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The variability and changes of precipitation in arid and semi-arid zones of Algeria (Ghardaia, Ouargla, Biskra and Laghouat) From 1969-2016

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Dedication

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents especially my mother, words of encouragement and push for tenacity ring in my ears. My brother, have never left my side and he is very special.

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Dedication

I dedicate my work to my family. A special feeling of gratitude towards my Loving parents and especially my mother the one that I study only for her.

Not forgetting also my brothers who care a lot about me and who want to see me succeed.

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Abstract

This study investigates the impact of climate change on extreme precipitation indicators in the arid and semi-arid regions of Algeria, specifically Ghardaïa, Ouargla, Laghouat, and Biskra, during the period 1969-2016. The research utilizes innovative trend analysis (ITA) and change point detection methods to analyze and calculate precipitation trends and indices. The results of the ITA and change point methods are compared, and 10 precipitation indices for extreme events are computed. The findings reveal increasing trends in mean precipitation for most stations, as well as varying trends in extreme daily precipitation events, often associated with flooding. However, no significant decreasing trend in precipitation is observed across all the analyzed stations. The change point detection analysis indicates that only two stations (Ghardaia and Biskra) exhibit three change points, signifying shifts in either station data or climate conditions. These findings provide insights into the behavior of precipitation data series and the specific dates of occurrence for these shifts. Notably, one station does not show any change point detection. This research aims to contribute to the understanding of climate change impacts in Algeria's arid and semi-arid regions and enhance preparedness for future extreme precipitation events.

Keywords: Rainfall, Climate change, change point, Ghardaia, Biskra, Laghouat, Ouargla, ETCCDI, Innovative trend analysis, Arid, semi-arid.

ملخص:

تبحث هذه الدراسة في تأثير تغير المناخ على مؤشرات هطول الأمطار الشديدة في المناطق القاحلة وشبه القاحلة في الجزائر ، وتحديداً غرداية ، ورقلة ، الأغواط ، وبسكرة ، خلال الفترة 1969-2016. يستخدم البحث تحليل الاتجاهات المبتكر (ITA) وتغيير طرق الكشف عن النقاط لتحليل وحساب اتجاهات ومؤشرات هطول الأمطار. تتم مقارنة نتائج ITA وأساليب نقطة التغيير ، ويتم حساب 10 مؤشرات لهطول الأمطار للأحداث المتطرفة. تكشف نتائج اختبار ITA عن اتجاهات متزايدة في متوسط هطول الأمطار لمعظم المحطات ، فضلاً عن الاتجاهات المتغيرة في أحداث هطول الأمطار اليومية الشديدة ، وغالبًا ما تكون مرتبطة مع الفيضانات. ومع ذلك ، لم يلاحظ أي اتجاه تنازلي كبير في هطول الأمطار عبر جميع المحطات التي تم تحليلها. يشير تحليل اكتشاف نقطة التغيير إلى أن محطتين فقط (غرداية وبسكرا) تعرضان ثلاث نقاط تغيير ، مما يدل على التحولات في بيانات المحطة أو الظروف المناخية. توفر هذه النتائج نظرة ثاقبة لسلوك سلسلة بيانات هطول الأمطار والتواريخ المحددة لحدوث هذه التحولات. والجدير بالذكر أن إحدى المحطات لا تعرض أي اكتشاف لنقطة التغيير. يهدف هذا البحث إلى المساهمة في فهم تأثيرات تغير المناخ في المناطق القاحلة وشبه القاحلة بالجزائر وتعزيز التأهب لظواهر هطول الأمطار الشديدة في المستقبل.

الكلمات المفتاحية: هطول الأمطار ، تغير المناخ ، نقطة التغير ، غرداية ، بسكرة ، الأغواط ، ورقلة ، **ETCCDI** ، تحليل الاتجاه المبتكر ، جاف ، شبه ج

Résumé

Cette étude examine l'impact du changement climatique sur les indicateurs de précipitations extrêmes dans les régions arides et semi-arides de l'Algérie, en particulier Ghardaïa, Ouargla, Laghouat et Biskra, au cours de la période 1969-2016. La recherche utilise des méthodes innovantes d'analyse des tendances (ITA) et de détection des points de changement pour analyser et calculer les tendances et les indices de précipitations. Les résultats des méthodes ITA et des points de changement sont comparés et 10 indices de précipitations pour les événements extrêmes sont calculés. Les résultats du test ITA révèlent des tendances croissantes des précipitations moyennes pour la plupart des stations, ainsi que des tendances variables des événements extrêmes de précipitations quotidiennes, souvent associés. Avec les inondations. Cependant, aucune tendance significative à la baisse des précipitations n'est observée dans toutes les stations analysées. L'analyse de détection des points de changement indique que seules deux stations (GHARDAIA et BISKRA) présentent trois points de changement, ce qui signifie des changements dans les données de la station ou les conditions climatiques. Ces résultats donnent un aperçu du comportement des séries de données sur les précipitations et des dates précises d'apparition de ces changements. Notamment, une station ne montre aucune détection de point de changement. Cette recherche vise à contribuer à la compréhension des impacts du changement climatique dans les régions arides et semi-arides de l'Algérie et à améliorer la préparation aux futurs événements de précipitations extrêmes.

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Mots clés : Précipitations, Changement climatique, Point de changement, Ghardaïa, Biskra, Laghouat, Ouargla, ETCCDI, Analyse des tendances innovantes, Aride, semi-aride.

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General Introduction

General Introduction

Over time, the Earth's climate has undergone changes, and it is predicted that there will be a significant climate change in the future. Human activities, such as the emission of greenhouse gases, are the primary cause of this change (as reported by the IPCC in 2013) “Intergovernmental Panel on Climate Change”. The Mediterranean region, which includes Algeria, is considered to be one of the areas most susceptible to the effects of climate change, according to global projections of future climate patterns. [1]

Indeed, much research around the world has been conducted to understand, characterize, and predict hydro meteorological variation; Very rare and intense precipitation events have increased and will become more frequent globally and especially in the semi-arid regions of the Mediterranean Basin in recent decades. [1]

Algeria is located in the southern Mediterranean region, and has an arid to semi-arid climate over most of its territory. Climate plays a crucial role in various social and economic aspects of society, and the region has faced many devastating events, including floods and flash floods, over the past 50 years. These events have become the most devastating natural disasters in the northern region, and the floods that occurred in Algeria (Ghardaïa) on October 1, 2008 are considered one of the most deadly natural disasters ever in the country, a poignant example of the devastating impact of these events

The study and monitoring of the evolution and change of the climate, extreme rainy events, calls for the analysis and calculation of extreme climatic indices as well as their trends. These indices (27 indices) were developed by the Expert Team on Climate Change Detection Indices (ETCCDI).

This study aims to analyses the effect of climate change on the climatic indicators of extreme precipitation, the possible maximum precipitation and to determine the direction of the precipitation, is it increasing or decreasing in Ghardaïa, Ouargla, Laghouat and Biskra.

A relevant question will be addressed during this work: **what are the trends in precipitation in the two climatic regions (arid and semi-arid) of Algeria during the period 1969/2016?**

To do this, we use the common methods of precipitation analysis such as: Innovative Trend Analysis (ITA) and change point detection, the trend analysis of rainfall extremes has been based on the climate indices developed by the ETCCDI. The ten ETCCDI rainfall indices used in this study concern three characteristics: intensity (Rx1day, Rx5day, R95p, R99p, SDII and PRCPTOT), duration (CWD and CDD) and frequency (R10mm and R20mm) of rainfall. Application of ITA on daily and extremes of rainfall will allow us to the use of new or unconventional methods to study and interpret the patterns and trends of precipitation over a given area or region. Also, change point detection will allow us to identify the abrupt variation in the process behavior due to distributional or structural changes. We divide our work into four chapters:

The first and second chapters Containing A presentation of a state of the art on the study of extremes on a global, regional and local scale and the definition of all the geomorphological and climatic parameters in arid and semi-arid of the study areas.as well as the rainfall data used in this study.

The third chapter describes in detail the trend detection methods commonly used for precipitation analysis, the ITA (Innovative Trend Analysis) method and the change point detection method also the software used in this work.

The last chapter (4^{th}), will highlight the discussion and analysis of extreme precipitation events on different time scales (daily, monthly, yearly) at the four stations and the results of the two methods used (ITA. Change Point). Including the calculation of precipitation indices for extreme events (10 indices) during the period 1969/2016.

Chapter I: Climate change and its Impact on extreme rainfall patterns

Chapter I: Climate change and its Impact on extreme rainfall patterns

I.1. Introduction

The objective of this chapter is to present the climate change in general and contextualize the stakes of this thesis by synthesizing the different approaches used to investigate the risk of extreme events in the context of changes in hydroclimatic conditions observed and projected on a global scale, the Mediterranean and Algeria and its consequences on the hydrological cycle.

For millennia, the Earth's climate has varied according to time and place. The changes observed are generally spread over long periods which attenuate the perception that man may have of them at a given moment. In recent decades, however, climate change appears to have accelerated. Under these conditions, it is not surprising that the public wonders about the reality of these changes, their causes, their future and, even more, their immediate and distant consequences on lifestyles, health, ecosystems and the economy. To these questions, Science can attempt to provide authorized answers, even if they are only partial or temporary, as long as they are guided by the concern for objectivity which must preside over any scientific approach [2].

Despite the new investigative tools available today and despite the considerable volume of data accumulated over the past twenty years, it must be emphasized that Science cannot answer everything, that it proceeds in stages and that it cannot provide at any given time only the interpretation of proven facts and forecasts.

I.2. The indicators of climate change

The increase in surface temperature on Earth has been 0.8 ± 0.2°C since 1870. It remains significantly different for the two hemispheres: stronger in the North and stronger at high latitudes. Variability between continents is also observed. Finally, a strong modulation over annual and multidecadal periods is also observed, with two periods of greatest increase (approximately from 1910 to 1940 and from 1975 to 2000) framed by periods of stagnation or decrease. Natural climatic variations (El Niño, volcanic eruptions, North Atlantic Oscillation) are visible there [3].

The temperature of the oceans, measured since the 1950s by merchant ships or oceanographic vessels (down to around 700 m depth) and more recently by the Argo profiling buoy system, shows an overall average increase over the past few decades. The thermal energy content of the ocean has therefore also increased, especially since the early 1980s. This warming is not uniform. It presents a significant regional variability with significant multi-annual, even decadal oscillations [4].

Shrinking Arctic Ocean ice surface. Sea ice, whose melting does contribute to sea level rise, is another strong indicator of accelerating climate change, the sea ice surface experienced a very rapid decrease down to 5.5 million km2 in 2010. The retreat of continental glaciers has been observed almost universally for 3 to 4 decades, with a marked increase over the last 20 years [5].

Global mean sea level (GMSL) is rising (virtually certain). Also, the mean sea level is another indicator that integrates the effects of several components of the climate system (ocean, continental ice, and continental waters). Before 1992, the sea level was measured by tide gauges along the continental coasts and some islands: the level of the oceans, on an annual average over the whole planet, rose at a rate of 0.7 mm/year between 1870 and 1930 and approximately 1.7 mm/year after 1930. Since 1992, measurements have been taken by satellite: the rise in global mean sea level is around 3.4 mm/year. This average elevation is superimposed by multiannual oscillations, linked to the natural variability of the climate system. Since the early 1990s, climatic contributions to this rise are approximately due [6].

Biological indicators, such as the movements of terrestrial or marine animal populations and the evolution of the dates of seasonal agricultural activities, also show the occurrence of global warming. Although difficult to quantify, these elements are important and have consequences in many fields of professional activities where they are widely taken into account [7].

In summary, since the second half of the 19th century, several independent indicators unambiguously show post-Little Ice Age global warming, modulated over time, with an increase from 1975 to 200

I.3. The factors of climate change

It has been observed the evolution of some of the factors likely to have a more or less significant effect on the climate balance.

I.3.1. The increase in atmospheric concentrations of greenhouse gases

Other than water vapor, which recycles rapidly and continuously, is a very important element, which must be observed with precision over several decades to give rise to a reliable interpretation.

a. **Carbon dioxide (CO_2):** its concentration has been increasing continuously since the middle of the 19ecentury, mainly due to industrial activities, dropping from 280 ppm around 1870 to 388 ppm in 2009. The growth rate measured since 1970 is about 500 times higher than that observed on average over the last 5,000 years. Isotopic studies show that the origin of this increase is due for more than half to the combustion of fossil fuels, the rest to massive deforestation and for a small part to the production of cement. [8]

b. **Methane (CH_4):** Methane has important anthropogenic emissions, and is the second largest driver of global radioactive forcing (0.97 ± 0.16 W m−2) after CO21. Understanding the global methane budget and its sources is crucial for climate mitigation efforts. Both process-based (bottom-up) and atmospheric-based (top-down) methods are used to constrain the sources and sinks of methane. However, large uncertainties exist in both approaches, which limits the complete understanding of the global methane budget. [9]

c. **Nitrous oxide (NOT2O):** Nitrous oxide is a greenhouse gas that does around 300 times more climate damage than carbon dioxide. The main point sources of nitrous oxide are fertilizers containing nitrogen, as well as livestock farming, chemical industry processes and incineration processes. Germany’s greenhouse gases have been declining since the 1990s, an evolution which, in the agricultural sector, is largely attributable to reduced livestock herds in the former East Germany and the consequent reduction in the use of livestock manure. To a lesser extent, this evolution is also attributable to set-aside measures and the consequent reduced use of mineral fertilizers, as well as statutory fertilizer management requirement. [10]

I.3.2. The solar radiation

Received at a given geographical site varies in time: between day-night due to the earth rotation and between seasons because of the earth orbit. At a given time it also varies in space, because of the changes in the obliquity of the solar rays with longitude and latitude. Notwithstanding the effects of the clouds and other atmospheric constituents, the solar radiation received at a given location and time depends upon the relative position of the sun and the earth. This is why both sun-earth geometry and time play an important role in the amount of solar radiation received at earth surface. A major part of this textbook is devoted to this matter. The geometry of the earth relative to the sun is described as well as its variation throughout the year. The concept of time is very important in solar radiation. It is detailed here and the notions of mean solar time and true solar time are dealt with. The apparent course of the sun in the sky is described; the solar zenithal, elevation and azimuthal angles are defined. These angles are identical at top of the atmosphere and earth surface; no change is introduced by the atmosphere. Equations are given in this part that can be easily introduced in e.g., a spreadsheet or a computer routine, to compute all quantities and reproduce the figures. Both horizontal and inclined surfaces are dealt with [11].

I.3.3. The cycles of the Sun's activity

Sunspots increase and decrease through an average cycle of 11 years. Dating back to 1749, we have experienced 23 full solar cycles where the number of sunspots have gone from a minimum, to a maximum and back to the next minimum, through approximate 11 year cycles. We are now well into the 24th cycle. This chart from the NASA/Marshall Space Flight Center shows the sunspot number prediction for solar cycle 24. The NASA/Marshall Space Flight Center also shows the monthly averaged sunspot numbers based on the International Sunspot Number of all solar cycles dating back to 1750. (Daily observations of sunspots began in 1749 at the Zurich, Switzerland observatory [12].

I.4. Impact of climate change on the characteristics of extreme rainfall

Changes in extreme meteorological and climatic phenomena have significant impacts on the evolution of society which it must face [13]. Extreme precipitation events have become more frequent in many parts of the world. They are one of the meteorological hazards that can cause several damages in terms of loss of human life and material damage, as well as the activation of the landslide causing the loss of crops and livestock. The greenhouse effect is expected to cause a large increase in the water vapor content of the atmosphere and changes in the hydrological cycle, which include an intensification of extreme precipitation and also the effect of natural climatic variability, resulting in particular low-frequency components of climate variability such as ENSO (El Niño Southern Oscillation) and decadal and multidecadal oscillations such as PDO (Pacific Decadal Oscillation) and AMO (Atlantic Multidecadal Oscillation). These large-scale forcings exert in-phase and out-of-phase oscillations in the amplitude of hydrological events such as extreme precipitation events. The IPCC (2014) pointed out that the number of heavy rainfall events has increased in a number of regions since 1950 [14]. Found that globally, maximum daily rainfall annual sightings have increased by an average of 5.73 mm over the past 110 years [15]. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the increase in global surface temperature has reached 0.85°C (0.65°C -1 0.06°C) from 1880 to 2012, and the last three years are the warmest of all the last ten years since 1850.

Due to global warming, climate models and satellite observations indicate that the water vapor content of the atmosphere has increased at a warming rate of about 7% [16]; [17]; [19], as predicted by the Clausius-Clapeyron equation under stable relative humidity. The increasing availability of moisture in the atmosphere can lead to an increase in the intensity of extreme precipitation events [18]; [20],

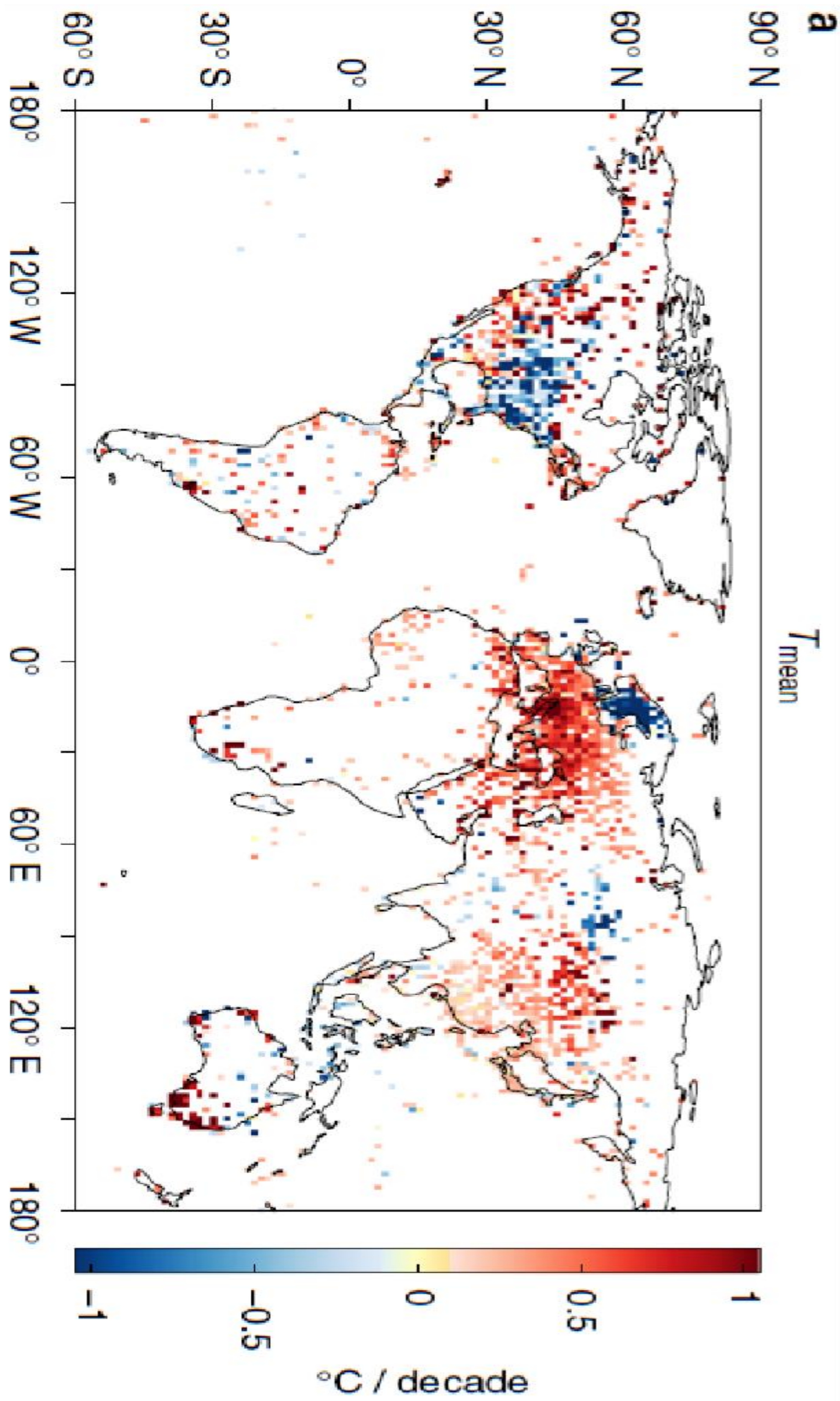
According to the IPCC report extreme events will become more frequent, and more intense during the 21st century. Such as floods, droughts and heat waves (heat waves) [21]. Extreme precipitation events occur on time scales of minutes, days to weeks and among them short-lived (less than a day), these are events, which are primarily responsible for the occurrence of flash floods, is more difficult to predict in advance [22]. The impacts of climate change are visible in all aspects of the world in which we live. It can alter land surface forcing, including precipitation, temperature, and other climate variables, and can also lead to changes in runoff. Many studies have been conducted and indicate that rainfall characteristics and watershed characteristics are the two major factors affecting runoff generation and soil erosion. The impacts of watershed characteristics, typically including topography, shape, slope, drainage pattern, and spatial variability of soil properties, have been widely studied and are still being researched. [23]

Among recent studies on the impact of extreme rainfall, found that there are positive trends in extreme precipitation and runoff in several regions of the world from 1980. This intensification of extreme precipitation is linked with the increase in temperatures **(Figure I.1)**. An increase in the frequency and intensity of extreme precipitation at the global level has already been identified in observations [24]; [25]; [26]; as well as identified by simulation of climate models [27]. Compare the two, they found results show that observations and climate models generally show increasing trends in extreme precipitation since 1901[15]. other reported in their studies of the risks induced by the increase in extreme precipitation under climate change, that the high frequency cells in the historical period or the precipitation above thresholds (50 mm) are distributed mainly in North America, south of South America, South Asia and East Asia and they meant that many dry regions can experience more extreme precipitation in both RCP 2.6 and RCP 8.5 scenarios most wet regions can experience more extreme precipitation only in the RCP8.5 scenario[28]. This result is consistent with the studies of, who also indicated that the infrastructure of some arid regions where extreme high-intensity rainfall occurs rarely is less able to adapt to more extreme rainfall. They also found that most "dry, arid" grid cells are located in central and northeast Asia, central Australia, northwestern North America and northern Africa. And the southwest. Flash floods attributed to these extreme rainfall events are among the most costly and dangerous natural hazards in the world [29]. These flash floods have caused a huge number of deaths and agricultural property and losses worldwide, increasing over the past half century and exceeding $30 billion per year over the past decade.

Floods are the costliest and deadliest weather-related natural disasters in the United States, with nearly 9,000 confirmed deaths in the 20th century and more than $2 billion in annual property damage. In fact, nearly 90% of natural disasters in the United States involve floods. Some examples include 3-day accumulated precipitation due to Hurricane Harvey (26-28 2017) [30]; over Houston (Texas) was about 800 mm, and the 500 mm of precipitation is equivalent to a return period of 2000 years for the same location [31]. The extreme precipitation magnitude of the Louisiana storm (August 2016) has been recognized as the 1000-year event that resulted in three times the precipitation of Hurricane Katrina [32]. This extreme rainfall in Louisiana resulted in flash flooding, river flooding, and backwater flooding over a period of time and this event is believed to have resulted in at least 13 deaths according to the USGCRP report, 2017, New England and the northeastern United States experienced the strongest precipitation events, thus historical floods increase by 55% (1958 to 2016) [33]. Show that extreme rainfall events are impacted by ENSO in a number of regions of the United States, also showed that meteorological and hydrological extremes, such as floods and droughts, are spatially correlated and are strongly influenced by the topographic properties of watersheds. [34]

A study have found that the intensity and frequency of occurrence of extreme rainfall events increased for dry and wet regions of China during (1961-2014) and faster trends are observed in regions droughts[35], others found that large-scale climate indices are more correlated with the recurrence of extreme precipitation and its intensity. In particular, the 1-year-ahead DMI plays an important role in the frequency of extreme rainfall with a significantly positive correlation in most parts of China, except southern China. Gupta and al.,2020 found that the Southern Oscillation Index (SOI) and Northern Oscillation Index (NOI) had similar spatial patterns of correlation with the extreme precipitation indices analyzed, In addition, most of these indices showed a positive and statistically significant correlation of large amplitude with land surface elevation for the elevation band above 1500 m. also reported a negative relationship between surface air temperatures (SAT) and extreme rainfall over India, which is mainly due to localized cooling of air temperature due to rainfall from the monsoon. Due to the negative C-C relationship between precipitation and SAT over the tropics [36], in other study they found that the dew point temperature (DPT), in the tropics, is a better prediction of extreme precipitation. Than the air temperature. [37]

Several studies have documented increasing trends in extreme rainfall events in different parts of Africa and attributed these trends to climate change. On the other hand, flooding occurs when total precipitation exceeds evapotranspiration, surface runoff, and water infiltration into the ground, creating excess water flooding the surface of the earth. This phenomenon considers as one of the most common climatic disaster in Kenya and the main hydro-meteorological disaster in East Africa [38]. Most floods in Kenya occur immediately after droughts, causing effects devastating events, loss of life (Houghton, 1977). [39]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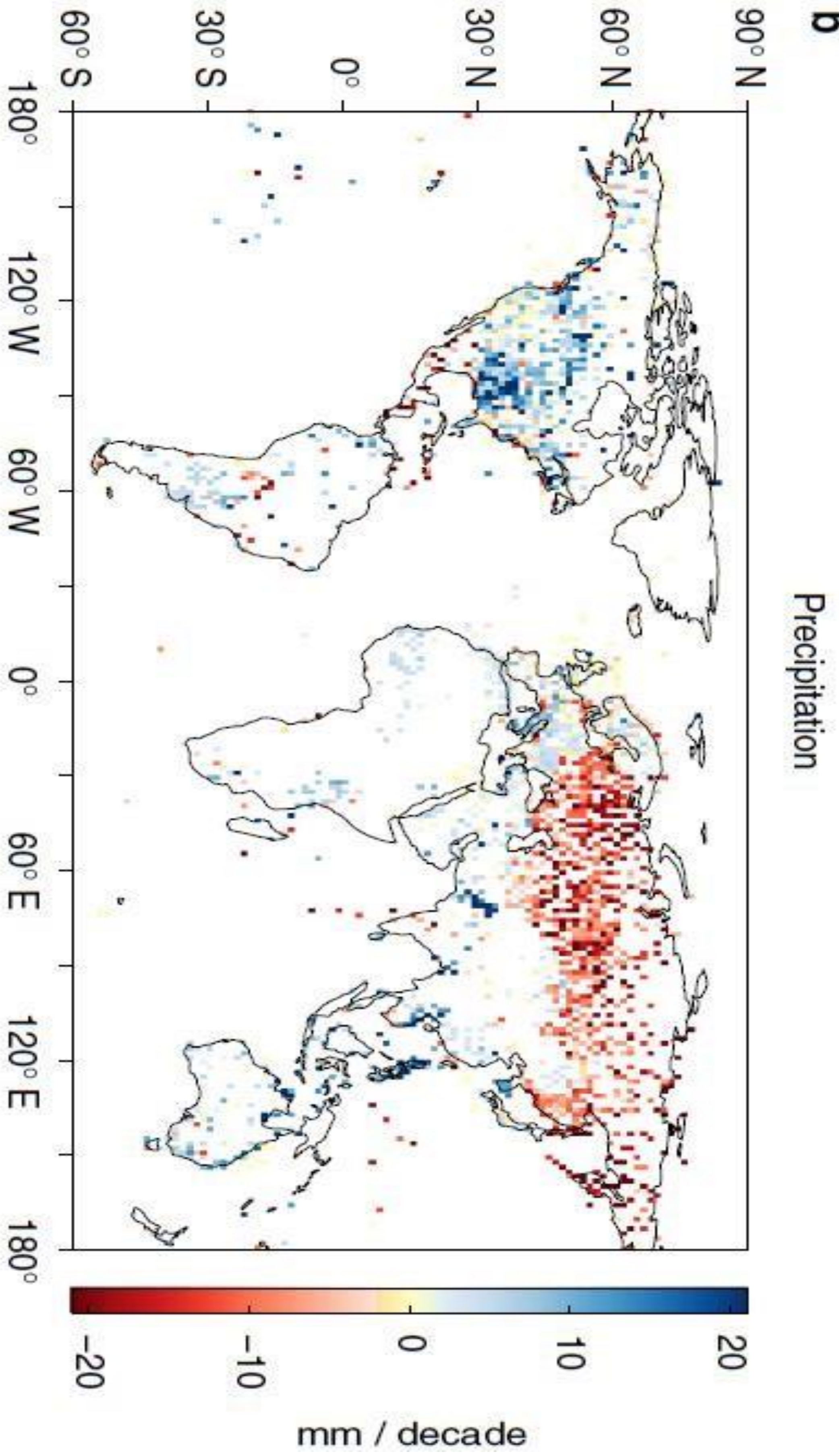
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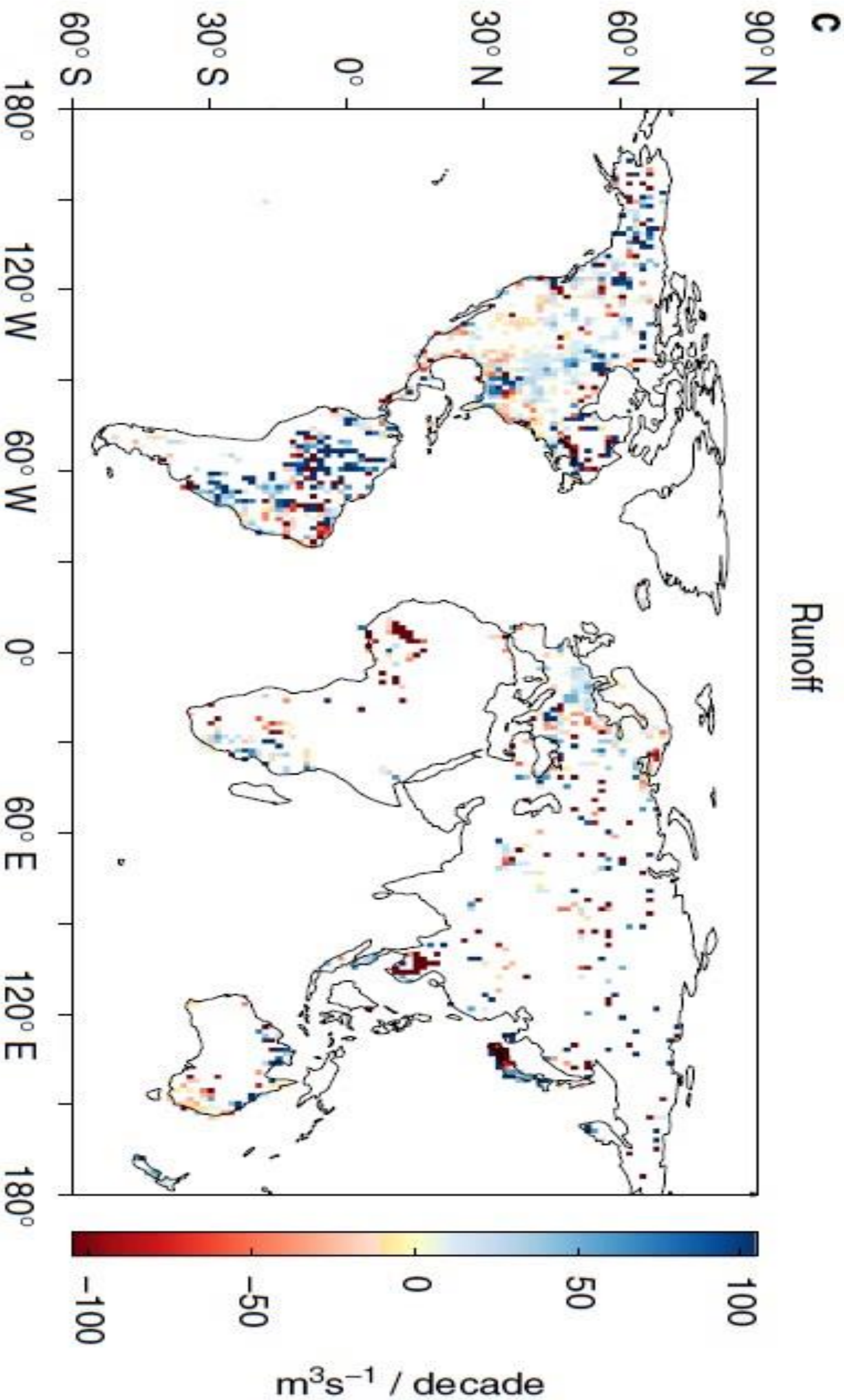


Figure I.1: Global trend results for annual 99th percentile daily extremes during 1929–2017. A–c Trend of T mean [°C] (a), Precipitation [mm] (b) and runoff [m^3S^{-1}] (c), respectively. White indicates grids with insufficient data or that the trend is insignificant at a 0.05 level. [40]

I.5. Extreme rainfall in the Mediterranean basin and North Africa

Projections under increased greenhouse gas forcing show dramatic changes in the mean, variability and extremes of temperature and precipitation over the 21st century, making North Africa one of important climate change hotspots (Deffenbaugh and Giorgio 2012). [41]

Rising temperatures associated with climate change are expected to reduce the amount of land suitable for agriculture, shorten the length of growing seasons and reduce crop yields. The decrease in annual rainfall that is projected for North Africa, especially in semi-arid and arid regions that depend on irrigation for crop growth. While extreme events associated with climate change, such as floods and droughts, are likely to set back economic development by years, approaches to climate change adaptation are generally not aligned with development issues. [41]

I.6. Climate change in Algeria

Algeria is actively involved in international initiatives and agreements aimed at addressing climate change and mitigating its effects. This includes efforts to reduce greenhouse gas emissions and promote renewable energy sources, which can contribute to combating desertification and preserving the country's natural resources. [42]

Overall, while Algeria's arid and semi-arid climate presents challenges, the country is taking steps to adapt to these conditions and promote sustainable development in the face of water scarcity and desertification.

The arid and semi-arid climate of Algeria also influences the flora and fauna found in the country. In the desert regions, plant life mainly consists of drought-resistant species such as cacti, succulents, and desert shrubs. The Sahara Desert, in particular, is known for its vast stretches of sand dunes and sparse vegetation. [43]

By implementing comprehensive strategies and collaborating with international partners, Algeria aims to overcome the challenges posed by its arid and semi-arid climate while safeguarding its natural heritage for future generations.

I.7. Conclusion

Through this chapter, a bibliographical synthesis was presented on climate change in the world. The Mediterranean basin is an area vulnerable to climate change and the semi-arid regions of the Mediterranean basin including northern Algeria have experienced several extreme events during the last century and during the beginning of the 21st century, of which they are considered the most affected. By flood events. Many works have been carried out for the analysis of the rainfall and hydrological variation in Algeria. The analysis of previous work shows the importance of investigating the possible variation in the characteristics of extreme elements and their impacts in the future on water resources and the safety of human lives and property. Other aspects of the effects of global warming on coastal areas of Algeria include high sea levels and harmful waves (stronger and more frequent storms in 1980, 1989, 1995 and 2001), causing erosion and even disappearance of beaches: e.g. the beaches west of Algiers, Bejaia Beach, Boumerdes and Oran. Such phenomena result in loss of beaches (e.g. West Beach in Sidi Fredj west of Algiers), and consequently a loss of eco-tourism and economic interest, saline intrusion (soil and groundwater salinisation) and flooding of low-lying coastal areas.

Chapter II: Presentation of the study area

Chapter II: Presentation of the study area

II.1. Introduction

The target study area concerns the southern and central parts of Algeria and, more specifically, the four hydrographic areas (Ghardaia, Laghouat, Biskra and Ouargla), and a presentation of their geographical, climatic and hydrographic characteristics is given in this chapter. We will also present the rainfall data used in carrying out our work.

II.2. Presentation of the study area

II.2.1. Geographic location

Ghardaia is a city located in the northern-central part of Algeria, specifically in the M'zab Valley. It lies in the Saharan Atlas Mountains, which are part of the larger Atlas Mountain range. The city is situated approximately 600 kilometers (370 miles) south of the capital city, Algiers. [44]

Ouargla is a city located in southeastern Algeria. It is situated in the Sahara Desert, specifically in the Saharan Atlas Mountains. The city lies approximately 800 kilometers (500 miles) south of the capital city, Algiers. Geographically, Ouargla is located on a vast plain within the Sahara Desert. The city is situated on the northern edge of the Great Western Erg, which is a massive expanse of sand dunes extending across the Algerian desert. The terrain around Ouargla is characterized by arid landscapes, sandy soils, and limited vegetation [45]

Biskra is a city located in northeastern Algeria. It is situated in the northern part of the Sahara Desert, specifically in the region known as the Saharan Atlas Mountains. Biskra lies approximately 330 kilometers (205 miles) southeast of the capital city, Algiers. Geographically, Biskra is situated in a vast desert plain surrounded by sand dunes and rocky terrain. It is located near the northern edge of the Grand Erg Oriental, which is one of the largest sand dune seas in the Sahara Desert. The city is known for its proximity to the Zibans, a chain of oasis towns that provide fertile land for agriculture. [46]

Laghouat is a city located in central Algeria. It is situated in the northern part of the Sahara Desert, specifically in the Saharan Atlas Mountains. Laghouat lies approximately 400 kilometers (250 miles) south of the capital city, Algiers .Geographically, Laghouat is positioned on a plateau surrounded by desert landscapes. The city is nestled within a rocky terrain, with the Sahara Desert stretching to the south. Laghouat is known for its proximity to the Amour Range, which is a mountainous region that forms part of the Saharan Atlas Mountains [47]

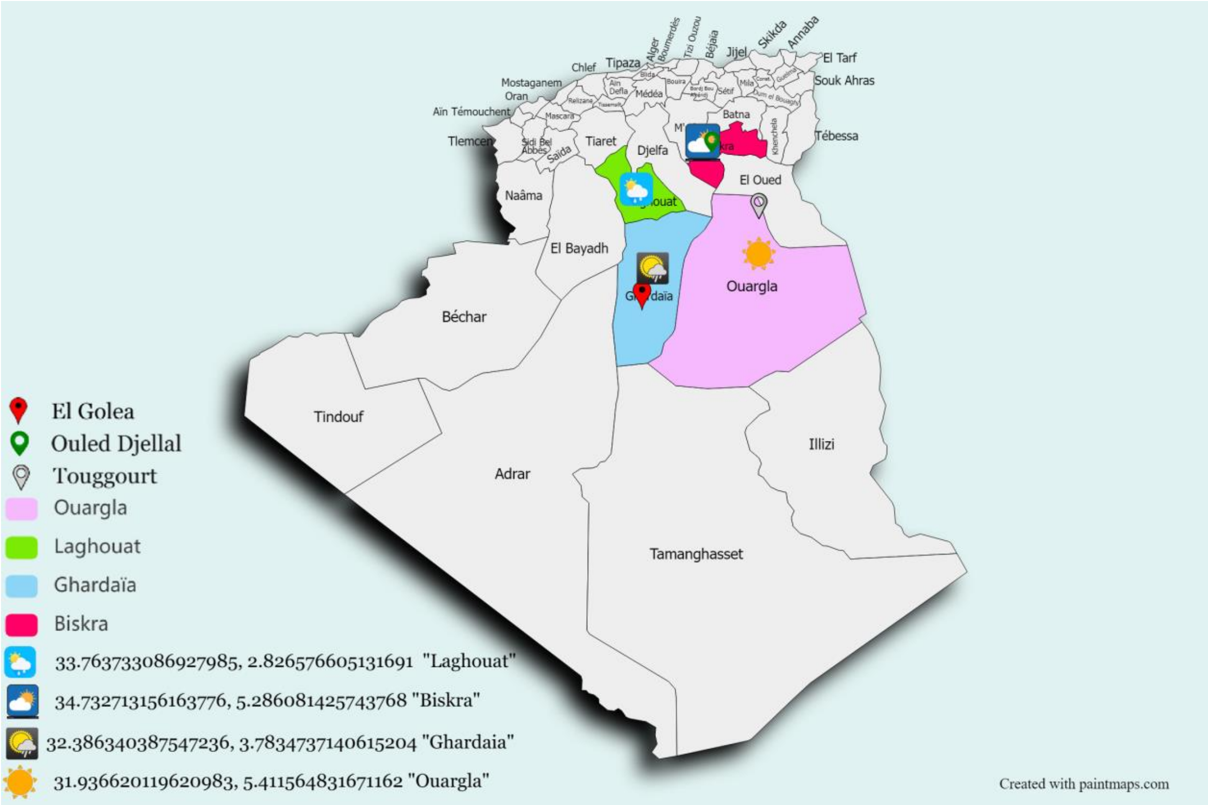


Figure II.1: Geographic location of the study area [48]

II.3. Climate of the target areas

II.3.1.Temperature

In Ghardaia, temperatures can reach extreme levels due to its desert climate. Summers are characterized by scorching heat, with average temperatures ranging from 40 to 46 degrees Celsius it is not uncommon for temperatures to exceed 45 degrees Celsius during the hottest months. Also winters in Ghardaia are relatively mild compared to the intense summer heat. Average temperatures during the winter months range from 12 to 18 degrees Celsius while the days can still be warm, the nights can bring cooler temperatures. Also, the transitional seasons of spring and autumn offer more moderate temperatures in Ghardaia. During spring, temperatures range from 20 to 30 degrees Celsius, while autumn temperatures range from 25 to 35 degrees Celsius. [49]

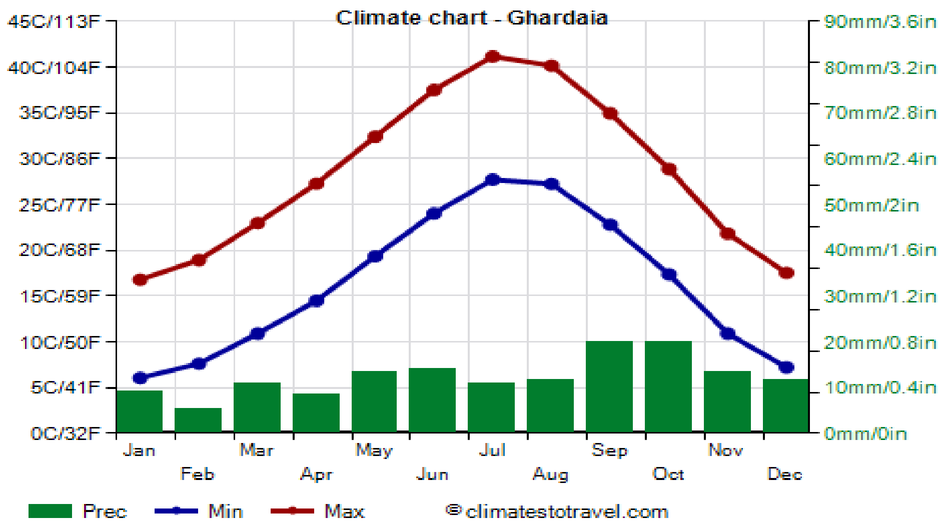


Figure II.2: Precipitation and temperatures in Ghardaia [49]

In Ouargla, temperatures can be extremely high due to its desert climate. Summers are characterized by scorching heat, with average temperatures ranging from 40 to 46 degrees Celsius. It is not uncommon for temperatures to exceed 50 degrees Celsius during the hottest months. Also winters in Ouargla are relatively mild compared to the intense summer heat. Average temperatures during the winter months range from 10 to 16 degrees Celsius. While the days can still be warm, the nights can bring cooler temperatures. Also the transitional seasons of spring and autumn offer more moderate temperatures in Ouargla. During spring, temperatures range from 25 to 35 degrees Celsius while autumn temperatures range from 30 to 40 degrees Celsius.

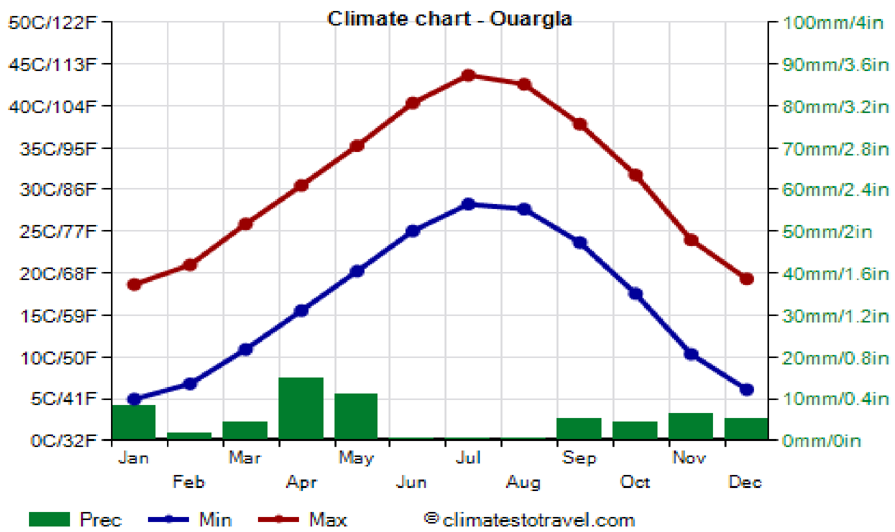


Figure II.3: Precipitation and temperatures in Ouargla [50]

In Biskra, temperatures can be extremely high due to its desert climate. Summers are characterized by scorching heat, with average temperatures ranging from 40 to 45 degrees Celsius It is not uncommon for temperatures to exceed 50 degrees Celsius during the hottest months. Also winters in Biskra are relatively mild compared to the intense summer heat. Average temperatures during the winter months range from 10 to 17 degrees Celsius while the days can still be warm, the nights can bring cooler temperatures. Also the transitional seasons of spring and autumn offer more moderate temperatures in Biskra. During spring, temperatures range from 25 to 35 degrees Celsius, while autumn temperatures range from 30 to 40 degrees Celsius

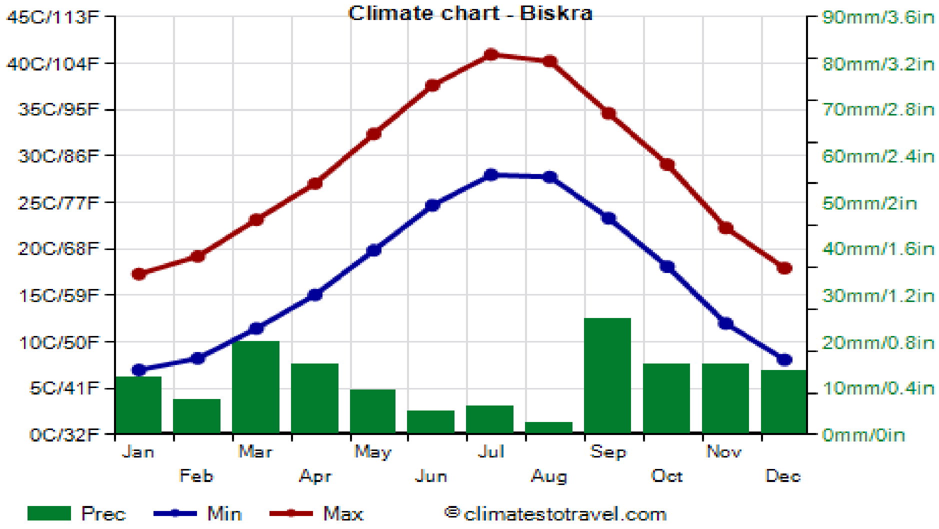


Figure II.4: Precipitation and temperatures in Biskra [51]

Laghouat experiences a hot desert climate with influences from the Saharan Atlas Mountains. Summers are hot, with average temperatures ranging from 35 to 40 degrees Celsius Winters are relatively mild, with average temperatures ranging from 9 to 16 degrees Celsius .Laghouat receives limited rainfall, averaging around 150 to 250 millimeters (6 to 10 inches) per year.

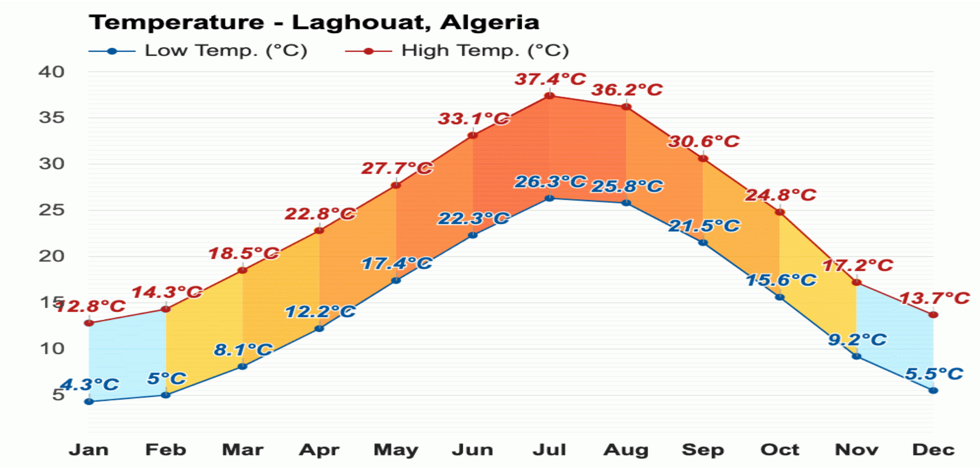


Figure II.5: Average temperature in Laghouat [52]

Table. II.1: Summary of climatic information for Ghardaia, Ouargla, Biskra, and Laghouat

City	Climate	Summer Temperature Range (°C)	Winter Temperature Range (°C)	Average Annual Rainfall (mm)
Ghardaia	Hot Desert	40-46°C	14-19°C	50-100 mm
Ouargla	Hot Desert	40-46°C	10-16°C	30-50 mm
Biskra	Hot Desert	40-45°C	10-17°C	100-200 mm
Laghouat	Hot Desert	35-40°C	9-16°C	150-250 mm

It's important to note that these climate characteristics are general averages, and temperatures and rainfall can vary from year to year. The arid conditions and limited rainfall in these regions contribute to the predominance of desert landscapes and the reliance on water sources such as underground wells and oasis agriculture.

II.3.2. Precipitation

The study of precipitation variability is very important for all hydrological studies, and has great bearing on the study of climate change.

On average, Ghardaia receives about 100 to 150 mm of precipitation per year. The majority of precipitation occurs during the winter months, particularly from November to March. During this period, Ghardaia may experience occasional showers and thunderstorms, which contribute to the annual precipitation. It is important to note that the amount of precipitation can vary from year to year and is affected by factors such as weather patterns and seasonal changes. Ghardaïa's desert climate is characterized by hot, dry summers, with temperatures exceeding 40°C, and mild winters. Water scarcity is also a major concern in the region due to the low rainfall and high evaporation rates. Local communities have developed various strategies to deal with water scarcity, including traditional water management systems and modern technologies such as desalination and water conservation. In general, while Ghardaia receives some rainfall, it is relatively low due to its location in the Sahara desert. The region's climate is primarily characterized by arid conditions, with hot, dry summers and mild winters. [53]

The limited precipitation in Ghardaïa is a characteristic feature of its desert climate. The city experiences an average of only 10 to 20 rainy days a year. Precipitation is often sporadic and erratic, with some years being drier than others. When it does rain in Ghardaia, it is usually in the form of short but intense showers or thunderstorms. These precipitation events are crucial to the local ecosystem and agriculture, as they provide some relief from arid conditions and support plant growth. The vegetation in the area consists mainly of drought-tolerant plants, such as cacti and acacia trees, which have adapted to survive the desert environment. These plants have specialized mechanisms to conserve water and tolerate prolonged periods of drought. [53]

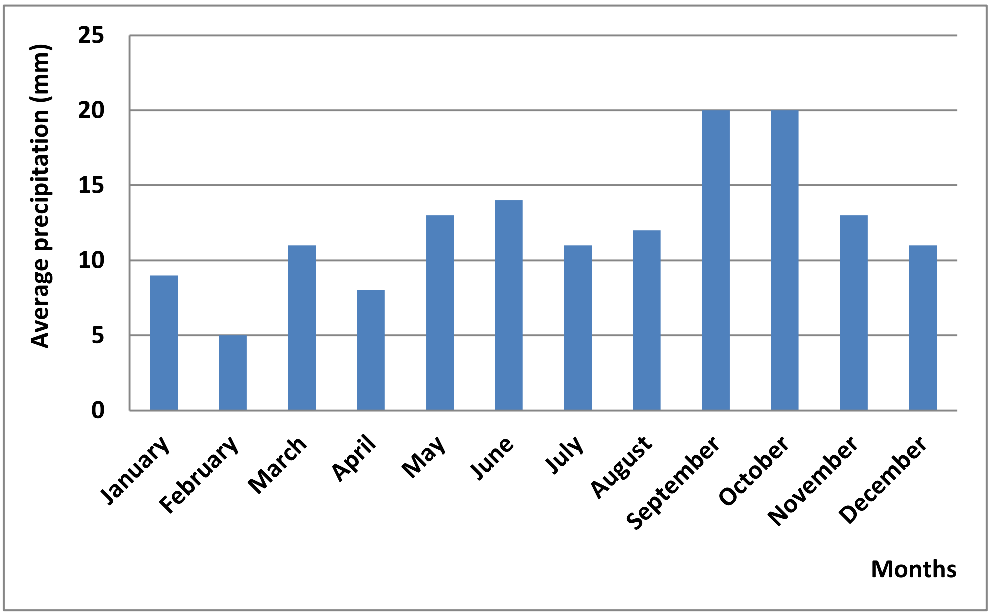


Figure II.6: Average Precipitation [mm] (1991-2020) – Ghardaia. [54]

On average, Ouargla receives around 50 to 100 millimeters of rainfall annually. The majority of the precipitation occurs during the winter months, particularly from November to March. However, it is important to note that the amount of rainfall can vary from year to year, and there may be significant variations in the distribution and intensity of rainfall events.

The rainfall in Ouargla is often characterized by short but intense showers or thunderstorms. These rain events are important for the local ecosystem, as they provide some relief from the arid conditions and support plant growth in the region. Also the desert climate of Ouargla is characterized by hot and dry summers, with temperatures often exceeding 40 degrees Celsius, and mild winters. Water scarcity is a significant concern in the area due to the limited rainfall and high evaporation rates. [55]

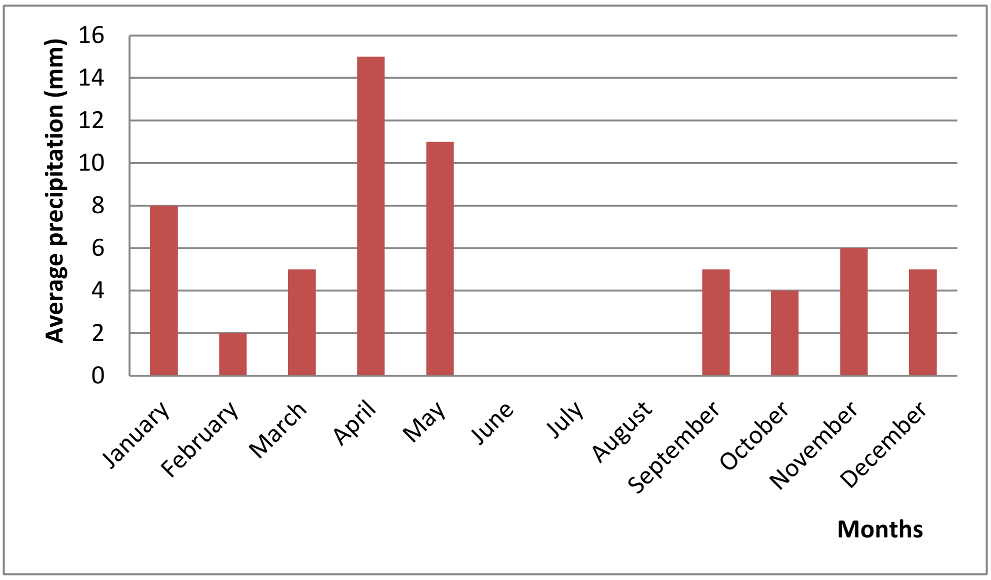


Figure II.7: Average Precipitation [mm] (1991-2020) – Ouargla [55]

On average, Biskra receives around 100 to 150 millimeters of rainfall annually. The majority of the precipitation occurs during the winter months, particularly from November to March. However, it's important to note that the amount of rainfall can vary from year to year, and there may be significant variations in the distribution and intensity of rainfall events. The rainfall in Biskra is often characterized by short but intense showers or thunderstorms. These rain events are important for the local ecosystem, as they provide some relief from the arid conditions and support plant growth in the region. Also, the desert climate of Biskra is characterized by hot and dry summers, with temperatures often exceeding 40 degrees Celsius, and mild winters. Water scarcity is a significant concern in the area due to the limited rainfall and high evaporation rates. [56]

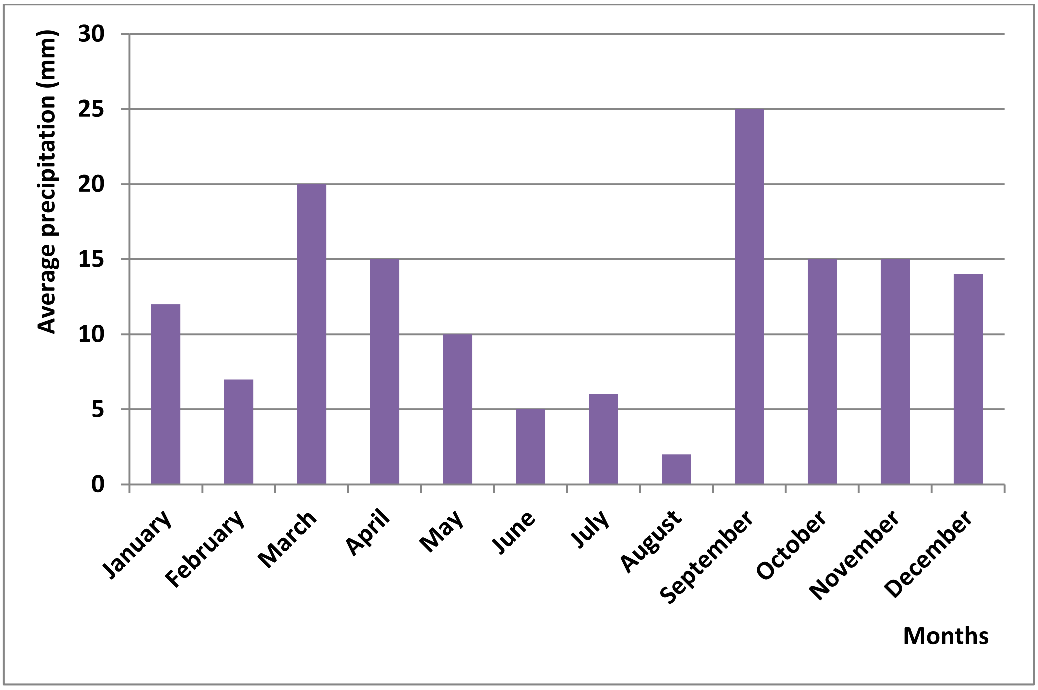


Figure II.8: Average Precipitation [mm] (1991-2020) – Biskra [56]

On average, Laghouat receives around 100 to 150 millimeters of rainfall annually. The majority of the precipitation occurs during the winter months, particularly from November to March. However, it's important to note that the amount of rainfall can vary from year to year, and there may be significant variations in the distribution and intensity of rainfall events.

The rainfall in Laghouat is often characterized by short but intense showers or thunderstorms. These rain events are important for the local ecosystem, as they provide some relief from the arid conditions and support plant growth in the region. Also the desert climate of Laghouat is characterized by hot and dry summers, with temperatures often exceeding 40 degrees Celsius, and mild winters. Water scarcity is a significant concern in the area due to the limited rainfall and high evaporation rates. [57]

II.4. Database

For our work, we have 4 rainfall stations. The stations are collected at the level of the National Agency for Hydraulic Resources (ANRH) and the National Meteorological Office (ONM). The choice of stations is based on the criteria of data quality and length of the rainfall series. Times vary from station to station. The (**Table. II.2**) represents the geographical characteristics and the data available from the rainfall stations in the study areas.

Table. II.2: Geographical characteristics and data available of the rainfall stations in the study area.

No	Station code	Name	Coordinates (decimal)		Elevation	Period
			X	Y	(m)	
1	605660	Ghardaïa	3.81	32.4	460	1975-2016
2	130402	Ouargla	5.27	31.55	154	1975-2009
3	060302	Laghouat (El Houita)	2.86	33.8	769	1969-2004
4	061416	Biskra	5.74	34.86	177	1973-2009

Table. II.3: Distribution of interannual rainfall

No	Station code	Name	Period	Interannuel rain (mm)
1	605660	Ghardaïa	1975-2016	75.19
2	130402	Ouargla	1975-2009	43.44
3	060302	Laghouat (El Houita)	1969-2004	117.26
4	061416	Biskra	1973-2009	128.2

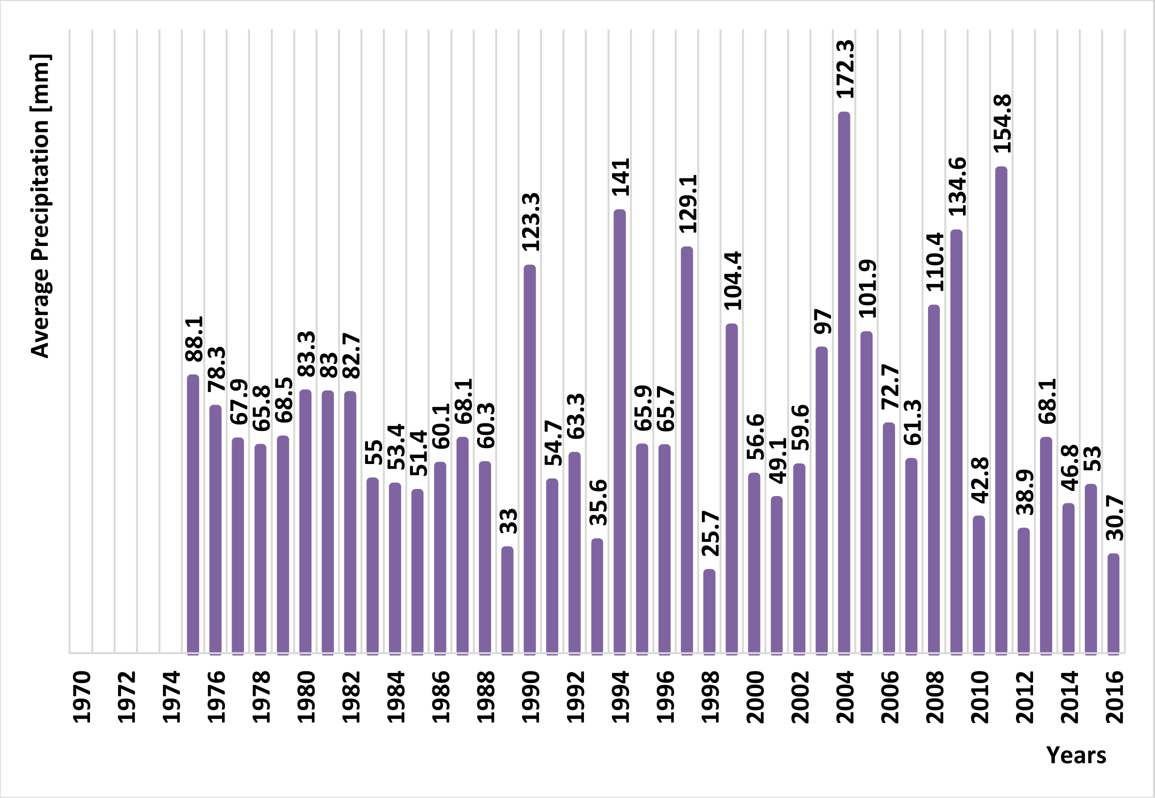


Figure II.9: Average annual Precipitation [mm] (1975-2016) – Ghardaia.

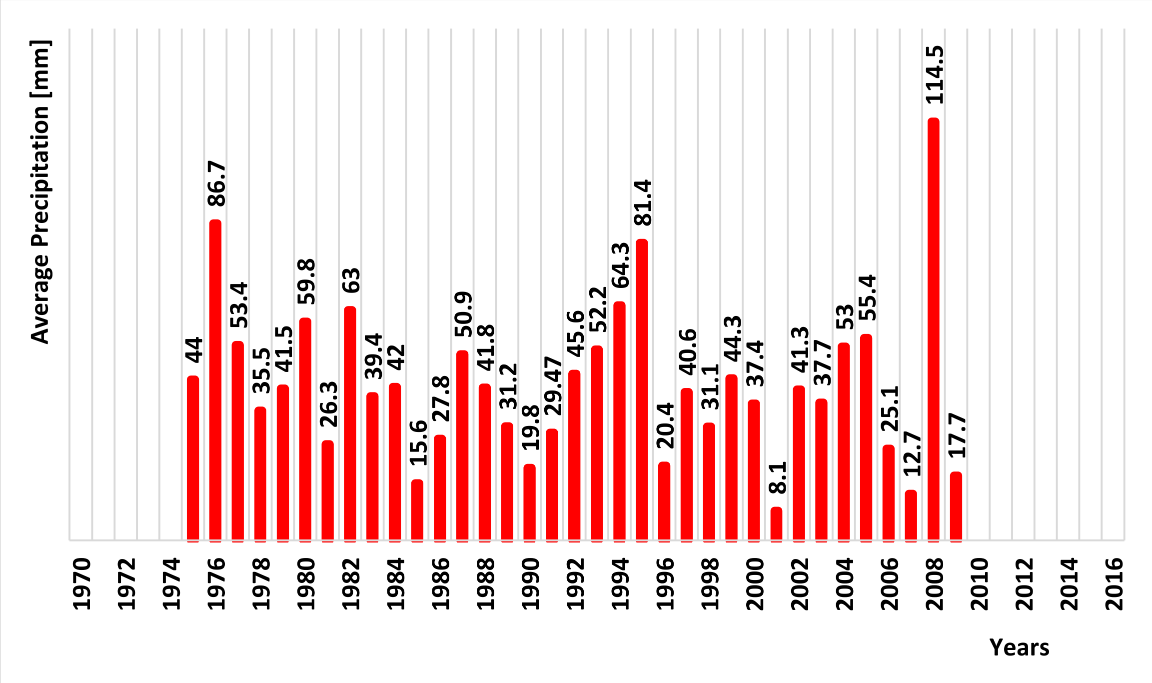


Figure II.10: Average annual precipitation (1975-2009) – Ouargla

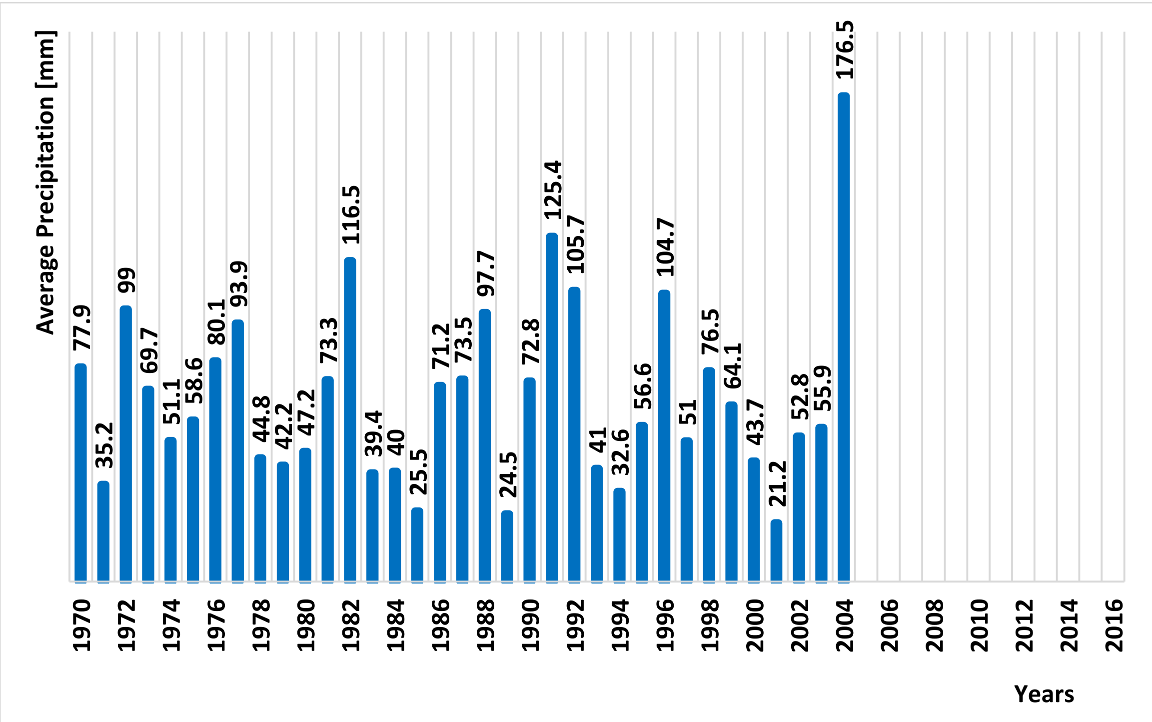


Figure II.11: Average annual Precipitation [mm] (1969-2004) - Laghouat

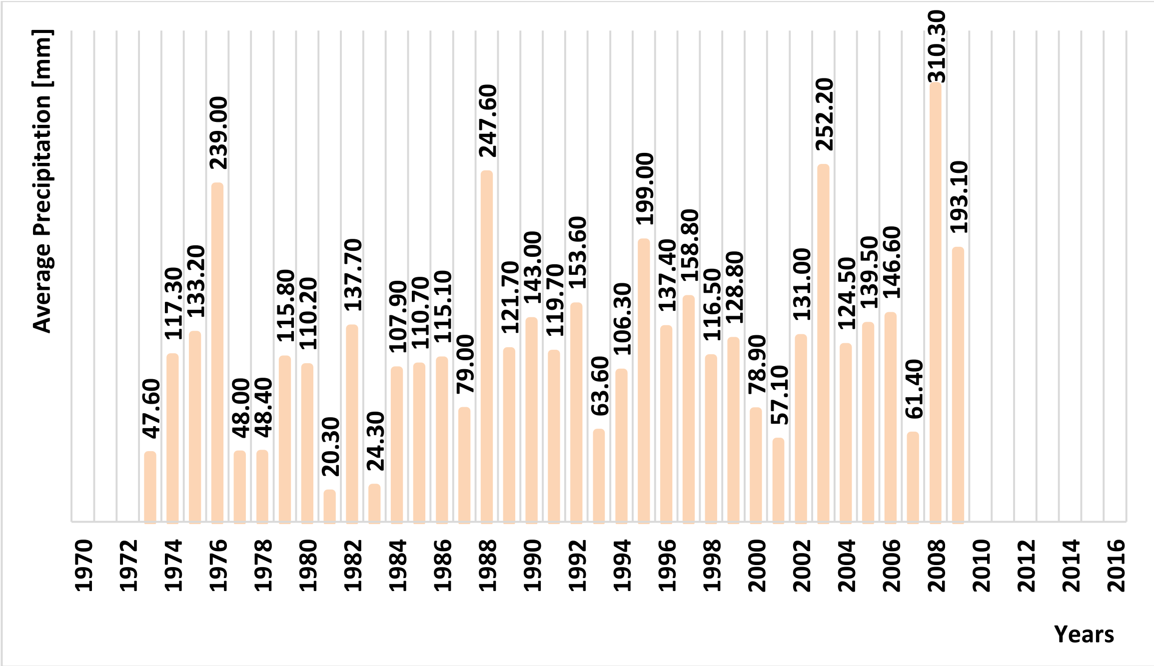


Figure II.12: Average annual Precipitation [mm] (1973-2009) – Biskra

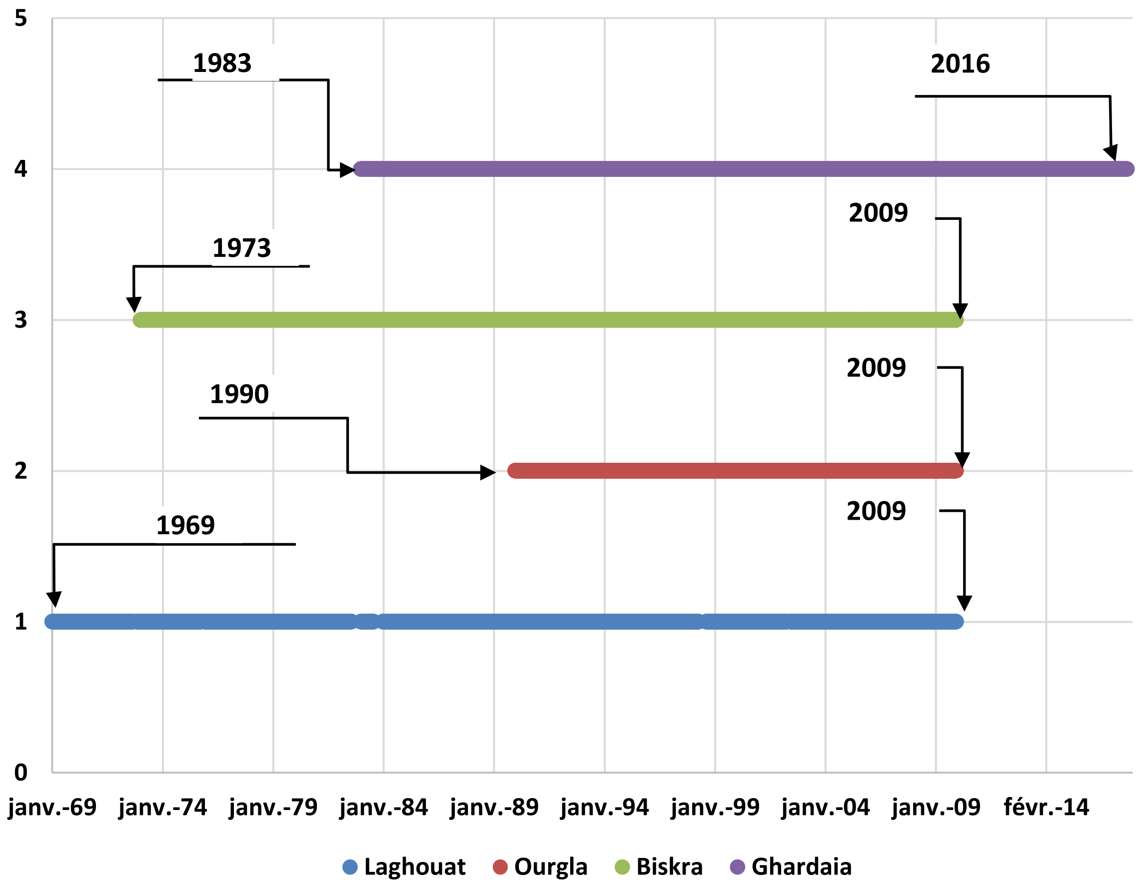


Figure II.13: Daily precipitation availability at Laghouat; Ouargla; Biskra and Ghardaia

II.5. Conclusion

The stations used are located in four regions of Algeria (Lagouat, Ouargla, Biskra and Ghardaia). Data were collected from the National Agency of Hydraulic Resources (ANRH) and the Organization of National Meteorology (ONM). We also encountered some difficulties regarding some missing data in this study. The selected climatic network includes 4 precipitation stations distributed over the entire study area. These cities experience high temperatures, particularly in the summer months, because of their proximity to the Sahara Desert and their arid climate. They have arid climates characterized by limited rainfall, with the majority of precipitation occurring during the winter season. The summer months are generally dry. These dry conditions contribute to the desert landscapes and arid environments that are prevalent in these areas

Chapter III: Materials and methods

Chapter III: Materials and methods

III.1. Introduction

In the analysis of extreme climatic events, the detection of trends in rainfall is an important aspect for understanding climate change and its effects. Expert teams utilize various trend detection methods to study and assess these extreme events. The following describes in detail the methods commonly used for rainfall analysis.

In this chapter, we will discuss two commonly used methods The **ITA** method focused on changes in extreme climate events, and **change point** analysis helped identify significant shifts or breakpoints in climate data**.** These techniques is valuable for understanding rainfall patterns and their spatial distribution. We talk about the software programs used to implement these methods and extract analytical results.

The flowchart of this study is showed in the (Figure III.1).

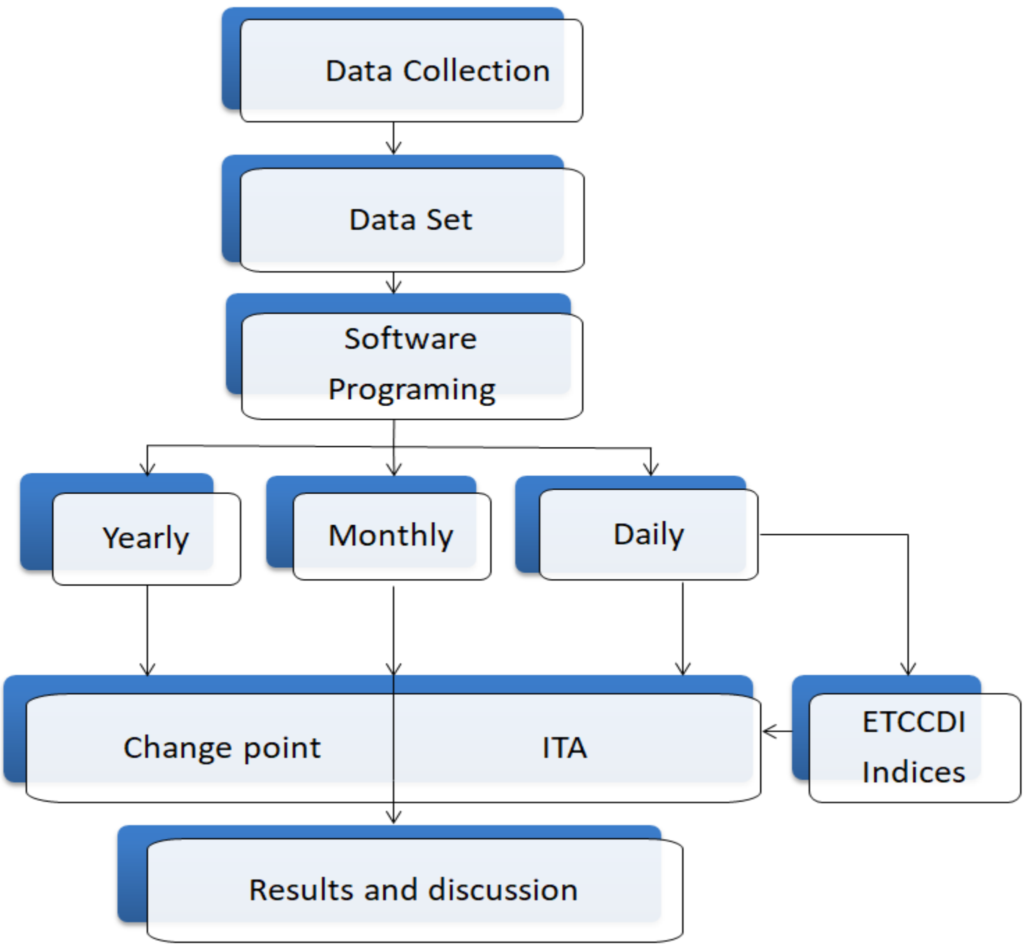


Figure III.1: Flowchart of the methodology followed for the detection of trends

III.2. Used software's

In meteorology, several software programs are used to determine the direction of rainfall. These software tools assist in the analysis and interpretation of meteorological data. Here are some commonly used software programs in meteorology:

III.2.1. EXCEL

Excel provides a set of features for formatting, organizing, and calculating data within a spreadsheet. The primary function of Excel is to provide users with a grid of cells organized into rows and columns. Users can enter data into these cells, perform calculations using built-in functions, or create custom formulas. The software allows data manipulation, sorting, filtering, and conditional formatting to improve data analysis and visualization. [59]

III.2.2. R software

R is a programming language and software environment commonly used for statistical computing, data analysis, and graphical visualization. It provides a wide range of tools, packages, and functions that support various statistical and data analysis tasks. R is known for its flexibility, extensibility, and open-source nature, making it popular among statisticians, researchers, and data scientists. It offers powerful capabilities for data manipulation and analysis, including support for different data structures such as vectors, matrices, data frames, and lists. [59]

R excels in statistical modeling and analysis, offering a comprehensive suite of functions for basic statistical measures, hypothesis testing, regression analysis, time series analysis, survival analysis, and multivariate analysis. Its graphics capabilities are also noteworthy, providing functions and packages for generating high-quality static and interactive plots, charts, maps, and graphs. These visualizations can be customized and annotated to effectively communicate data insights and patterns. Furthermore, R has an extensive ecosystem of packages contributed by the community, extending its functionality in various domains such as machine learning, data mining, geospatial analysis, and more. [60]

R promotes reproducible research practices by supporting the creation of scripts and documents that combine code, data, and text. Formats like R Markdown and Jupyter Notebooks facilitate transparent and reproducible analyses, enabling researchers to easily share and reproduce their findings. R also supports integration and interoperability with other programming languages, databases, and tools. It can interface with various data formats, including CSV, Excel, SQL databases, and web APIs. Its interoperability with popular tools like Python and MATLAB allows users to leverage the strengths of different environments.[59]

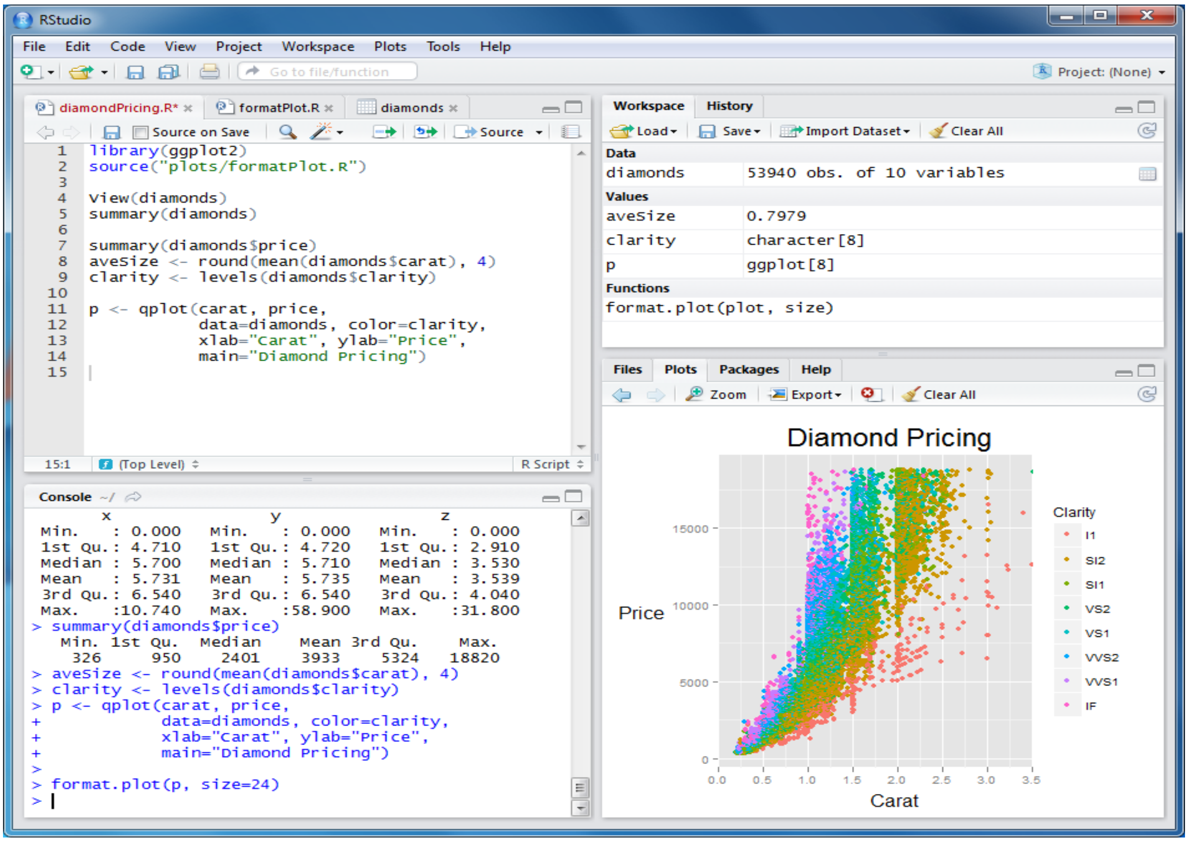


Figure III.2: R-studio interface [61]

In summary, R is a powerful and versatile software environment for statistical computing and data analysis. Its extensive functionality, active community support, and open-source nature make it a preferred choice for researchers and analysts working on a wide range of data-driven projects. [60]

III.2.3. R Climdex (Climdex package)

ClimDex is a software package designed for the calculation of climate extremes indices, used to monitor and detect climate change. Originally developed as an Excel-based program by Byron Gleason at the National Climate Data Centre (NCDC) of NOAA, it was later ported to R to ensure compatibility across different operating systems. The decision to use R was based on its robustness, power, and widespread use for statistical analysis and graphics. The transition to R was driven by the need to address inhomogeneity issues in the indices series, which required implementing a bootstrap procedure that was challenging to achieve in an Excel environment. The resulting R-based package, RClimDex, offers a user-friendly interface and computes various climate indices, including the core indices recommended by the CCl/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). [61]

RClimDex, developed under R 1.84 or later versions, provides a comprehensive set of capabilities for computing climate indices of extremes. It includes all 27 core indices calculated by ClimDex, as well as additional temperature and precipitation indices with user-defined thresholds. The package is primarily intended for climate change monitoring and detection studies. While data homogenization is planned for future releases, the current version of RClimDex incorporates a simple data quality control procedure similar to that used in ClimDex. This procedure ensures that data are appropriately quality controlled before computing the indices. The users' manual accompanying RClimDex offers step-by-step instructions on installing R, setting up the user environment, performing data quality control, and calculating the 27 core indices. [61]

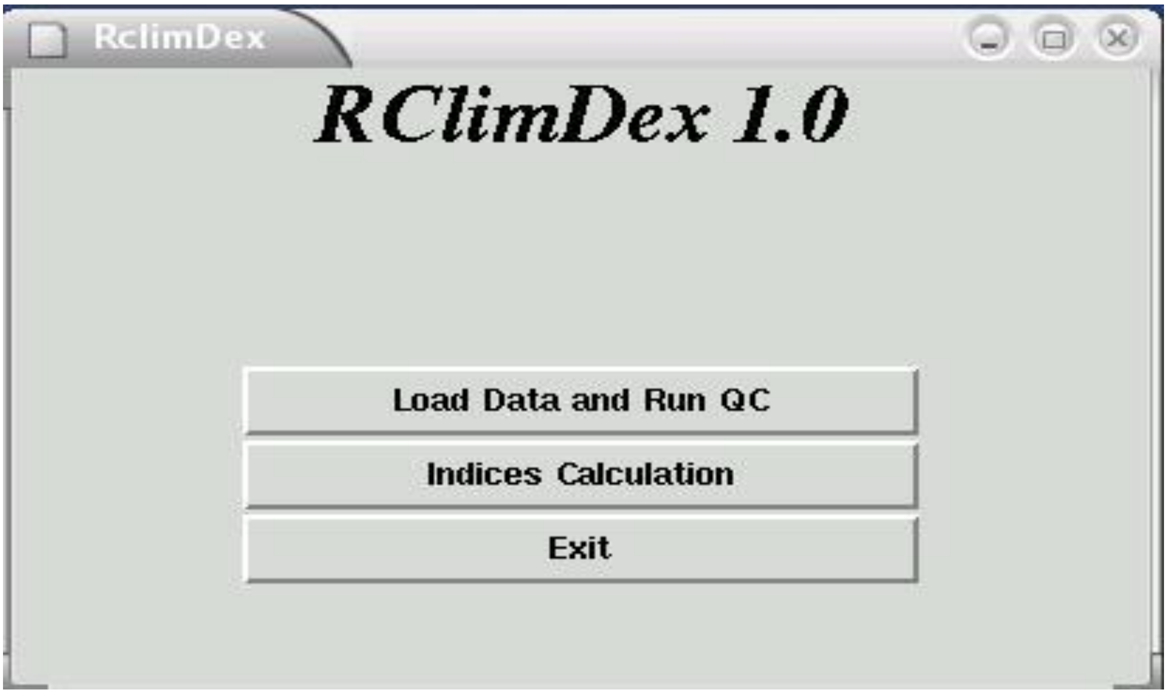


Figure III.3: RClimdex Interface [61]

The Climdex package, implemented in the R programming language, encompasses a collection of software tools and functions tailored for the analysis of climate extremes and the calculation of various climate indices. It facilitates the detection, analysis, and visualization of climate change-related information based on observed or modeled climate data. With the Climdex package, users can compute a wide range of climate indices, including temperature, precipitation, and related indices recommended by the ETCCDI. The package also includes features for trend analysis, allowing users to assess the significance and magnitude of changes in climate extremes over time. Additionally, RClimdex provides capabilities for data quality control, spatial analysis, and visualization of climate indices, making it a valuable tool for climate scientists, researchers, and practitioners involved in climate change studies, impact assessments, and related fields. Its integration with the R programming language further enhances its flexibility and usability, enabling users to customize analysis settings and handle different data formats according to their specific research or application requirements. [62]

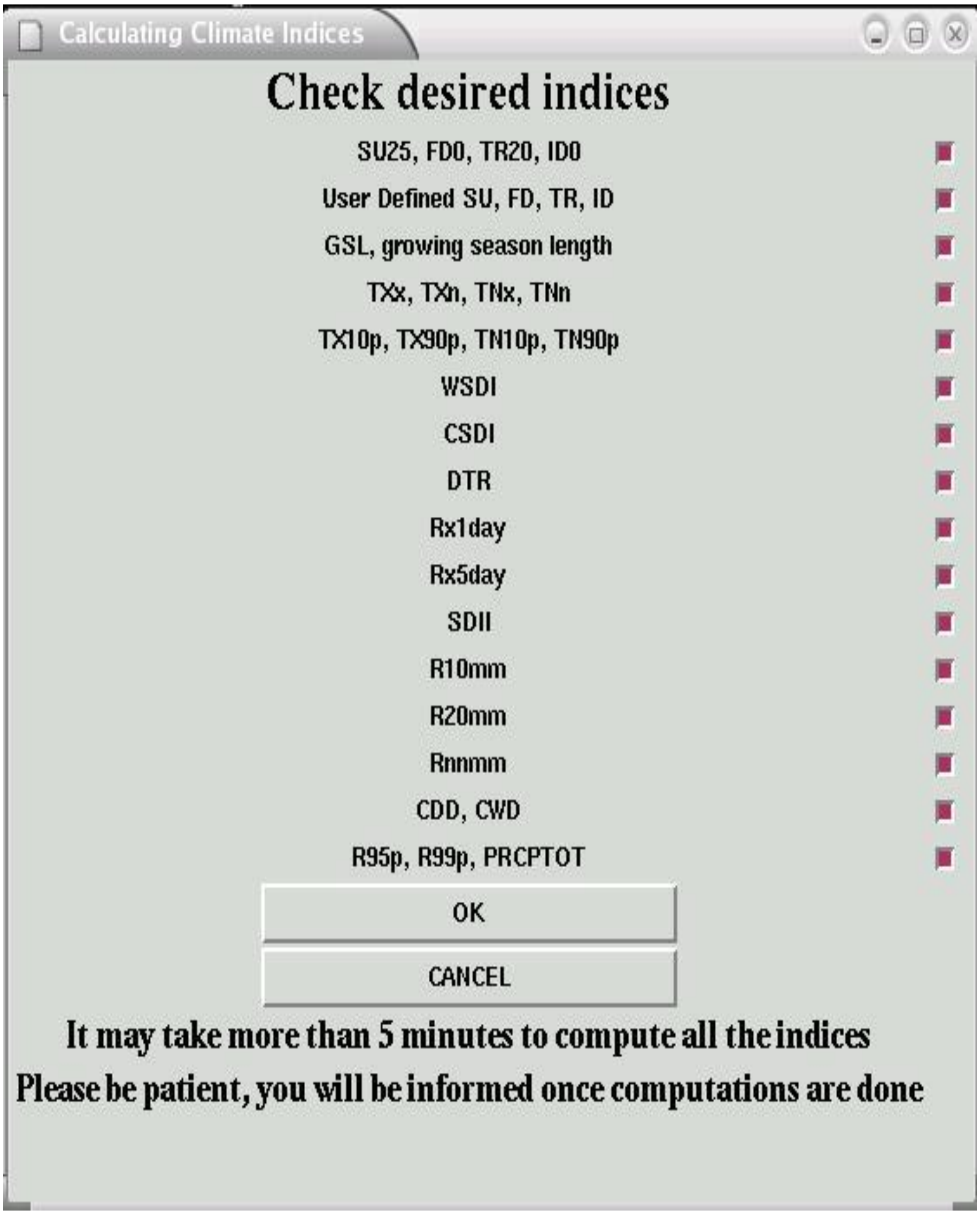


Figure III.4 : RClimdex Interface description [61]

III.3. Expert Team Climate Change Detection Indices (ETCCDI)

The Expert Team on Climate Change Detection and Indices (ETCCDI) is a working group established by the World Meteorological Organization (WMO) in collaboration with other international organizations and climate scientists. The main goal of the ETCCDI is to develop a set of standardized climate indices that can be used to detect and analyze changes in climate extremes and assess their impacts. [62]

The ETCCDI indices are designed to provide quantitative measures of climate extremes, including temperature extremes, precipitation extremes, and other relevant variables. These indices help in understanding the characteristics, trends, and variability of extreme weather and climate events, and their potential linkages to climate change. [63]

The development of the ETCCDI indices involves a rigorous scientific process that includes extensive analysis of observational data, climate model outputs, and statistical methods. The indices are carefully selected based on their relevance, robustness, and ability to capture key aspects of climate extremes. They are designed to be applicable globally, allowing for consistent analysis and comparison of climate extremes across different regions and time periods [62]

Some of the commonly used ETCCDI indices include:

a) Temperature indices

- Warmest day (TXx) and coldest night (TNn) of the year
- Warmest night (TNx) and coldest day (TXn) of the year
- Number of days with maximum temperature exceeding a certain threshold (e.g., TX90p)

b) Precipitation indices

- Maximum 1-day and 5-day precipitation amounts (RX1day and RX5day)
- Number of wet days with precipitation exceeding a certain threshold (e.g., R10mm)
- Number of consecutive dry days (CDD)

These indices, along with others in the ETCCDI set, provide valuable information on the frequency, intensity, duration, and spatial distribution of climate extremes. They help in identifying changes in extreme weather events over time and provide a basis for assessing climate change impacts on various sectors such as agriculture, water resources, health, and infrastructure. [62]

The ETCCDI indices are widely used in climate change research, impact assessments, and policy-making processes. They facilitate the understanding of climate change trends and enable the development of adaptation and mitigation strategies to address the challenges posed by climate extremes. [62]

III.4. Extreme rainfall indices

The analysis of extreme rainfall events often involves the calculation of indices, which provide valuable insights into the characteristics and frequency of these events. In this study, the focus was on 10 rainfall indices related to precipitation. These indices were specifically chosen to highlight extreme rainfall events and their occurrence rates. Table N presents the abbreviations, names, and definitions of these indices. This approach of using indices is commonly employed for studying extreme events and has been widely adopted. The trend analysis of rainfall extremes in this study relied on the climate indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI). These indices have been designed to ensure consistent calculations across individuals, countries, and regions, allowing for seamless integration into the global understanding of climate patterns. The ETCCDI provides standard software, such as the freely available RClimDex software package, which facilitates the calculation of climate indices. For the purposes of this study, RClimDex was utilized to compute the 10 rainfall indices based on series data. It should be noted that the software considers rainfall amounts greater than 1 mm for the calculation of these indices.[64]

The 10 ETCCDI rainfall indices (**Table. III.1)** used in this study encompass three key characteristics of extreme rainfall events: intensity, duration, and frequency. Intensity-related indices include Rx1day (maximum 1-day precipitation), Rx5day (maximum 5-day precipitation), R95p (precipitation from days exceeding the 95th percentile), R99p (precipitation from days exceeding the 99th percentile), SDII (simple daily intensity index), and PRCPTOT (total annual precipitation). Duration-related indices comprise CWD (consecutive wet days) and CDD (consecutive dry days), which capture the duration of wet and dry spells, respectively. Frequency-related indices encompass R10mm (number of days with precipitation greater than or equal to 10 mm) and R20mm (number of days with precipitation greater than or equal to 20 mm). These indices collectively provide valuable information on the intensity, duration, and frequency of extreme rainfall events, contributing to a comprehensive understanding of rainfall patterns and their implications for various applications, such as climate change studies and water resource management. [63]

Table. III.1: The 10 indices concerning precipitation [63]

ID	**Index name**	**Definition**	**Unit**
Rx1day	Max 1-Day Precipitation monthly	Maximum monthly precipitation of 1 day	Mm
Rx5day	Max 5-Day Monthly Precipitation	Maximum consecutive precipitation of 5 days per month	Mm
R10	Number of days with heavy precipitation	Annual number of precipitation ≥ 10 mm	Days
R20	Number of very heavy precipitation days	Annual number of precipitation ≥ 20 mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with precipitation < 1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days during precipitation ≥ 1 mm	Days
R95P	Very humid days	Total annual precipitation per day > 95th percentile	Mm
R99P	Extremely humid days	Total annual precipitation of days > 99th percentile	Mm
PRCPTOT	Annual wet day total precipitation	Total annual precipitation of days ≥ 1 mm	Mm
SDII	Simple Daily Intensity Index	The ratio of total annual precipitation to the number of rainy days (≥ 1 mm)	Days

These indices can be calculated using the R software included in the package "RClimDex". RClimDex provides a user-friendly graphical interface to calculate 27 basic indexes. A simple quality check is also performed on the daily data entry. It is developed and maintained by Zhang Xuebin and Yang Feng in the department climate research.[63]

The software was used for the first time during an African workshop Southern event in Cape Town, South Africa, June 2004, also used in other areas ET workshop.

III.5. Trend methods

Trend analysis is, fundamentally, a method for understanding how and why things have changed – or will change – over time. One issue to be aware of when attempting to understand trend analysis is the wide variety of disciplinary contexts within which it is discussed. This makes it more difficult to define in a universal sense, but for the purposes of clarity, it can be defined here as an approach to analysis which collates data and then attempts to discover patterns, or trends, within that data for the purposes of understanding or predicting behaviors. This typically involves the elimination of "noise" or error in a time-series dataset.

III.5.1. ITA method (Innovative Trend Analysis)

The innovative trend analysis (**ITA**) was applied to detect the trends in rainfall time series. Unlike the most commonly used classical trend analysis methods like the M-K/mM-K and SS tests, the **ITA** method is free from the assumptions of serial autocorrelation, normality, and length of the records. The time series is divided into two equal parts in **ITA** from the first date to the end date. Both sub-series are arranged in ascending order. The first half of the series is placed on X-axis, and the second half is placed at the Y-axis of the Cartesian coordinate system. If the data points are collected on 1:1 line, it indicates there is no trend in the data. If the data points fall above the 1:1 line, it is indicative of a positive trend, while if the data points accumulate below the 1:1 line, it indicates a negative trend. [64]

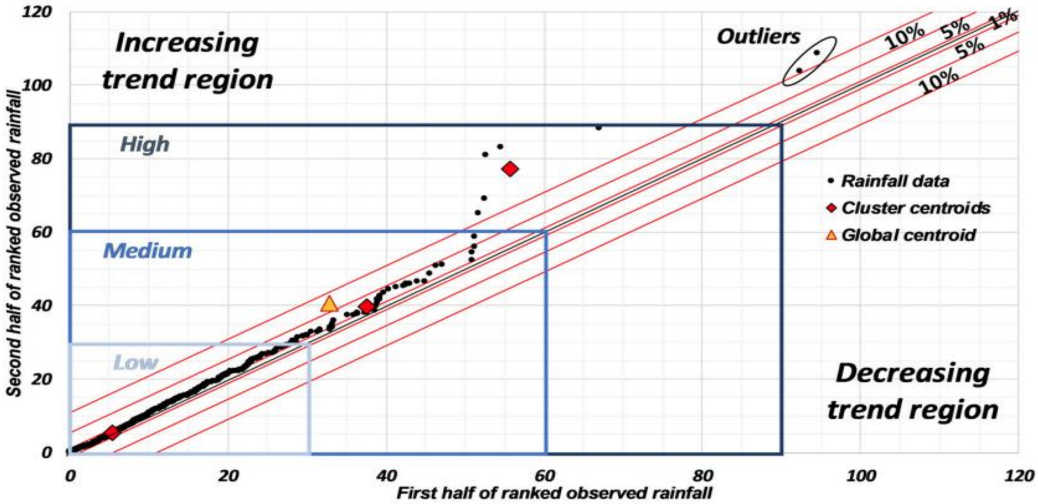


Figure III.5: Example of trend detection using innovative method [64]

III.5.2. Change points

Identifying multiple change points within time series data is becoming increasingly important. However, as datasets grow in length, the number of possible solutions to the multiple **change point** problem grows exponentially. To tackle this challenge, various algorithms have been proposed over the years. Notably, the binary segmentation algorithm (Scott and Knott, 1974; Sen and Srivastava, 1975), the segment neighborhood algorithm (Auger and Lawrence, 1989; Bai and Perron, 1998), and the PELT algorithm (Killick, Fearnhead, and Eckley, 2012a) have been developed .The "**change point**" package (Killick, Eckley, and Haynes, 2014) is available for the R programming language. It can be obtained from the Comprehensive R Archive Network (CRAN) at http://CRAN.R-project.org/package=changepoint [65].

The "changepoint" package is a powerful tool for change point analysis in R. It offers a wide range of functions and algorithms for detecting and analyzing structural breaks in time series data. This package finds applications in various fields, including economics, finance, environmental science, and engineering. The package includes key features such as multiple change point detection methods and assessment techniques. For example, it provides implementations of the binary segmentation algorithm, the PELT algorithm, segment neighborhoods, and window-based methods. These methods employ different approaches to identify change points within the data, allowing users to choose the most suitable method for their analysis. [65]

In addition to change point detection, the "**change point**" package offers tools for change point assessment and visualization. Users can assess the significance and confidence of detected change points using methods like p-values and information criteria. The package also provides functions for visualizing change points and their associated statistical measures. Furthermore, the "**change point**" package supports multiple change point analysis, enabling the identification of multiple change points within a time series. It provides methods to estimate and visualize the locations and magnitudes of these multiple **change points**. Additionally, the package includes non-parametric change point methods, such as rank-based and robust estimators, to cater to various data characteristics. The versatility and flexibility of the "**change point**" package, along with its extensive documentation, make it a valuable tool for change point analysis tasks in time series data. [65]

III.5.2.1. R packages for detecting change points

The **change point** package provides many methods for performing change point analysis of univariate time series. Although the package only considers the case of independent observations, the theory behind the implemented methods allows for certain types of serial dependence. For specific methods, the expected computational cost can be shown to be linear with respect to the length of the time series. The **change point** package is only suitable for finding changes in mean or variance. This package also estimates multiple change points through the use of penalization. [66]

The core function we will use here is **cpt.mean (….)** with the default AMOC method for single **change point** detection

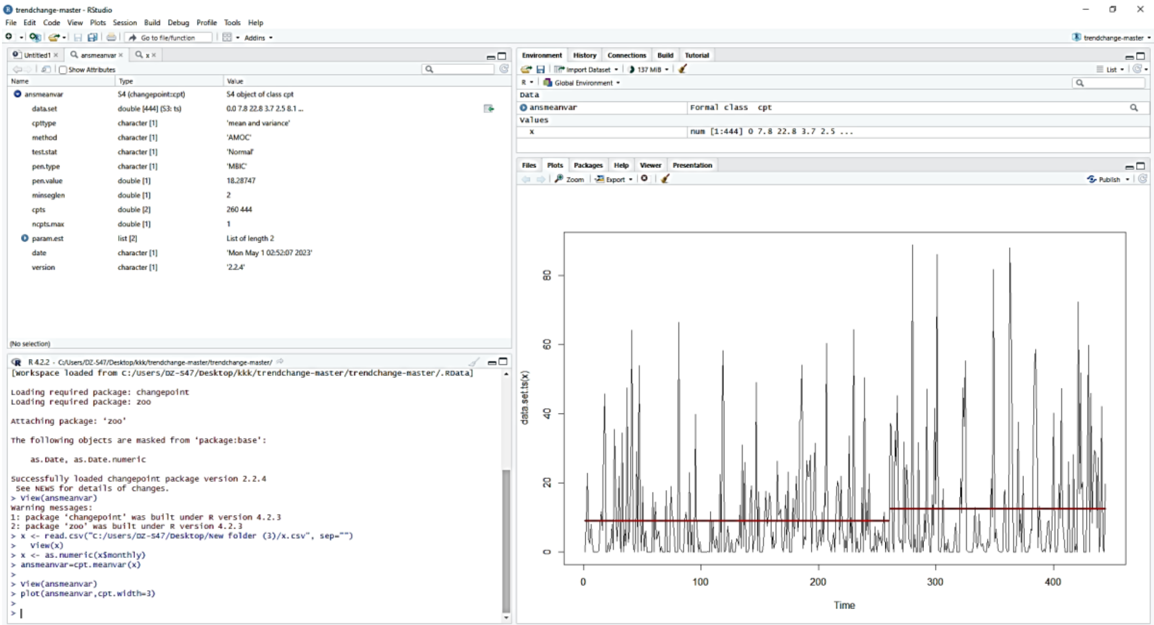


Figure III.6: Change point detection using R packages

III.5.2.2. Change points in mean and variance

The change point package contains four distributional choices for a change in both the mean and variance; Exponential, Gamma, Poisson and Normal. The Exponential, Gamma and Poisson distributional choices only require a change in a single parameter to change both the mean and the variance. In contrast, the Normal distribution requires a change in two parameters. The multiple parameter change point problem has been considered by many authors including Horvath (1993) and Picard, Robin, Lavielle, Vaisse, and Daudin (2005). [67]

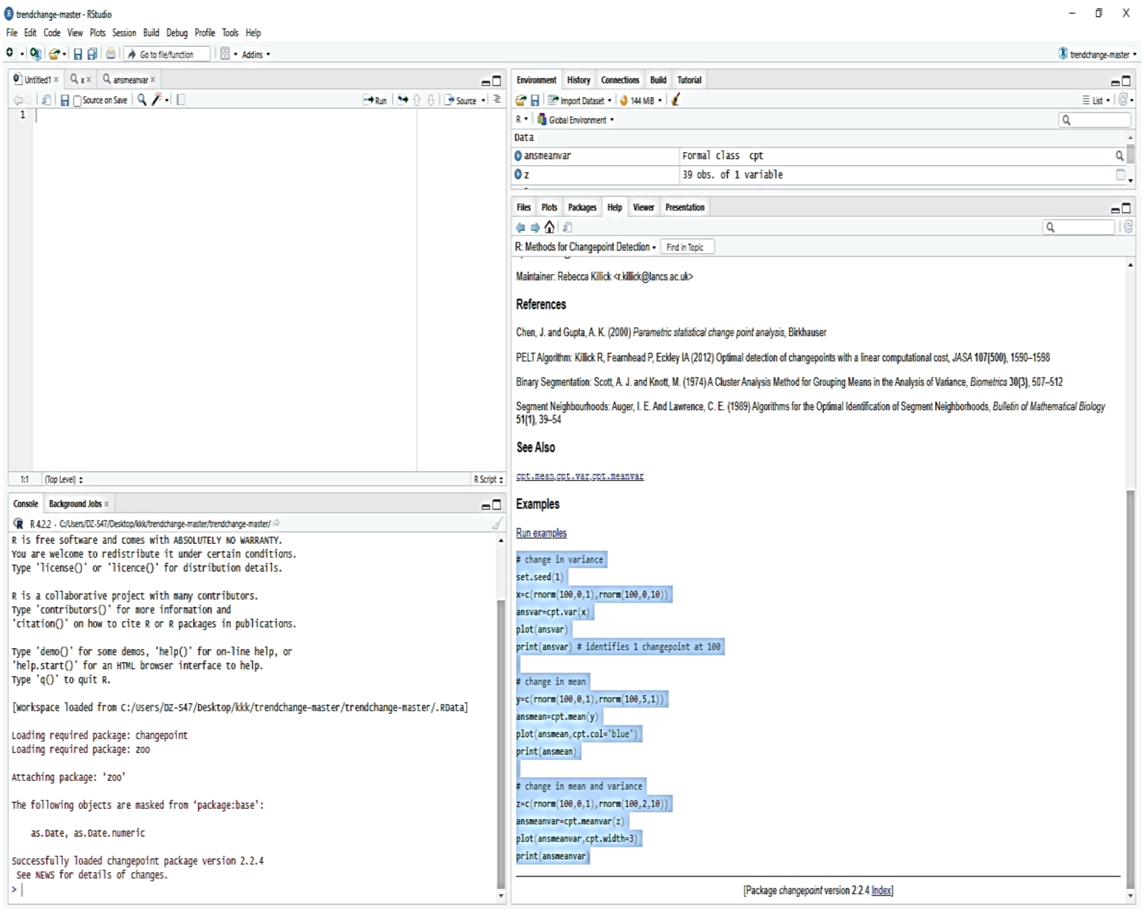


Figure III.7: Changes in mean and variance: The cpt.meanvar function

The **figure III.8** shows an example of the change point application on the monthly rainfall (Ghardaia station)

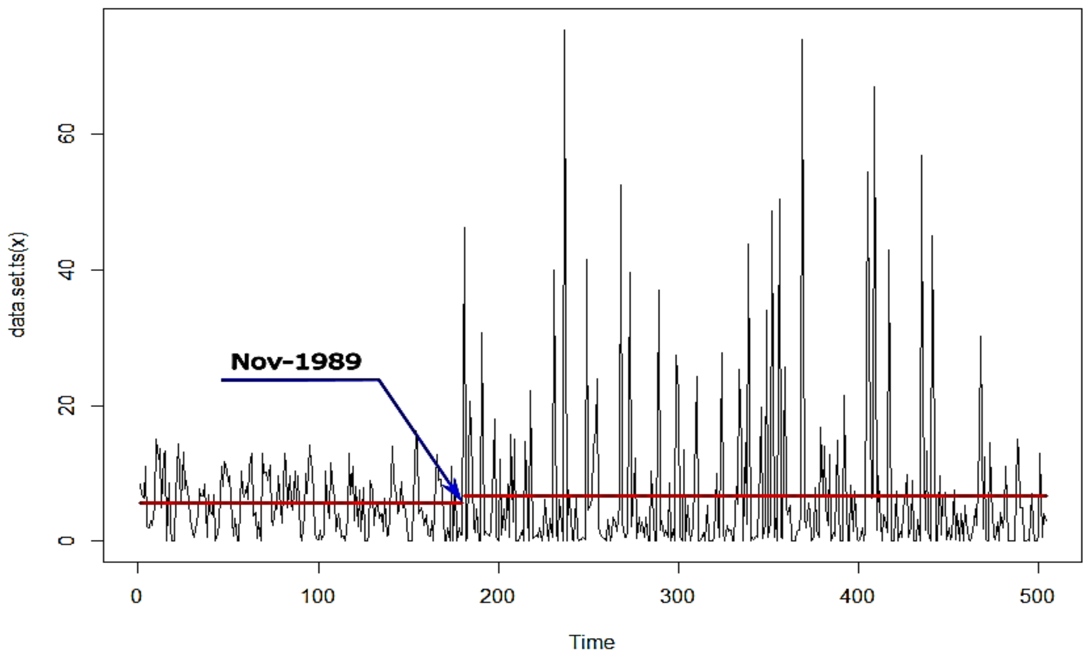


Figure III.8: Single Change point detection in Ghardaia **AMOC Method (Monthly data series).**

Here is the obtained result after running the script:

Class 'cpt' : Changepoint Object

~~ : S4 class containing 12 slots with names

cpttype date version data.set method test.stat pen.type pen.value minseglen cpts ncpts.max param.est

Created on : Mon May 1 02:52:07 2023

summary(.) :

Created Using changepoint version 2.2.4

Changepoint type : Change in mean and variance

Method of analysis : AMOC

Test Statistic : Normal

Type of penalty : MBIC with value, 18.66773

Minimum Segment Length : 2

Maximum no. of cpts : 1

Changepoint Locations : 180

Date----Nov-1989

III.6. Conclusion

The ETCCDI and Trend methods provide valuable tools for analyzing long-term climate data and detecting trends in climate variables, while the ITA method focuses on changes in extreme climate events. Additionally, change point analysis aids in identifying significant shifts or breakpoints in climate data. By utilizing these methods together, we can gain a comprehensive understanding of climate change and its impacts on various aspects of the Earth's climate system.

Chapter IV: Results and discussion

Chapter IV: Results and discussion

IV.1. Introduction

In this chapter, we present the results of the two used methods (**ITA** and **Change point** detection) at the daily, monthly, and annual time periods as we described in Chapter III. The following is a step-by-step approach to address the different aspects of the methods used:

- Filling Missing Rainfall Data: we use average/mean imputation to estimate the missing rainfall data points.
  - Innovative Trend Methods: Once the missing data is fixed "We fixed it manually by comparing several statistics from several data sources ,we apply innovative trend methods to analyze the long-term trends in the rainfall data (monthly,yearly,daily).
- ETCCDI Indices (Expert Team on Climate Change Detection and Indices): After analyzing the trends, we use daily rainfall data to calculate various ETCCDI indices using (RClimdex packages) such as the Simple Daily Intensity Index (SDII), the Maximum 1-day Precipitation Total (Rx1day), or the Number of Heavy Precipitation Days (R10mm).
- Change Point Analysis: Change point analysis helps identifying a significant shifts or changes in the statistical properties of a time series. By applying change point detection using (R packages for detecting change points) we can determine the locations in rainfall data where significant changes or breakpoints have occurred.

IV.2. Analysis of precipitation data series at different temporal scales (Daily,Monthly,Yearly)

Analyzing precipitation data series at different temporal scales involves examining the patterns, trends, and variability of precipitation over various time intervals. This analysis can provide insights into the characteristics of precipitation, its seasonality, and potential climate changes.

IV.2.1. Trend analysis ITA

By applying the **ITA** test on three time levels (daily, monthly, and yearly) for Ghardaia, Laghouat, Ouargla and Biskra, we obtained the results described below.

At Ghardaia station (**Figure IV.1**), we can see that the daily rainfall trend is decreasing, which represents extreme events, and a weak negative trend for medium rainfall, meaning that there is a low negative trend for the entirely daily rainfall data. Also in monthly, there is a high positive trend for low rainfall, a high positive trend for medium rainfall, and some existence of a strong upward tendency for high rainfall, leading to a high positive trend for the entire monthly rainfall data. Similarly, in yearly rainfall data, there is a medium positive trend for low rainfall, a low positive trend for medium rainfall, and existence of a strong upward tendency for high rainfall so the total annual precipitation data shows a high positive trend.

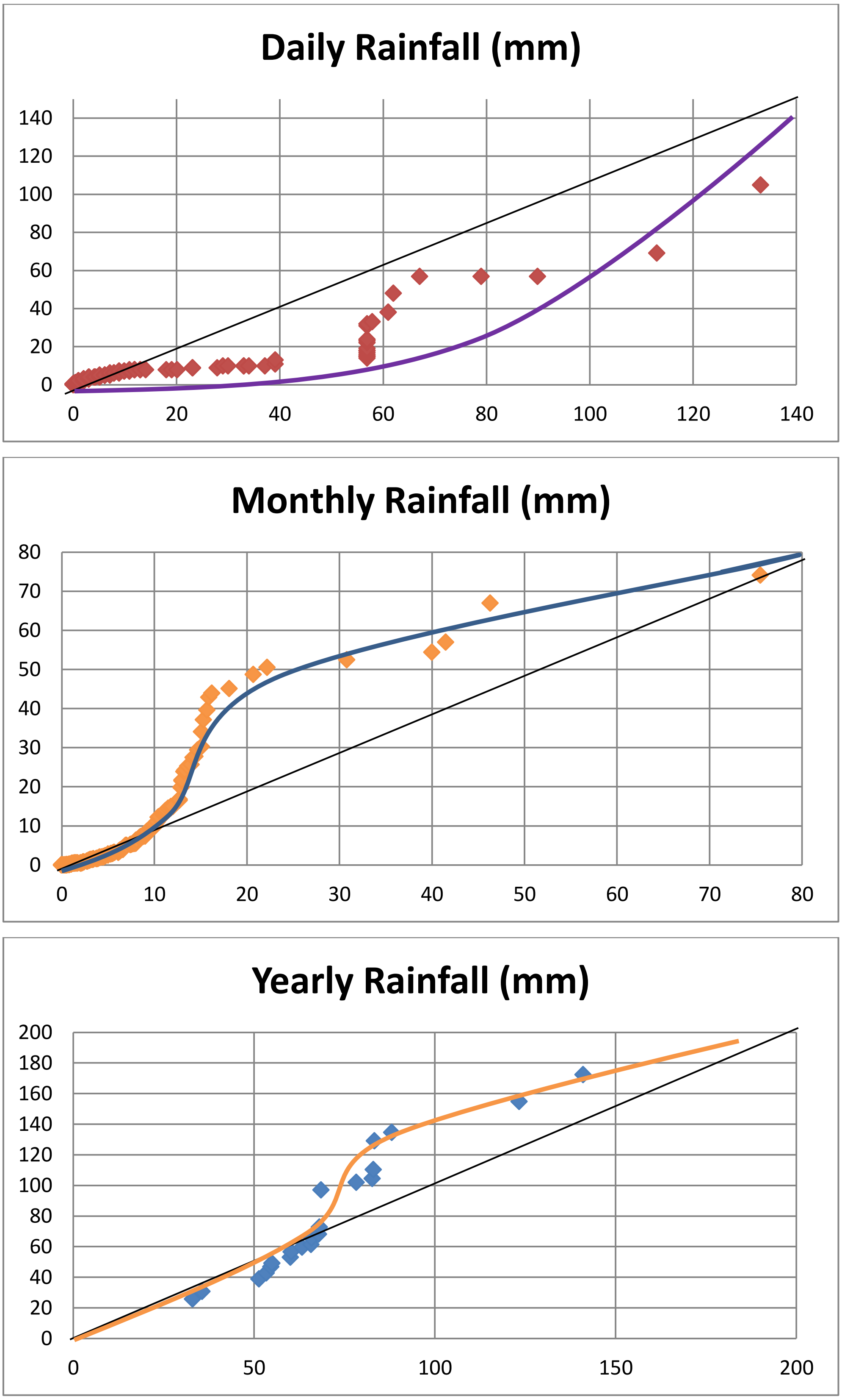
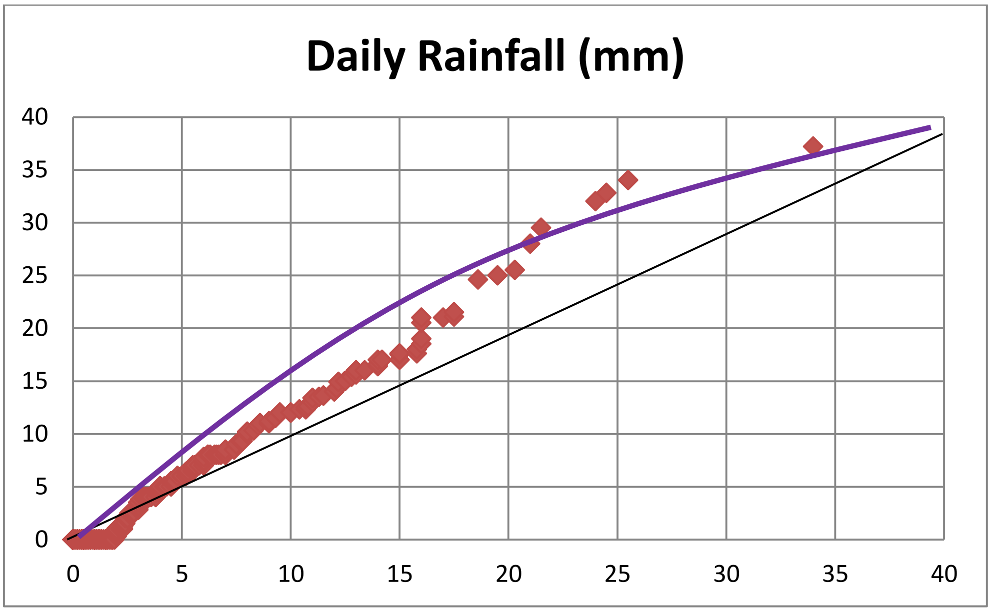
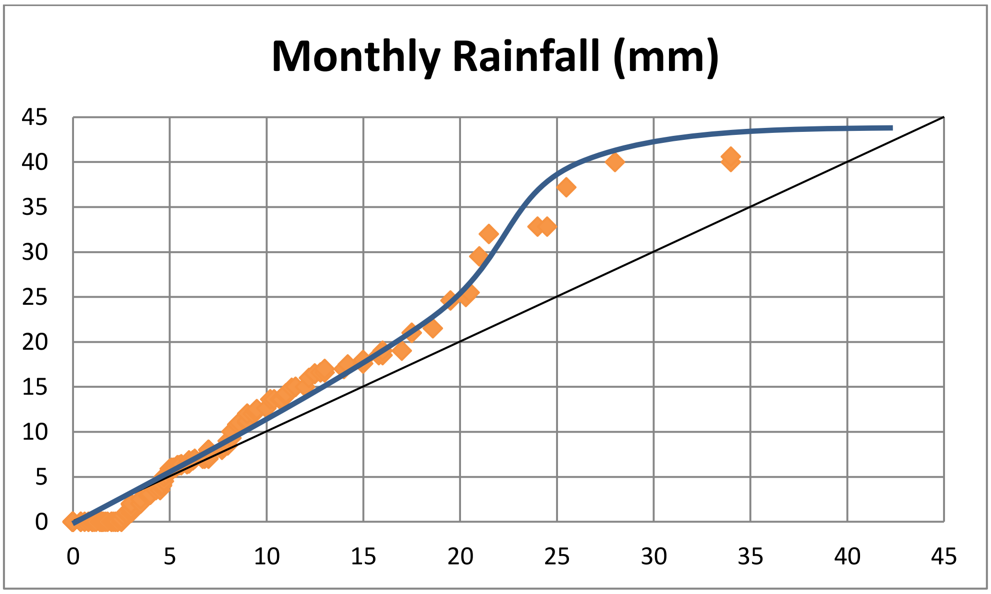


Figure IV.1: Trend results of Precipitation [mm] at daily, monthly and yearly in Ghardaia

We can observe at Laghouat station that there is no significant trend for low rainfall (daily and monthly), and there is a weak positive trend for medium rainfall so there is a medium positive trend for the entire (daily and monthly) rainfall data. While at the Yearly scale, there is an insignificant trend for low rainfall and an existence of a weak upward tendency for high rainfall so the annual precipitation data shows a medium positive trend.





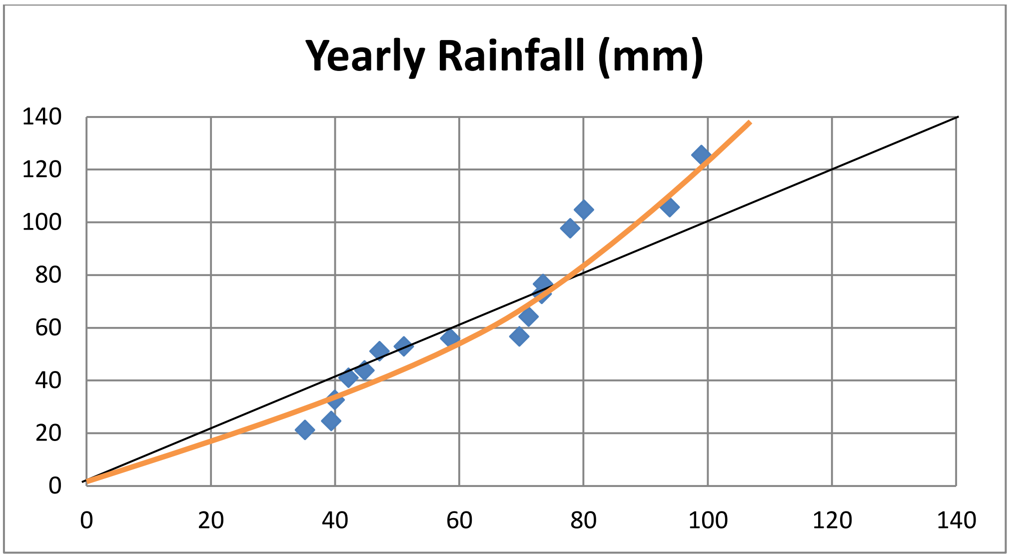
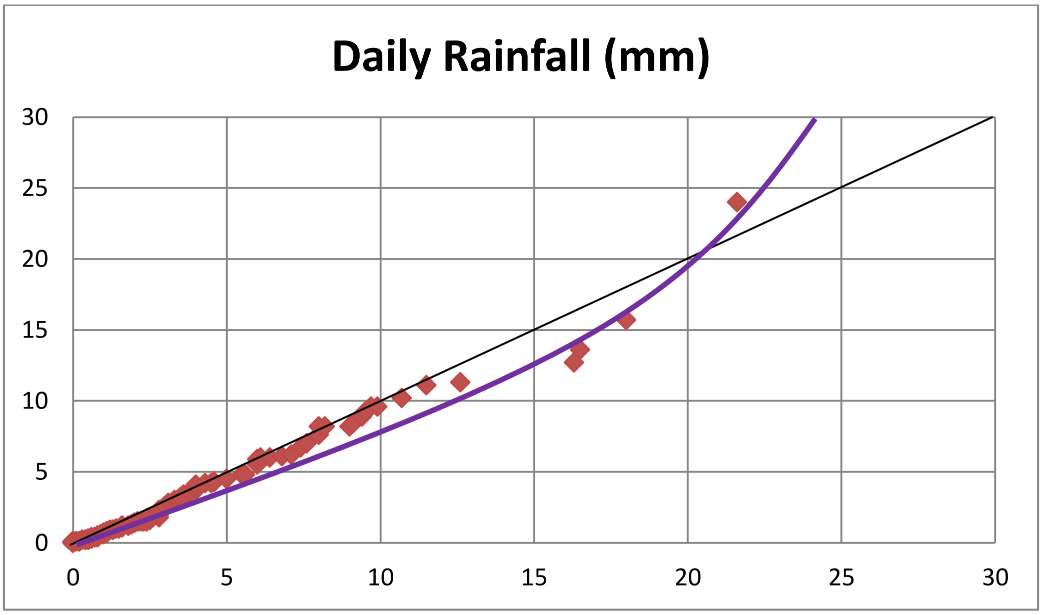
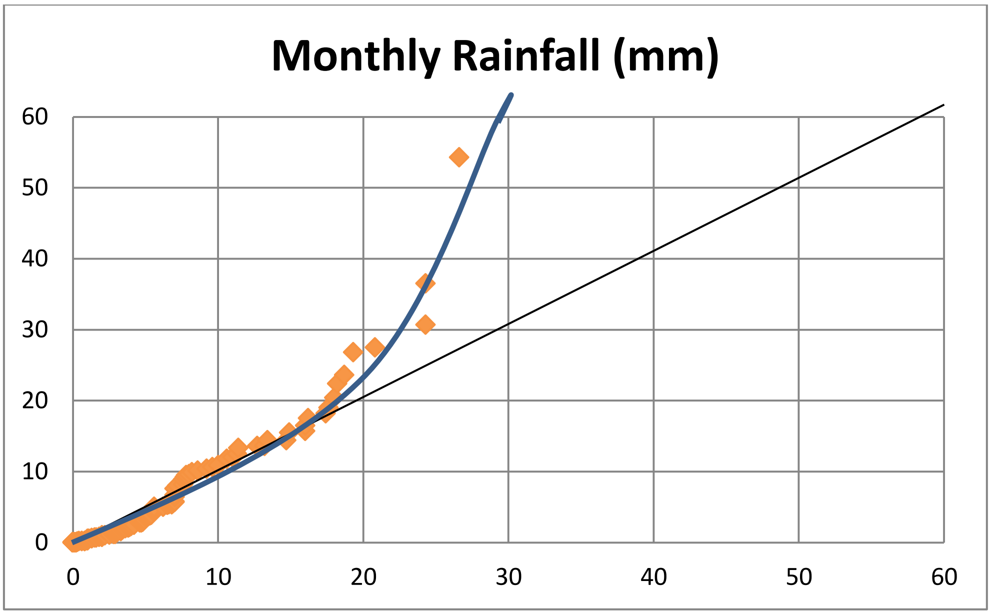


Figure IV.2: Trend results of Precipitation [mm] at daily, monthly and yearly in Laghouat.

At Ouargla station (**Figure IV.3**), the daily low precipitation has no significant trend, the high precipitation has a slight upward trend, and the daily total precipitation data shows a positive trend. Also in the month, we can see that the low precipitation shows a low trend, the medium precipitation shows a weak positive trend, and the high precipitation shows a strong upward trend, so the monthly total precipitation data shows a medium positive trend. Similarly, there is no significant trend in (low and **medium) yearly** rainfall data, but there is a strong upward trend in high precipitation, so the total annual precipitation data shows a positive trend.





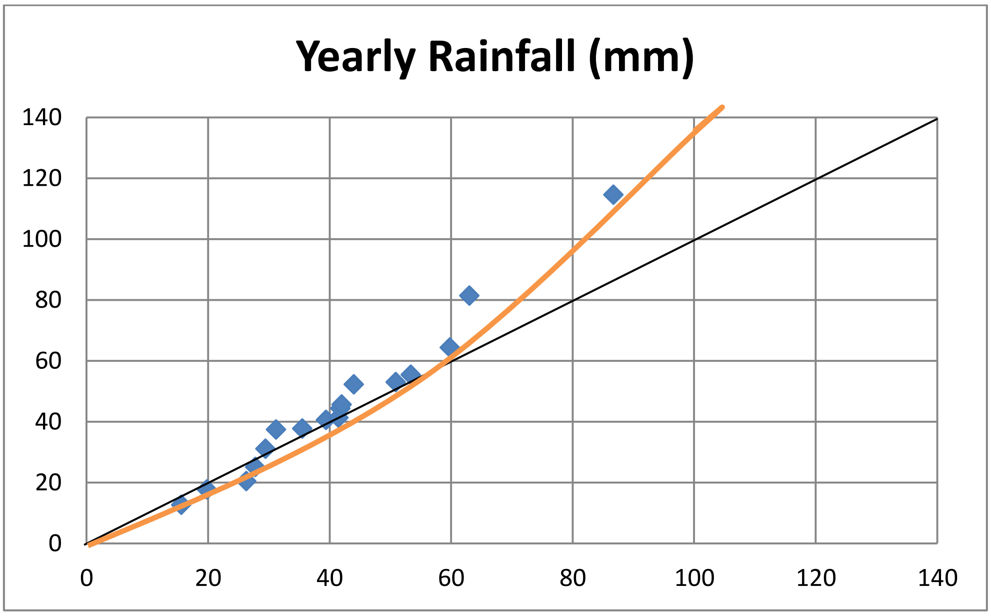


Figure IV.3: Trend results of Precipitation [mm] at daily, monthly and yearly in Ouargla.

Daily low precipitation in Biskra station (**Figure IV.4**) has no significant trend, medium precipitation has a strong positive trend, and high precipitation has a weak positive trend, so the daily total precipitation data has a medium positive trend. Also on a monthly basis, there is no clear trend for low precipitation, a strong positive trend for moderate precipitation, and some strong upward trends for high precipitation, so the monthly total precipitation data has a moderately positive trend. Also during the year, there was a positive, strong upward trend in (low, medium, high) precipitation, so the total annual precipitation data showed a positive trend.

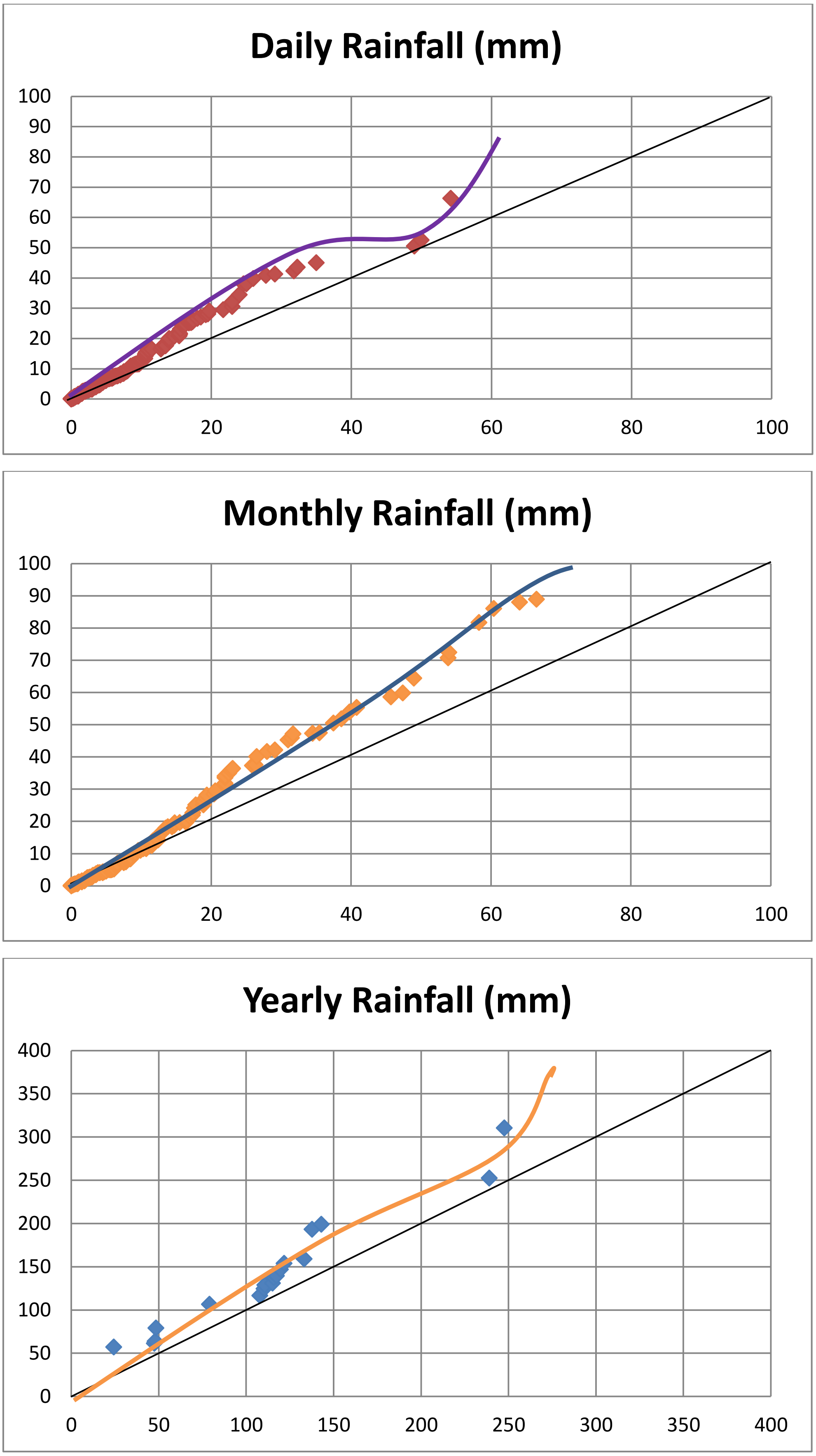


Figure IV.4: Trend results of Precipitation [mm] at daily, monthly and yearly in Biskra.

IV.3. Analysis of ETCCDI data series

Only daily precipitation data are used for the trend indicator study. The daily precipitation statistics are synchronized with this check to ensure accuracy. Also in order to get the results and do the analyses we depend on the availability of long sequence data (over thirty years) at the precipitation areas that we choose. To calculate these indicators, we utilized the R software and the RClimDex package (as explained in Chapter III).

As example, the CDD index is a measure used to evaluate the duration of consecutive dry days, the **Figure IV.5** below shows an example of the analysis of the CDD index in Ghardaïa given by the RClimDex test package. We can observe a high mark between 1998-2000 which means a doubling of consecutive dry days in that period, by following the changing patterns of dry spells, it enables the implementation of appropriate measures to mitigate the impacts of drought.

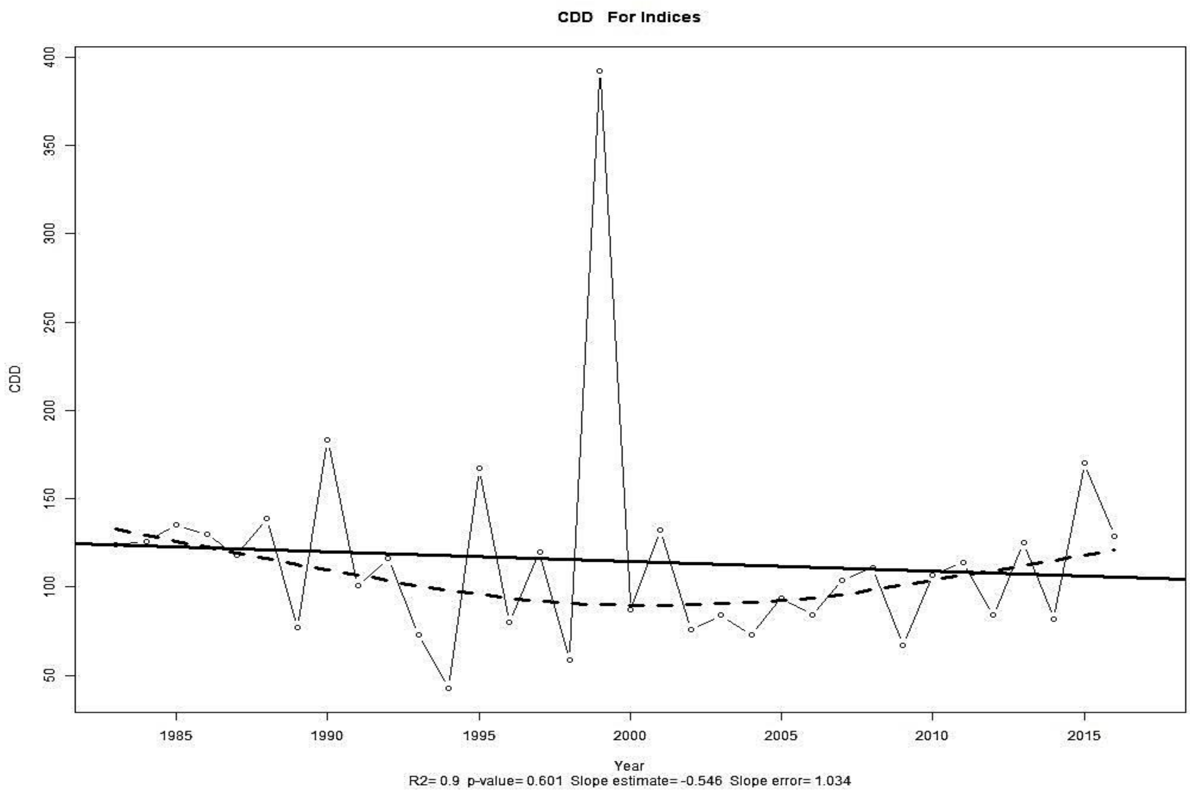


Figure IV.5: Example of CDD in Ghardaia

IV.3.1. Trend of precipitation indices

The ten ETCCDI rainfall indices used in this study concern three characteristics: intensity (Rx1day, Rx5day, R95p, R99p, SDII and PRCPTOT), duration (CWD and CDD) and frequency (R10mm and R20mm) of rainfall.

Intensity:

- Rx1day (mm): Maximum 1-day precipitation total.
- Rx5day (mm): Maximum 5-day precipitation total.
- R95p (mm): Annual sum of daily precipitation > 95th percentile.
- R99p (mm): Annual sum of daily precipitation > 99th percentile.
- SDII (mm/day): Simple daily intensity index (annual total precipitation divided by the number of wet days).
- PRCPTOT (mm): Annual contribution from wet days precipitation >=1mm (PRECPTOT).

Duration:

- CWD (days): Maximum number of consecutive wet days (Rday > 1 mm).
- CDD (days): Maximum number of consecutive dry days (CDD) (Rday < 1 mm).

Frequency:

- R10mm (days): Annual number of days when precipitation ≥ 10 mm.
- R20mm (days): Annual number of days when precipitation ≥ 20 mm.

The application of the methodology presented in previous Chapter makes it possible to establish the following results for indices which are presented as box-plot and discussed in **Figures IV.6**, **IV.7**, **IV.8**, **IV.9**, and **IV.10.**

These indices of intensities (Rx1day, Rx5day, R95p, R99p, SDII and PRCPTOT), duration (CWD and CDD) and frequency (R10mm and R20mm) have been calculated for the four studied stations (Ghardaia, Laghouat, Ouargla, and Biskra).

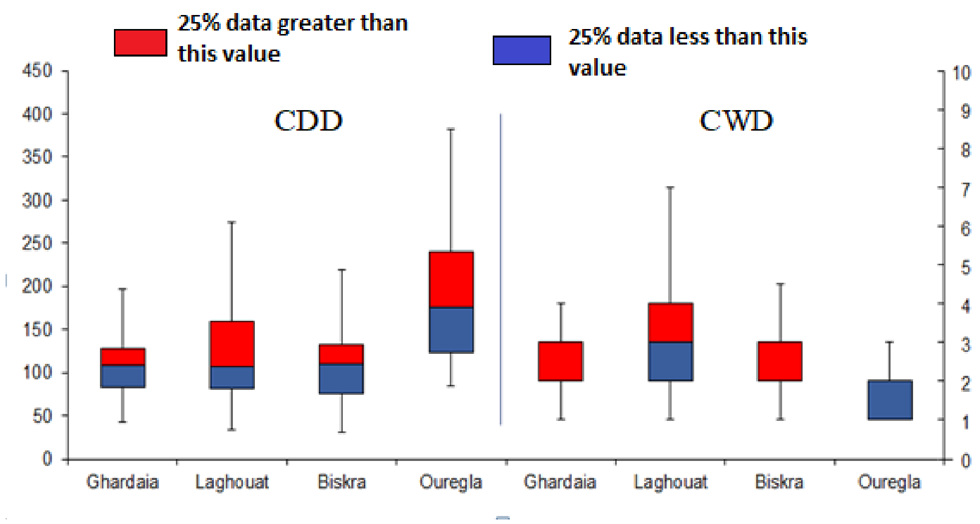


Figure IV.6: Box plot of CDD and CWD indices at different locations

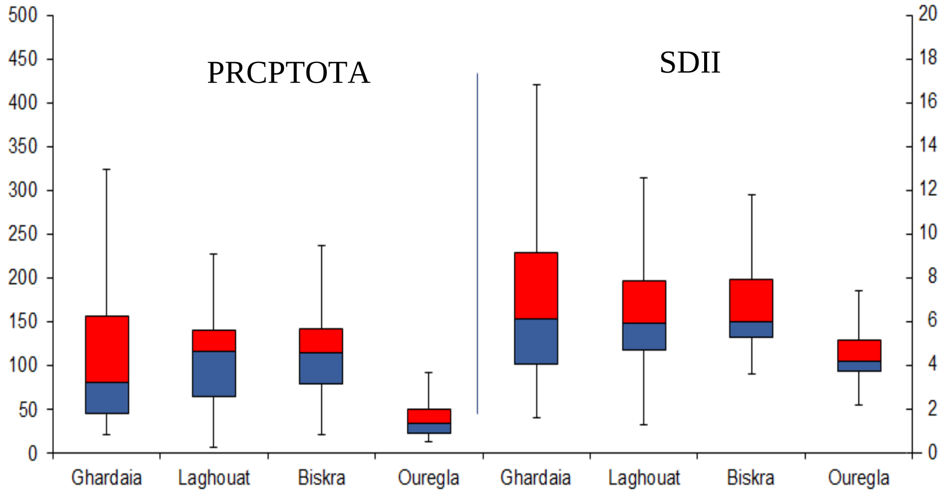


Figure IV.7: Box plot of PRCPTOTA and SDII indices at different locations

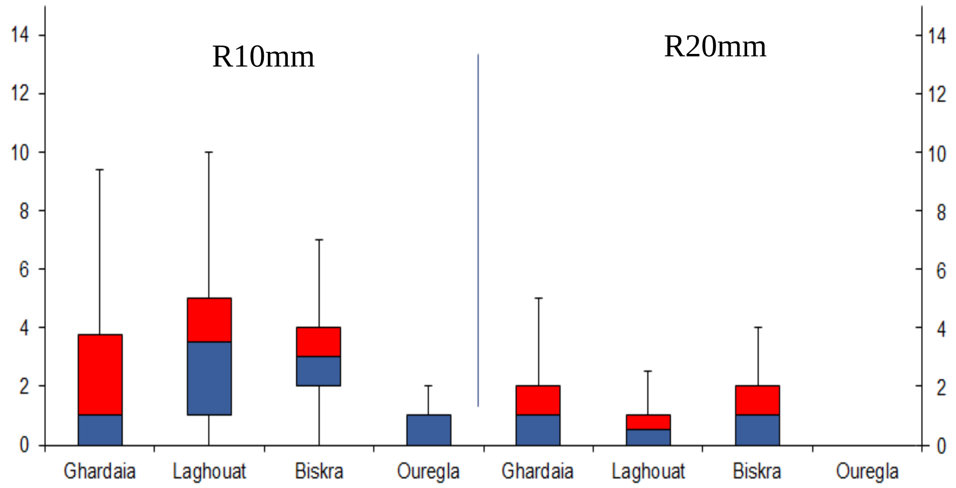


Figure IV.8: Box plot of R10mm and R20mm indices at different locations

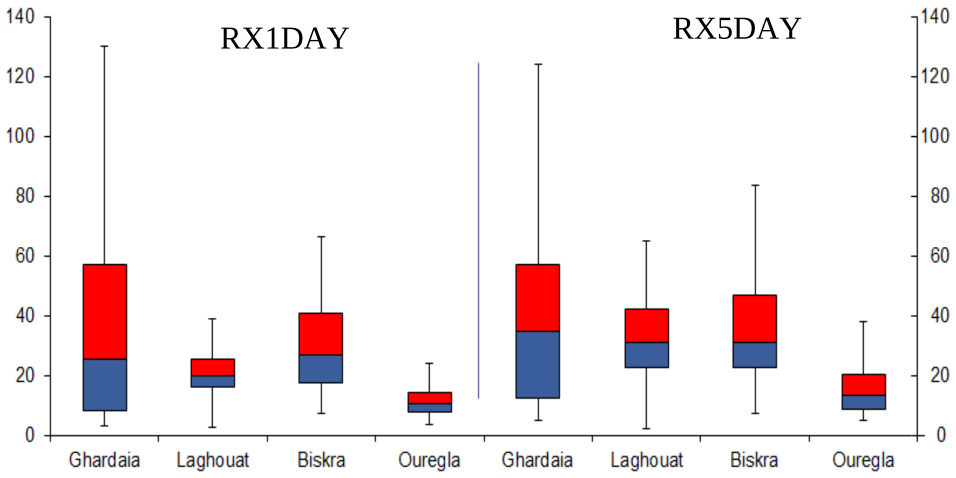


Figure IV.9: Box plot of RX1DAY and RX5DAY indices at different locations

The Sen Slopes, also known as the Sen's estimator, is a statistical technique used to estimate the trend or rate of change in a data series over time. It is commonly applied in climate studies and is a part of the Expert Team on Climate Change Detection and Indices (ETCCDI) developed by the World Meteorological Organization (WMO). The table **IV.1** show the obtained Sen's slope of the indices at different station.

Table IV.1: Represents Sen's slope results for the indices.

Stations	CDD	CWD	RX1DAY	RX5DAY	R10mm	R20mm	R95P	R99P	PRCPTOTA	SDII
	days	days	mm	mm	days	days	mm	mm	mm	mm/day
GHARDIA	1.034	**0.013**	0.586	0.621	0.059	0.047	1.095	0.631	2.798	0.112
LAGOUAT	1.215	0.023	0.147	0.242	0.039	0.012	0.393	0.261	0.863	0.036
OUREGLA	**3.347**	0.024	0.274	0.38	0.031	0.014	0.532	0.263	0.958	0.079
BISKRA	0.755	0.013	0.22	0.287	0.035	0.019	0.612	0.385	0.934	0.034

The Sen Slopes, which is used to evaluate trends and variations in various aspects of precipitation, provided by the RCLIMDEX test are an important source of data for understanding climate patterns and extremes. According to (Figures 26 BOX-PLOT) trend analyses for event indices for extreme rainfall, most indices (CDD, CWD, SDII, Rx1Day, Rx5Day) show a slight increase, with Sen slopes that vary from 0.013 to 3.34 (Table IV.1).

We notice that the three stations (Ghardaia, Lagouat, Biskra) have trends (weak and strong) more or less similar for the PRCPTOTA, Rx1 and 5day, R10, R20, and SDII indices. While in OUARGLA station there is an increase at the level of the CDD index (consecutive dry days), usually occurs during the driest season of the year. The driest season in Algeria is summer where the longest dry period per year can be expected in more than five months, Index values CDD are between 17 days/year (for the shortest dry period) and 120 days/year for the longer dry period with respective slopes of 3.347.

The number of consecutive wet days (CWD) as a measure of the longest period of precipitation, also shows some minor trends; to a dry condition the longest time of the year is usually between winter and spring, November to April. In addition, CWD trends indicate whether precipitation has become more extreme in winter.

The CWD trends are more important so that they can give an idea of the precipitation during the summer season. However, the results show positive trends in CWD in all stations that are not significant with PRCPTOT, suggesting that the inconsistency between these indices leads to severe drought.

The maximum amount of precipitation over 1 day (RX 1 day) and the maximum amount of precipitation over 5 days (RX 5days) show a slight increase in trend with respectively slopes of 0.14 and 0.58 mm for the 1-day RX index and around 0.24 to 0.62 mm for the 5-day RX index across all stations

The indicators of heavy rainfall (R95p) and heavy rain (R99p) show no trends in most of the studied stations. The decrease in the annual amount of precipitation and the indices of heavy precipitation indicate that daily precipitation is becoming less extreme in arid and semi-arid regions.

In addition, the decrease also affects the number of very heavy rainfall (R10mm, R20mm, and R25mm). Relatively few days with less than 0.1 mm occur throughout the region studied.

IV.3.2.Trend analysis of ETCCDI

Trend analysis of ETCCDI (Expert Team on Climate Change Detection and Indices) indicators involves examining the long-term trends in climate variables using specific indices developed by the ETCCDI. These indices provide standardized measures to assess changes in extreme climate events, such as temperature extremes, precipitation extremes, and drought characteristics. Here are the steps involved in conducting trend analysis of ETCCDI indicators:

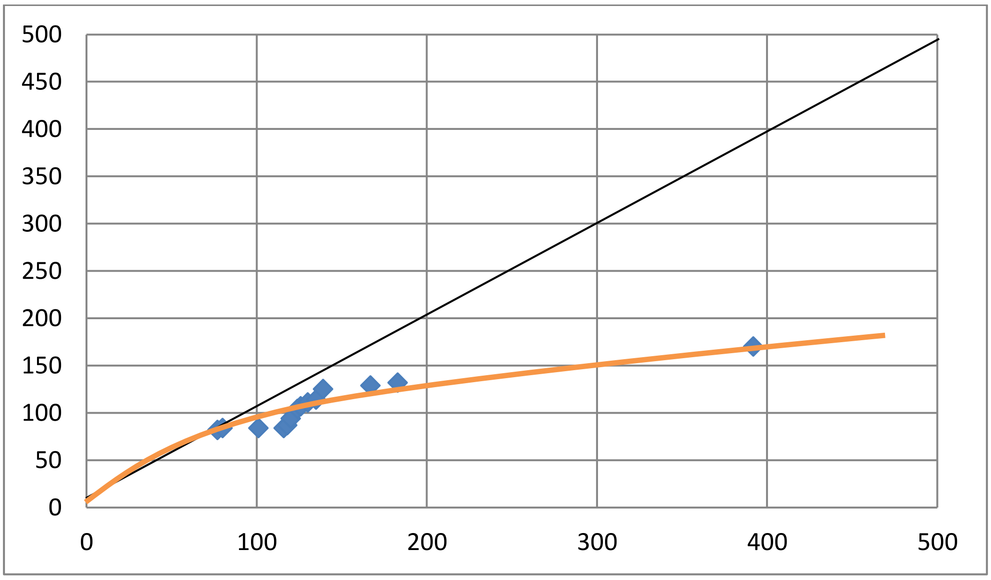


Figure IV.10: Example of ITA method on CDD indices at Ghardaia station

By applying the ITA method on these indices (**Figure IV.12**) we found that in Ghardaia, Laghouat, and Biskra there is no significant trend for CDD. But in Ouargla we do see a trend coming only on CDD which means that there's a very dry days passed. In the other hand, the fourth stations have a similarity in results such as (CWD R10MM PRCPOTA) with no trend for these indicators. Both of Biskra and Laghouat have a positive trend on RX1DAY-5DAY R20-95MM SDII) meaning that there is rainy days passed. Unfortunately, Ghardaia did face a very dry days as we can see there is a very low trend for (RX1-5DAY R95-99P-SDII)

Table IV.2: ETCCDI indices classification trend

GHARDAIA	 ——————————————— **RX1DAY RX5DAY R95P R99P SDII**	**+1** **0** **-1**
LAGHOUAT	**RX1DAY RX5DAY R20mm R95P R99P SDII** ——————————————— 	**+1** **0** **-1**
OUARGLA	**CDD** ——————————————— 	**+1** **0** **-1**
BISKRA	**RX1DAY RX5DAY R20mm R95P SDII** ——————————————— 	**+1** **0** **-1**

Observation

According to the table results, we find that:

- «+1 »mean there is a positive trend for the indices.
- «0»mean there is a medium trend for the indices.
- «-1»mean there is a negative trend for the indices.

IV.4.Change point detection

By applying the Change point detection method test on three time levels (monthly, daily, and yearly) for Ghardaia, Laghouat, Ouargla and Biskra, we got the results showed in **(Figure IV.12).**

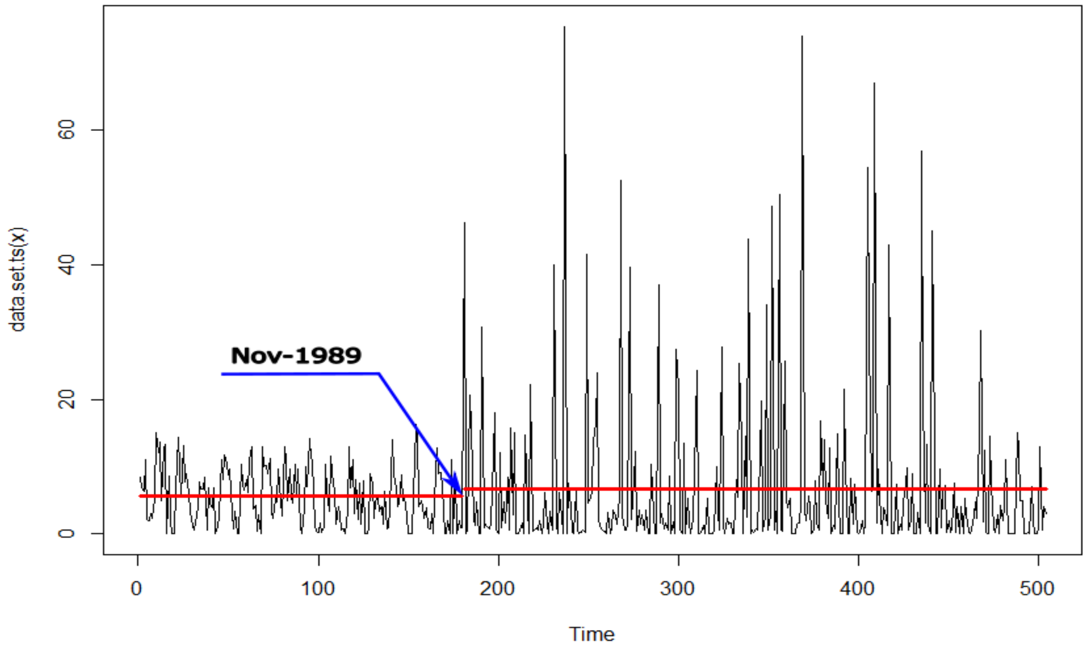


Figure IV.11: Change point detection monthly in Ghardaia

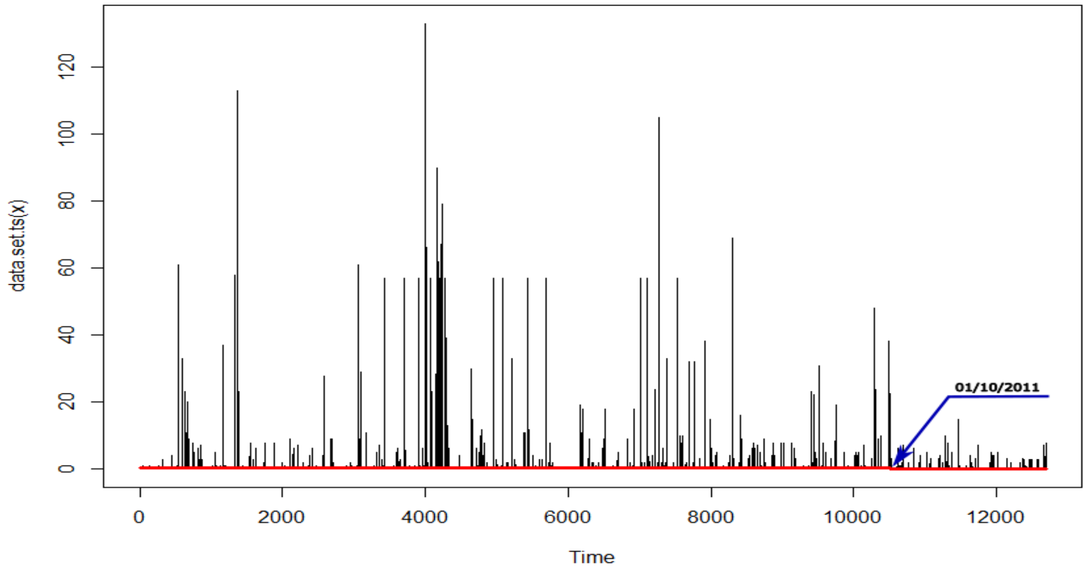


Figure IV.12: Change point detection daily in Ghardaia

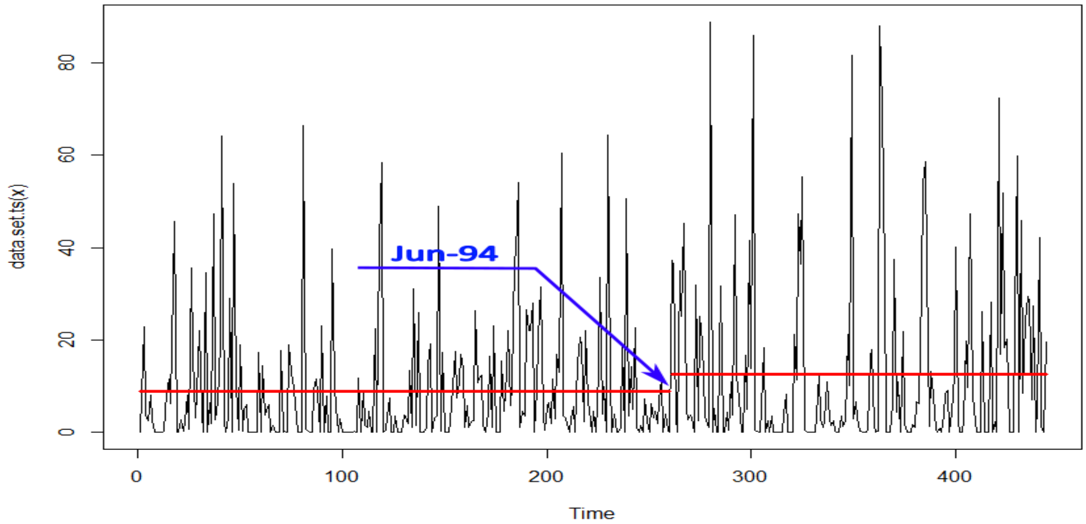


Figure IV.13: Change point detection monthly in Biskra

According to the (**Table IV.3**) we found only 3 change point due to lack of data accuracy, in two stations (Ghardaïa, Biskra) we observe the presence of **change points**. In monthly and daily databases during a 40-year period (1975–2016) of the study area at Ghardaïa station, followed by the monthly (November 1989) and daily (01–10–2011) dates, which indicate a shift in the station data or a change in climate. However, the annual database has not changed. There has only been one **change point** in the monthly database according to the monthly date (June 1994) over the 35 years of the study area at the Biskra station (1973–2009), indicating either a change in the station data or a change in the climate. However, there is no change point detection in the annual and daily database.

On the other side, we highlight that in our study's yearly, monthly, and daily databases, we did not uncover any change points at Ouargla station during (1975–2009) period or Laghouat during (1969–2004).

Table IV.3: The change point detection (daily, yearly, monthly) in the four stations

Stations	Yearly	Monthly	Daily
Ghardaïa	No change point	**Existing change point November 1989**	**Existing change point 01-10-2011**
Laghouat	No change point	No change point	No change point
Ouargla	No change point	No change point	No change point
Biskra	No change point	**Existing change point June 1994**	No change point

IV.5. Conclusion

The ITA test makes it possible to detect if there is a trend and determine its direction. These results by analyzing the results showing the spatial distribution of the trends of different precipitation groups (low, medium and high), it can be seen that almost all stations provide an increase in mean precipitation. And increased (decreased) in most daily precipitation that represent extreme events. These events are a reason for the increase in floods. However, the decrease in precipitation does not show a significant trend for all analyzed stations.

The ETCCDI study is based on the daily precipitation series allows the calculation of 10 indices of extreme weather events describing climate variability. The S-slope estimation test by RCLIMDEX makes it possible to know the value of these indices.

The change point detection analysis on the precipitation data series (daily, yearly, monthly) at the four stations was shown in the last three figures.

It appears in the data series of the two stations (GHARDAIA, BISKRA), there were only three detections of change points that indicated either a change in the station data or a change in climate, according to these statistics we learn more about the behavior of the series precipitation data and the day it occurred by finding These change-points. However, the other station shows no change point detection.

General Conclusion

General conclusion

In conclusion, this study presented a bibliographical synthesis on climate change, focusing on the vulnerable Mediterranean basin and specifically the semi-arid regions of northern Algeria. These regions have experienced numerous extreme events, particularly flood events, during the past century and the early 21st century. The analysis of previous works emphasized the importance of studying variations in extreme climate elements and their potential impacts on water resources, human lives, and property safety in the future.

The study area encompassed central and southern Algeria, defined by the 29° and 37° parallels and the 0°W and 9°E longitudes. Four precipitation stations Ghardaïa, Ouargla, Laghouat, and Biskra located in different regions of Algeria were used for the analysis. The average rainfall exhibited variations along an east-west and north-south gradient, while temperatures showed significant differences from south to north, with minimums in January and maximums in June and August.

To analyze long-term climate data and detect trends in climate variables, the ETCCDI and Trend methods proved to be valuable tools. The **ITA** method focused on changes in extreme climate events, while **change point** analysis helped identify significant shifts or breakpoints in climate data. By employing these methods together, researchers gained a comprehensive understanding of climate change and its impacts on various aspects of the Earth's climate system.

Furthermore, the ETCCDI study, utilizing daily precipitation series, allowed for the calculation of 10 indices describing extreme weather events and climate variability. The S-slope estimation test by RCLIMDEX provided valuable insights into the values of these indices.

The **ITA** test revealed trends in precipitation, indicating an increase in mean precipitation for most stations and an increase or decrease in extreme daily precipitation events, which are often associated with flooding. However, there was no significant trend in precipitation decrease across all analyzed stations.

The **change point** detection analysis on precipitation data series (daily, yearly, monthly) at the four stations demonstrated that only two stations (GHARDAIA and BISKRA) showed three change points, indicating shifts either in station data or in climate conditions. These detections helped understand the behavior of precipitation data series and the specific dates of occurrence for these change points. However, the remaining station did not exhibit any change point detection.

In summary, this study contributes to the understanding the trend of rainfall, its impact on water resources, and the societal evolution under the influence of climate change in central and southern Algeria. The findings highlight the importance of ongoing research on climate change.

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