry seasons	Deviations from the Average	Surpluses and Deficits
1940	2850.1mm	1000.4mm	1849.7mm	EX	1982	1006.4mm	1000.4mm	6.0mm	EX
1941	706.9mm	1000.4mm	-293.5mm	DEF	1983	631.4mm	1000.4mm	-369.0mm	DEF
1942	672.8mm	1000.4mm	-327.6mm	DEF	1984	649.5mm	1000.4mm	-350.9mm	DEF
1943	858.2mm	1000.4mm	-142.2mm	DEF	1985	904.1mm	1000.4mm	-96.3mm	DEF
1944	792.3mm	1000.4mm	-208.1mm	DEF	1986	923.4mm	1000.4mm	-77.0mm	DEF
1945	1179.2mm	1000.4mm	178.8mm	EX	1987	701.2mm	1000.4mm	-299.2mm	DEF
1946	917.2mm	1000.4mm	-83.2mm	DEF	1988	1190.4mm	1000.4mm	190.0mm	EX
1947	854.2mm	1000.4mm	-146.2mm	DEF	1989	893.4mm	1000.4mm	-107.0mm	DEF
1948	1092mm	1000.4mm	91.6mm	EX	1990	1032.3mm	1000.4mm	31.9mm	EX
1949	911.8mm	1000.4mm	-88.6mm	DEF	1991	1132.9mm	1000.4mm	132.5mm	EX
1950	536.2mm	1000.4mm	-464.2mm	DEF	1992	892.4mm	1000.4mm	-108.0mm	DEF
1951	1028.2mm	1000.4mm	27.8mm	EX	1993	1029.1mm	1000.4mm	28.7mm	EX
1952	905mm	1000.4mm	-95.4mm	DEF	1994	1168.1mm	1000.4mm	167.7mm	EX
1953	480.2mm	1000.4mm	-520.2mm	DEF	1995	1053.8mm	1000.4mm	53.4mm	EX
1954	818.1mm	1000.4mm	-182.3mm	DEF	1996	1157.7mm	1000.4mm	157.3mm	EX
1955	850.7mm	1000.4mm	-149.7mm	DEF	1997	1029.7mm	1000.4mm	29.3mm	EX
1956	704.9mm	1000.4mm	-295.5mm	DEF	1998	1010.6mm	1000.4mm	10.2mm	EX
1957	1067.4mm	1000.4mm	67mm	EX	1999	1192.0mm	1000.4mm	191.6mm	EX
1958	894.1mm	1000.4mm	-106.3mm	DEF	2000	857.8mm	1000.4mm	-142.6mm	DEF
1959	938.6mm	1000.4mm	-61.8mm	DEF	2001	954.3mm	1000.4mm	-46.1mm	DEF
1960	938.6mm	1000.4mm	-61.8mm	DEF	2002	943.0mm	1000.4mm	-57.4mm	DEF
1961	758.7mm	1000.4mm	181.6mm	EX	2003	979.6mm	1000.4mm	-20.8mm	DEF
1962	926.9mm	1000.4mm	-241.7mm	DEF	2004	1021.3mm	1000.4mm	20.9mm	EX
1963	1041.5mm	1000.4mm	-73.5mm	DEF	2005	931.3mm	1000.4mm	-69.1mm	DEF
1964	1427.3mm	1000.4mm	41.1mm	EX	2006	930.9mm	1000.4mm	-69.5mm	DEF
1965	1026.9mm	1000.4mm	26.5mm	EX	2007	1070.3mm	1000.4mm	69.9mm	EX
1966	1019.7mm	1000.4mm	19.3mm	EX	2008	1059.5mm	1000.4mm	59.1mm	EX
1967	1002.5mm	1000.4mm	2.1mm	EX	2009	1242.5mm	1000.4mm	242.1mm	EX
1968	1179.3mm	1000.4mm	178.9mm	EX	2010	1124.1mm	1000.4mm	123.7mm	EX
1969	1287.2mm	1000.4mm	286.8mm	EX	2011	1061.2mm	1000.4mm	60.8mm	EX
1970	809.8mm	1000.4mm	-190.6mm	DEF	2012	1190.4mm	1000.4mm	190.0mm	EX
1971	1092.9mm	1000.4mm	92.5mm	EX	2013	893.4mm	1000.4mm	-107.0mm	DEF
1972	1157.5mm	1000.4mm	157.1mm	EX	2014	1176.8mm	1000.4mm	176.4mm	EX
1973	1205.1mm	1000.4mm	204.7mm	EX	2015	952.3mm	1000.4mm	-48.1mm	DEF
1974	970.3mm	1000.4mm	-30.1mm	DEF	2016	1033.6mm	1000.4mm	33.2mm	EX
1975	1083.0mm	1000.4mm	82.6mm	EX	2017	843.7mm	1000.4mm	-156.7mm	DEF
1976	1070.5mm	1000.4mm	70.1mm	EX	2018	980.9mm	1000.4mm	-19.5mm	DEF
1977	859.3mm	1000.4mm	-141.1mm	DEF	2019	1128.5mm	1000.4mm	128.1mm	EX
1978	1176.8mm	1000.4mm	176.4mm	EX	2020	659.2mm	1000.4mm	-341.2mm	DEF
1979	952.3mm	1000.4mm	-48.1mm	DEF	2021	922.4mm	1000.4mm	-78.0mm	DEF
1980	930.6mm	1000.4mm	-69.8mm	DEF	2022	1173.4mm	1000.4mm	173.0mm	EX
1981	9.0mm	4.1mm	4.9mm	EX	-	-	-	-	-
S1 Balance Sheet (1940-1981): **18 excess rainy seasons/42; or 42.85%** **23 rainy seasons deficit/42; or 56.76%** **NB: IpSP ≥ 1.09 (i.e. ≥ 1100mm) = 5/42** **PRI: 5/42 = 11.90%**					**S2 report (1982-2022):** **22 excess rainy seasons/41; or 53.65%** **19 rainy seasons deficit/41; or 46.34%** **NB: IpSP ≥ 1.09 (i.e. ≥ 1100mm) =** **12/4 PRI: 11/41 = 26.82%** **1**				

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: MENA Marin and YANGNE Claire, March 2025.

Table 3 presents a summary of rainfall amounts and deviations from the average for the rainy seasons in Garoua from 1940 to 2022. Analysis of these data reveals significant climate trends and interannual variability. This representation includes not only climate trends in Garoua, but also their potential implications for agriculture, water supply, and natural resource management in the locality.

Over the decades, some years are distinguished by abundant rainfall, as was the case in 1940 with 1850.1 mm illustrating extreme rainfall events. Other years, such as 2000 and 2020, show significant deficits, reaching up to (-341.2 mm), which testifies to the existence of deficit rainy seasons during the rainy seasons. Thus, during sequence 1 (1940-1981), the **Probability Risk Flood Risk (RPI)** then estimated at 11.90%, will experience an increase during sequence 2 (1982-2022) since it will rise to 26.82%. To this end, the **Probability Risk Flood Risk (RPI)** observed between 1982 and 2022 has almost doubled since 11 rainy seasons have rainfall above 1100mm. This increase in the risk of flooding probability during the second sequence reflects the resurgence of flooding in Garoua.

In summary, the analysis of summary tables of rainfall amounts and deviations from the average for the dry and wet seasons in Garoua from 1940 to 2022 highlights marked climate trends. Dry seasons exhibit fluctuations, with years of surplus and deficit revealing periods of extreme drought and humidity. At the same time, rainy seasons also display complex dynamics, oscillating between periods of abundant rainfall and severe drought. This highlights the potential impact of climate change on local rainfall patterns. These data are essential for water resource planning, crop management, and environmental risk assessment.

Figure 9 illustrates the evolution of the ten-year averages of rainfall in Garoua from 1940 to 2022. These variations are manifested by periods of both excess and deficit. The decade 1940-1949 is distinguished by an average of 1083.47 mm, indicating a period of abundant rainfall. Similarly, the decades 1970-1979 and 2000-2009 show excess averages, respectively 1069.1 mm and 1038.5 mm, highlighting phases of favourable climatic conditions. Conversely, the decade 1950-1959 shows an average of 822.34 mm, illustrating a period of low rainfall. The decade 1980-1989 shows a similar trend, also with an average of 822.34 mm, confirming a decrease in rainfall during this period. The moving average further details the fluctuations showing a gradual increase in precipitation, particularly marked towards the end of the period studied (2010-2019).

Thus, the decade (2010-2019) with 1038.5mm of rainfall explains the floods observed in Garoua with enormous damage in 2012 so that the districts of Lopéré 4, Lopéré 5 and Bibemiré 2 suffered significant damage, with a primary school submerged and around twenty houses collapsed (Invest in Cameroon, 2012).

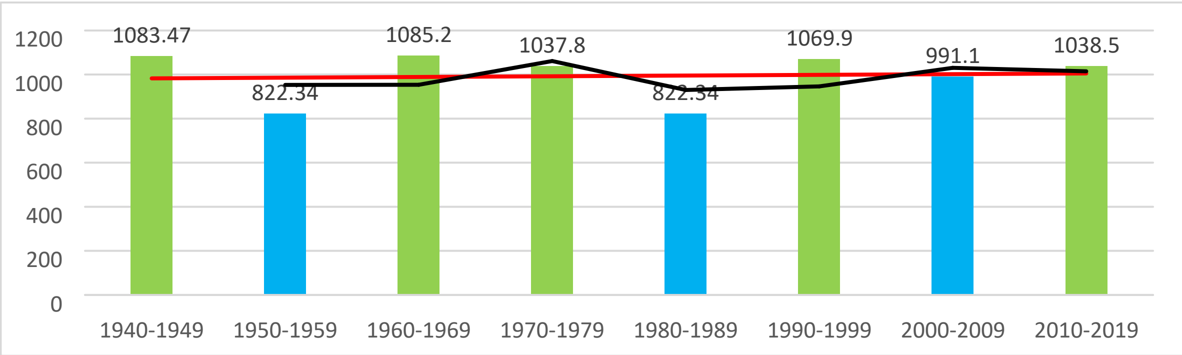


Figure 9: Excessive evolution of ten-year averages in Garoua from 1940 to 2022.

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

Figure 10 shows the evolution of the five-year averages of rainfall for the rainy seasons from 1940 to 2019. For this purpose, the interval from 1940 to 1944 with a height of 1179.2mm was the wettest. On the other hand, the period (1950-1954) with only a height of 756.76mm was the least wet. Thus, after abundant rainfall observed from (1960-1979) and (1990-1994), the period from 2005 to 2014 is characterized much more by rainfall deficits. This five-year analysis shows that the rainy seasons were wet between 1940 and 1970 despite the existence of deficit periods. After the deficit triggers observed between 1980 and 1989 and then between 1995 and 2004, we observed a resumption of rainfall increases between 2005 and 2019. Overall, the trend in rainfall during the rainy seasons is constant with a very slight increase in rainfall.

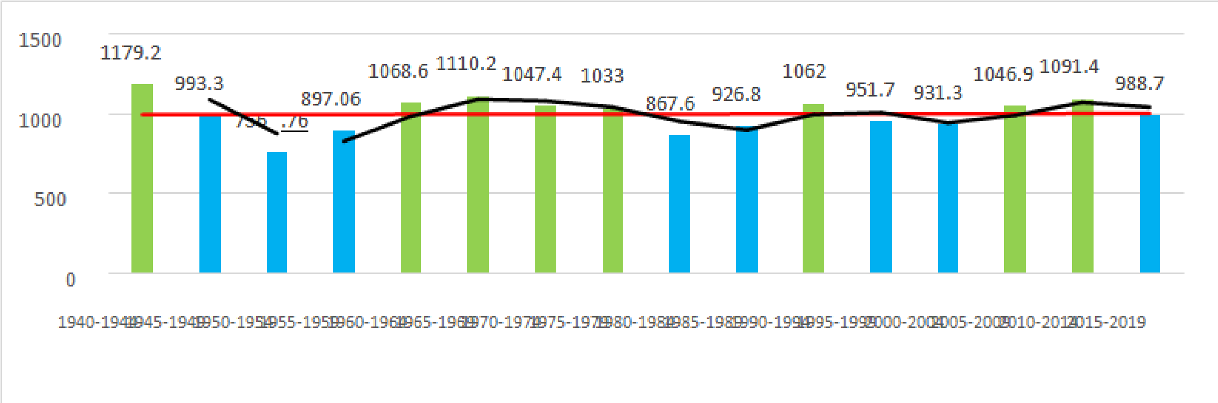


Figure 10: Constant evolution of five-year averages in Garoua from 1940 to 2022

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

2.1.4 El Niño and La Niña episodes, real factors of flooding in Garoua from 1963 to 2022

This section examines the impact of El Niño and La Niña climatic phenomena on annual rainfall in Garoua between 1963 and 2022 and, consequently, on flooding. These climatic events, which influence rainfall patterns globally, have effects on local weather conditions. See Table 4.

Table 4: Impact of El Niño and La Niña episodes on annual rainfall in Garoua from 1963 to 2022

El Niño/La Niña Episodes	Years	Annual heights (mm)	Normal mm	Px-Pm	Observation	Balance sheet (%)
El Niño	1963	1048.2	1021.0	27.2	Humid	
El Niño	1965	1058.1	1021.0	37.1	Humid	
La Niña	1969	1291.5	1021.0	270.5	Humid	
El Niño	1972	1157.5	1021.0	136.5	Humid	
El Niño	1973	1205.1	1021.0	184.1	Humid	El Niño: 9 deficit seasons/19 (47.36%) and 10 wet surplus seasons/19 (52.63%)
La Niña	1975	1091.3	1021.0	70.3	Humid	
El Niño	1976	1081.2	1021.0	60.2	Humide	
El Niño	1977	859.3	1021.0	-161.7	Dry	
La Niña	1979	956.6	1021.0	-64.4	Dry	
La Niña	1980	967.8	1021.0	-53.2	Dry	
La Niña	1982	1006.4	1021.0	-14.6	Dry	
El Niño	1983	631.4	1021.0	-389.6	Dry	
El Niño	1986	923.7	1021.0	-97.3	Dry	
La Niña	1987	701.2	1021.0	-319.8	Dry	
La Niña	1990	1033.3	1021.0	12.3	Humide	
La Niña	1991	1133.0	1021.0	112.0	Humide	
La Niña	1992	937.5	1021.0	-83.5	Dry	La Niña: 08 deficit seasons /18 (44.44%) and 10 surplus seasons /18 (55.55%)
La Niña	1993	1038.1	1021.0	17.1	Humide	
El Niño	1995	1062.2	1021.0	41.2	Humide	
El Niño	1997	1033.3	1021.0	12.3	Humide	
El Niño	1998	1010.6	1021.0	-10.4	Dry	
El Niño	2002	945.4	1021.0	-75.6	Dry	
El Niño	2003	979.6	1021.0	-41.4	Dry	
El Niño	2004	1021.3	1021.0	0.3	Humide	
La Niña	2005	931.3	1021.0	-89.7	Dry	
El Niño	2006	930.9	1021.0	-90.1	Dry	
La Niña	2007	1070.3	1021.0	49.3	Humide	
La Niña	2008	1059.5	1021.0	38.5	Humide	
La Niña	2009	1242.5	1021.0	221.5	Humide	
La Niña	2010	1124.1	1021.0	103.1	Humid	
El Niño	2015	956.6	1021.0	-64.4	Dry	
El Niño	2016	1033.6	1021.0	12.6	Humide	
El Niño	2018	980.9	1021.0	-40.1	Dry	
El Niño	2019	1128.5	1021.0	107.5	Humide	

La Niña	**2020**	**664.5**	**1021.0**	**-356.6**	**Dry**	
La Niña	**2021**	**945.9**	**1021.0**	**-75.2**	**Dry**	
La Niña	**2022**	**1173.7**	**1021.0**	**152.7**	**Humide**	

Sources: Russian Institute of Hydrometeorology (Saint-Petersburg); Rainfall data from the National Meteorological Directorate of Cameroon; https://www.aviso.altimetry.fr/ Production: MENA Marin and YANGNE Claire, (August 2024)

Table 4 illustrates the impact of El Niño and La Niña episodes on annual rainfall between 1963 and 2022. Analysing this table, we find that 9 years were dry among the 19 El Niño episodes recorded, namely in 1977, 1983, 1986, 1998, 2002, 2003, 2006, 2015 and 2018, which gives a probability of aridity of 47.36%. On the other hand, 10 years were wet, (1963, 1965, 1972, 1973, 1976, 1995, 1997, 1998, 2004 and 2019). This translates to a 52.63% probability of humidity during El Niño episodes in Garoua between 1963 and 2022. Regarding the 18 La Niña episodes, we note that 8 years were dry, namely 1979, 1980, 1982, 1987, 1992, 2005, 2020 and 2021, which represents a 44.44% probability of aridity. However, 10 years are wet, namely: 1969, 1975, 1990, 1991, 1993, 2007, 2008, 2009, 2010 and 2022. This results in a 55.55% probability of humidity. Thus, La Niña episodes in Garoua are associated with a preponderance of humidity over drought. **Table 5** shows some records capable of causing flooding during El Niño and La Niña episodes from 1963 to 2022.

Table 5: Some record years at the Garoua weather station and links with El Niño and La Niña episodes from 1963 to 2022

Some El Niño/La Niña Episodes (year)	Record Years Observed	Rainy Season Height (mm)	Normal (Pm)	Percentages of surpluses and deficits (Px-Pm/pm× 100)	Observation
(1963) El Niño	**1964**	**1427.3 mm**	**1016.9 mm**	**+40.36%**	**Abnormally excess**
(1969) La Niña	**1969**	**1287.2 mm**	**1016.9 mm**	**+26.58%**	**Abnormally excess**
(1973) El Niño	**1973**	**1205.1 mm**	**1016.9 mm**	**+18.50%**	**Abnormally excess**
(2009) La Niña	**2009**	**1242.5 mm**	**1016.9 mm**	**+22.19%**	**Abnormally excess**

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, August 2024

Table 5 presents some record rainfall years related to El Niño and La Niña events. The data show rainfall variability that highlights the marked influence of these climatic phenomena on rainfall patterns. Years associated with La Niña, such as 1969 and 2009, are distinguished by above-normal rainfall amounts, with respective excesses of +26.58% and +22.19%. This indicates favourable rainfall conditions during these periods. Regarding El Niño events, the year 1964 recorded an excess percentage of +40.36%. These observations highlight the complexity of the interactions between El Niño and La Niña events and their effects on rainfall.

Analysis of the impact of El Niño and La Niña episodes on the evolution of monthly, seasonal and annual rainfall in Garoua from 1963 to 2022 shows that these global climatic phenomena are real catalysts for rainfall disturbances that sometimes cause flooding.

2.1.5 The nature of the soils favourable to the frequency of flooding

Flooding in Garoua is caused by a combination of soil and geomorphological factors. The soils are predominantly sandy and exhibit rapid infiltration with low water retention capacity. With proportions exceeding 80% sand, Garoua's soils quickly reach their saturation point during heavy rains. This characteristic generates accelerated surface runoff, further aggravated by the low proportion of clay, which would normally limit vertical drainage. Indeed, sandy soils have high hydraulic conductivity initially, but this decreases rapidly after the first rains, promoting runoff (Bachir, 2012).

The city of Garoua, located on an alluvial plain in the Benue Basin, has a flat relief with minimal slopes. This topographic configuration reduces water flow velocity and promotes stagnation, particularly in densely populated urban areas. Level failures amplify this phenomenon by releasing massive volumes of water into low-lying watersheds.

The combination of sandy soils and flat terrain creates a critical and rapid saturation threshold. Hydrological studies show that a high ratio of antecedent soil moisture to rainfall reverses the correlation with peak flows, making areas with previously saturated soils extremely vulnerable (Mbilou et al., 2016). In Garoua, intense monsoon rains on already wet soils explain the rapid onset of catastrophic flooding. Water infiltration into sandy soils is rapid initially but decreases over time, increasing the risk of runoff and flooding (Ahuja et al., 1998). In summary, flooding in Garoua results from a complex interaction between the pedological characteristics of the soils, mainly sandy, and the morphology of the flat terrain, which favour runoff and water stagnation. This combination makes the area particularly vulnerable to intense rainfall, thus requiring adapted strategies to manage these natural hazards.

2.1.6 Considerable contribution of vegetation to the understanding of floods

The vegetation in Garoua is mainly composed of South Sudanese savannahs, with a dominance of grasses and shrubs adapted to the Sudano-Sahelian climate. Woody species such as *Anogeissus leiocarpus, Combretum glutinosum,* and *Acacia gerrardii* are common in lowland areas (Olivry, 1974). Dominant grasses include *Hyparrhenia rufa* and *Andropogon gayanus* (Letouzey, 1985). This vegetation is often degraded around urban and agricultural areas, which may affect its role in regulating and retaining water and soil in flood dynamics. On the one hand, dense vegetation can reduce runoff by increasing water infiltration into the soil, thanks to plant roots that improve soil structure. However, in areas where vegetation is sparse or degraded, as is often the case in urban or intensive agricultural regions where infiltration capacity decreases and promotes water runoff causing flooding (Bielders et al., 2003). In Garoua, the vegetation is mainly grassy with degrading forest remnants, which may limit its positive effect on infiltration (Olivry, 1974).

Furthermore, vegetation can also influence the hydrological cycle by altering evapotranspiration. In the context of Garoua, where rainfall is concentrated over a short period, the main effect of vegetation is manifested by its ability to stabilize the soil and reduce runoff. Unfortunately, deforestation and soil degradation reduce this capacity, thus increasing vulnerability to flooding.

To this end, vegetation in Northern Cameroon is a catalyst for flooding episodes. Indeed, dense vegetation cover not only promotes rainwater absorption, slows runoff, and also reduces flood risks. However, deforestation and land degradation, caused by human activities such as land clearing and overgrazing, lead to a significant decrease in vegetation cover. This situation makes soils more vulnerable to runoff, as the lack of vegetation prevents effective absorption of rainwater. Moreover, the nature of the soils, often shallow and not very permeable, complicates water retention and contributes to flooding. Thus, the combination of insufficient vegetation covers and unsuitable soils promotes rapid water flow and increases the frequency of floods. Vegetation degradation exacerbates flood risks. It is therefore important to promote sustainable land management practices to restore vegetation cover and strengthen the resilience of ecosystems to flooding (Mena Marin, 2024).

2.1.7 The involvement of the Adamaoua plateau in the flooding process

Rainfall in the Adamawa region varies by area, with significant differences from year to year. This variability is influenced by climatic factors, including seasonal changes and extreme weather events. Fluctuations in rainfall directly affect water flow and exacerbate flood risks, especially when periods of heavy rain are associated with inappropriate land management practices. Rainfall variation in the Adamawa region is a determining factor in the dynamics and understanding of flooding in the city of Garoua. Indeed, Garoua, located in northern Cameroon, faces marked rainfall variations, with periods of heavy rain, particularly in July and August, which can lead to rapid soil saturation and increased water runoff.

Heavy rainfall in Adamawa, particularly near Garoua, contributes to water accumulation in surrounding basins. This accumulation, combined with often inadequate infrastructure to manage flooding, increases the risk of flooding in the city. Furthermore, the nature of Garoua's soils, which are often shallow and not very permeable, prevents effective absorption of rainwater, thus exacerbating the situation during heavy rainfall events. Consequently, the combination of rainfall variability and Garoua's geographical characteristics contributes to making the city a flood-prone area (Mena Marin, 2024).

The Adamawa Plateau is even one of the main catalysts of flooding in Garoua. It is located between an average altitude of 1200m and is the main natural water tower of Cameroon. It is also on this plateau that the Benue and its tributaries, namely the Mayo-Rey and the Mayo-Godi, have their sources. It is obvious that heavy rains on the Adamawa Plateau can cause flooding on the waterways. However, the locality of Garoua, whose average altitude is less than 200m, constitutes an outlet or even a natural water collector where water stagnates. For example, a comparative study of the heights of seasonal rainfall in Ngaoundéré on the Adamawa Plateau and Garoua testifies to the existence of the implication of the rainfall of the Adamawa Plateau on the floods of the locality of Garoua. To this end, **Table 6** provides more details.

Table 6: Comparison of Precipitation Heights in Garoua and Ngaoundéré (1945-2022)

Years	Rainfall in Garoua >1000.4mm	Rainfall in Ngaoundéré >1400 mm
1968	1179.3mm	1522.4 mm
1972	1157.5mm	1494.8 mm
1973	1205.1mm	1419.5 mm
1988	1190.4mm	1513.1 mm
1991	1132.9mm	1473.0 mm

1994	**1168.1mm**	**1444.6 mm**
1996	**1157.7mm**	**1403.4 mm**
1999	**1192.0mm**	**1679.4 mm**
2009	**1242.5mm**	**1674.8 mm**
2010	**1124.1mm**	**1539.0 mm**
2019	**1128.5mm**	**1830.2 mm**
2022	**1173.4mm**	**1871.0 mm**

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: MENA Marin and YANGNE Claire, March 2025.

Table 6 provides a comparative analysis of rainfall between Garoua and Ngaoundéré over the period 1945 to 2022. This comparative analysis of rainfall between the localities of Ngaoundéré and Garoua demonstrates the existence of implicit links where a minimum rainfall of 1400mm also impacts that of Garoua and, by extension, the floods of the Benue River. Heavy rains in Ngaoundéré cause floods towards Garoua, which exacerbates the risk of flooding in the latter. Drainage systems, often insufficient to manage this excess water, quickly become saturated. This intensifies flooding, especially in vulnerable low-lying areas. This situation underlines the importance for the authorities of Garoua to develop and implement effective storm water management and flood prevention strategies. By integrating Ngaoundere's rainfall trends into their planning, they can better anticipate and mitigate the impacts of these climatic phenomena to ensure the safety and well-being of the population. **Table 7** provides an overview of flooding in Garoua over the years, highlighting the significant events, affected areas, human and material consequences, and information sources for each incident. This table illustrates the significant impact of flooding on this city, both in terms of human losses and damage to infrastructure and agriculture.

Table 7: Some years of flooding in Garoua between 1988 and 2022

Years	Neighborhoods/ Locati ons	Démonstrations	Damage	References
1988	Garoua	Maximum flood recorded in Garoua: 1946m $^{3/}$ s $^{-}$	Filling of the Lagdo dam up to the 216m coast	Books.openedition.org
1999	Lidiré	Flooding of the main dike at Garoua bridge	The death toll stands at 30 and hundreds are affected as far away as neighboring Nigeria.	Cameroon news/voaafrique.com
2008	Garoua	Floods due to torrential rains	Destruction of roads and infrastructure; agricultural losses	2008 Annual Report
2012	Bibémiré, Loppéré	Flood following heavy rains	Evacuation of several neighborhoods; 12 dead; 6,637 households affected	Investing in Cameroon
2013	Garoua	Heavy rains causing flooding	15 dead	Ministry of the Environment
2022	Lidiré	Exceptional flooding of the Benue River	Evacuation of the population; human and economic losses	Red Cross Report

Source: Rainfall data from the National Meteorological Directorate of Cameroon, produced by: YANGNE Claire, March 2025.

The data revealed by **Table 7** show that Garoua has been particularly vulnerable to flooding, with significant events in 1988, 1999, 2008, 2012, 2013 and 2022. For example, the remarkable flood of 1988 led to the filling of the Lagdo dam, illustrating the magnitude of the rainfall. The floods of 1999 and 2012 not only caused considerable human losses with 30 and 12 deaths respectively, many victims but also extensive destruction of infrastructure. The events of 2008 and 2013 show an alarming trend: the destruction of essential infrastructure and agricultural losses worsen the economic situation of the affected populations. Finally, the exceptional flood of 2022 required the evacuation of the population, highlighting the need for better flood risk management and adequate preparation to deal with these extreme natural disasters.

2.2 Anthropogenic factors

2.2.1 Urbanization

Urbanization in Garoua is a key factor contributing to flooding in the city. The rapid and often unplanned growth of urban areas leads to an increase in impervious surfaces, such as roads, buildings, and parking lots. These surfaces significantly reduce water infiltration into the ground, thus increasing direct runoff during rainfall (Gupta, 2020). In Garoua, as in other developing cities, urbanization has often occurred at the expense of green spaces and natural areas capable of regulating water flows (Olivry, 1974). Also, uncontrolled urban development has led to rock fill on natural waterways and drainage areas. Construction in flood-prone areas, sometimes on the major channels of the Benue River and rivers or near watercourses, disrupts the natural flow of water and increases the likelihood of flooding. Added to this is the inadequacy or poor design of urban drainage infrastructure, which is not adapted to manage the increasing volumes of runoff generated by impervious surfaces (O'Donnell & Thorne, 2020).

Finally, rapid urbanization in Garoua is often accompanied by inadequate solid waste management. This waste clogs existing drainage systems, further exacerbating flooding problems during heavy rains (Gupta, 2020). The lack of integrated urban planning and runoff control measures makes the city particularly vulnerable to flooding.

2.2.2 The failure of flood control projects

The failure of flood control projects in Garoua stems from a combination of systemic and contextual factors. To improve the effectiveness of these initiatives, it is essential to adopt an integrated approach, taking into account local realities and environmental challenges. Several factors may explain this failure. First, we have inadequate planning; the success of flood control projects relies on a thorough understanding of local hydrological dynamics. However, many projects have been developed without sufficient studies of the geographical and climatic characteristics of the region. This often leads to poorly designed infrastructure, unable to manage variations in rainfall events. For example, drainage systems may not account for peak rainfall events, leading to rapid saturation and overflows. Design standards for hydraulic diversions must incorporate specific return periods to avoid saturation of drainage systems during peak rainfall events (UNIDO, 2024).

We also deplore the inadequacy of financial resources deployed for flood control. Often undersized budgets compromise the sustainability of infrastructure. In Cameroon, the Yaoundé Storm Water Sanitation Project required three phases of financing (including 15.8 billion FCFA in 2022) for still partial results, revealing the gap between needs and commitments (Invest in Cameroon, 2022). In Europe, 47% of flood risk management plans (PGRI) lack guaranteed financing, limiting cross-border investments (European Court of Auditors, 2024). Financing is a major challenge in the implementation of infrastructure projects. Often, allocated budgets are insufficient to cover all costs, including construction, maintenance, and infrastructure upgrades. This lack of financial resources can also limit the ability of local authorities to invest in modern technologies or innovative solutions for storm water management. As a result, existing infrastructure becomes obsolete and inefficient.

Thus, there is a maintenance problem: flood control infrastructure, such as drainage channels and dams, requires regular maintenance to function effectively. Unfortunately, a lack of monitoring and maintenance can lead to their degradation. Debris, sediment, or obstructions in drainage systems can reduce their ability to evacuate rainwater, thus increasing flood risks. Preventive maintenance programs should be implemented to ensure the proper functioning of infrastructure. Post-construction management standards require strict protocols to prevent sediment from clogging drains (United Nations Industrial Development Organization, 2024). Furthermore, we note a weak community and institutional synergy. Indeed, the lack of involvement of local communities in the design and implementation of projects can lead to solutions that are not adapted to their real needs. A participatory approach, where residents are involved from the outset, would allow for better targeting of the specific problems of each neighbourhood or region. However, when communities are integrated into projects, they are more likely to support and maintain these initiatives over the long term. The "Loire Grandeur Nature Plan" showed that local buy-in is crucial: municipalities often neglected their obligations (safeguard plans), while the State struggled to delegate clear responsibilities (Organisation for Economic Co-operation and Development, 2010). The World Bank recommends involving local populations in risk assessments, particularly through participatory simulations (World Bank, 2023).

Naturally, flood management involves the collaboration of multiple government institutions, non-governmental organizations, community actors, and state actors. A lack of collaboration and coordination among these various stakeholders can lead to scattered and even contradictory efforts, which in turn can amplify flood risks. It is clear that synergistic relationships can lead to rapid and effective strategies capable of reducing the impact of flooding.

3. Discussion

The flooding phenomenon is real and increasingly regular in the locality of Garoua. These catastrophic floods are exacerbated by natural and anthropogenic factors. Regarding natural factors, we can cite: torrential rains, increased rainfall in certain months, wet episodes of the La El Niño and La Niña phenomena; the nature of the soil, the degradation of the vegetation cover, the relief, the rainfall of the Adamaoua plateau and the existence of a low slope in Garoua. As for the anthropogenic motives on the origins of floods in Garoua, we can list: urbanization; the adoption of unreliable projects; the non-involvement of local populations in flood control projects; the lack of synergies between actors involved in flood control; insufficient financial resources and the failure of projects. Flood risk management in Garoua is essential to protect residents, infrastructure, and the environment. This includes strategies implemented to mitigate the impacts of flooding and strengthen community resilience to extreme and dangerous climate events. As we witness the increase in flooding, exacerbated by the increase in rainfall in certain months, it is clear that we will not be able to prevent the occurrence of stormy and torrential rains, including floods. This indicates that floods will continue to be regular and devastating. Therefore, only rapid and effective warning measures will help reduce flood vulnerability in Garoua. As part of flood control and vulnerability reduction in the locality of Garoua, we propose:

- Evaluating the preventive or proactive measures adopted in Garoua to manage flood risks is essential to determine their effectiveness and relevance in the face of climate challenges. Thus, preventing flood risks in Garoua requires land use planning; integrating hydrological considerations into land use planning is a key measure. The assessment of risk areas and the creation of buffer zones, such as green spaces and retention basins, have helped reduce the impact of rainwater (Ousmaïla Mohamadou, 2022). However, it is crucial to continue monitoring these areas to ensure their effectiveness. Also,assessing the occurrence of flooding during periods of calm highlights the importance of a proactive and integrated approach to risk management. Periods of calm do not guarantee the absence of flood risks. Climate change can lead to unpredictable variations in rainfall patterns, making some areas more vulnerable to flooding even outside of normal rainy seasons. An assessment of long-term climate data is therefore necessary to anticipate these fluctuations.
- The establishment of drainage infrastructure is essential. Investments in drainage infrastructure, such as canals and drains, must be a priority. The assessment shows that some infrastructure has improved storm water drainage, but others require repairs and regular maintenance to prevent blockages and deterioration.The Urban C2D program funded road and sanitation works, including the construction of a drain in Cartoucherie RoumdéAdjia, to improve storm water management (MINHDU, 2024). Drainage infrastructure, although in place, requires constant maintenance to remain effective. During periods of calm, lack of maintenance can lead to the accumulation of debris and sediment, which clogs the channels and increases the risk of flooding during subsequent heavy rains. Regular assessment of the condition of this infrastructure is important to ensure its proper functioning (Alioum Garga, 2020).
- Adopting early warning systems can help communities better prepare for flooding. Evaluations of these systems show increased awareness and faster response times to warnings. However, further efforts are needed to ensure that all populations, including the most vulnerable, receive this information.
- Regular awareness-raising and training of the population; Awareness-raising campaigns and training programs help increase awareness of flood risks among residents. The evaluation indicates that these initiatives have had a positive impact on preventive behaviours, although there are still gaps to be filled, particularly in rural areas;
- The real and effective need for inter-institutional collaboration; Collaboration between different stakeholders, including local authorities and NGOs, is fundamental to the success of prevention initiatives. The evaluation shows that partnerships strengthen response capacity and promote resource sharing. However, closer coordination is needed to optimize efforts.
- In the Garoua area, the increasingly rapid urbanization must be controlled, so geographers and the national cartography institute must map the areas at real risk of flooding.
- Surface water management, including runoff, is a key aspect of flood prevention. An assessment of current practices reveals that strategies such as creating retention areas or using sustainable drainage techniques can reduce flood risks. Green infrastructure projects should be encouraged to improve this management.

Conclusion

Moreover, this study reveals the complexity of the climatic and environmental dynamics affecting the city of Garoua. The locality of Garoua, an ecological niche for hundreds of thousands of people, faces environmental challenges exacerbated by climate change. These increasingly frequent floods cause loss of life, destruction of infrastructure, decreasing agricultural yields, and food crises, making these populations particularly vulnerable. This analysis demonstrates the existence of rainfall variability marked by periods of drought and torrential rains, often exacerbated by fluctuations in climatic phenomena such as El Niño and La Niña. These events influence not only rainfall patterns, but also the physicochemical properties of soils and water resource management. Rapid urbanization in Garoua, coupled with inefficient drainage infrastructure, exacerbates the situation, increasing the risk of catastrophic flooding. An analysis of flood control projects in Garoua highlights a series of challenges that compromise their effectiveness. Systemic and contextual factors, such as inadequate planning, lack of financial resources, and poor infrastructure maintenance, help explain the observed failures. The success of these initiatives depends on an integrated approach that takes into account local hydrological dynamics and environmental specificities. Planning flood control projects requires a thorough understanding of Garoua's geographical and climatic characteristics. Financing is a major issue in the implementation of these projects. Often insufficient budgets compromise the sustainability of infrastructure, thus limiting its ability to effectively meet growing needs. Financial resource management must be improved to ensure adequate investments and innovative solutions for storm water management. To this end, preventive maintenance programs must be established to ensure the proper functioning of drainage systems. At the same time, the integration of local communities in the design and implementation of projects is imperative, as a participatory approach promotes solutions tailored to the real needs of residents and strengthens their support for the initiatives implemented. Finally, it is imperative to adopt an integrated approach that combines rigorous planning, adequate financing, regular maintenance, and community engagement. These measures will strengthen community resilience to flooding and ensure sustainable water resource management in this vulnerable region. Also to manage hydro meteorological event such as flood at Garoua, it will be an imperative duty to control rainy season of Adamaoua plateau.

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