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End of study dissertation.

To obtain a Master's degree in Hydraulics.

THEME:

Detecting Breaks In Precipitation Series In Soummam Basin.

Presented by:

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ملخص:

الانقطاع في سلسلة الأمطار تشير إلى التغييرات الناجمة فجأة في أنماط الهطول على مر الزمن. يمكن أن تكون هذه التغييرات زيادات أوانخفاضات. يمكن أن تؤدي الزيادة بعد الانقطاع إلى الفيضانات، بينما يمكن أن يؤثر انخفاض الهطول على موارد المياه. تقدم هذه الدراسة تحليلاً لكشف الانقطاع استنادًا إلى بيانات الامطارالسنوية المجمعة خلال الفترة من عام 1960 إلى 2013 في حوض الصومام الموجود في شمال شرق الجزائر. من خلال استخدام الأساليب الإحصائية(Pettitt،Buishand، Ellipse of Bois، Hubert،Lee،وHaghinian) في برنامج Khronostat تظهر النتائج انقطاع من 1973 إلى 2001 مع انخفاض في الهطول بسبب الجفاف الذي ظهر في الحوض. بدأت نسبة الأمطار تتزايد في العقود الأخيرة.

الكلمات المفتاحية: الأمطار، حوض الصومام، الأساليب الإحصائية،برنامج khronostat ، الانقطاع، اتجاه الأمطار .

Abstract:

Breaks in a precipitation series refer to abrupt changes in rainfall patterns over time. These changes can be increases or decreases in precipitation. Increased precipitation after a break can lead to floods, while a decrease in precipitation can impact water resources. This study provides an analysis of detecting breaks based on annual precipitation data collected during the period from 1960 to 2013 in the Soummam basin located in northeastern Algeria. By using statistical methods (Pettitt, Buishand, Ellipse of Bois, Hubert, Lee, and Haghinian) in Khronostat software, the results show breaks from 1973 to 2001 with decreases in precipitation due to drought that appeared in the basin; the recovery of precipitation started from the 2000s onwards.

Key words: Precipitations, Soummam basin, statistical methods, khronostat software, break, trends.

Résumé :

Les ruptures dans une série de précipitations font référence à des changements abrupts dans les schémas de précipitations au fil du temps. Ces changements peuvent être des augmentations ou des diminutions des précipitations. Une augmentation des précipitations après une rupture peut entraîner des inondations, tandis qu'une diminution des précipitations peut affecter les ressources en eau. Cette étude fournit une analyse de la détection des ruptures basée sur les données annuelles de précipitations collectées pendant la période de 1960 à 2013 dans le bassin de la Soummam situé dans le nord-est de l'Algérie. En utilisant des méthodes statistiques (Pettitt, Buishand, Ellipse de Bois, Hubert, Lee et Haghinian) dans le logiciel Khronostat, les résultats montrent des ruptures de 1973 à 2001 avec des diminutions des précipitations dues à la sécheresse qui a affecté le bassin, la récupération des précipitations a commencé à partir des années 2000.

Les mots clé : Les précipitations, bassin de Soummam, méthodes statistiques, logiciel khronostat, rupture, tendance.

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General introduction.

General introduction:

Climate has always fluctuated over time under the direct or indirect influence of natural forcing. Unfortunately, anthropogenic activities have compromised this fragile balance and disrupted the climate due to the amplification of greenhouse gases in the atmosphere. Greenhouse gas-induced climate warming could affect precipitation severely, in different ways, including changes in frequency, intensity, and timing of occurrence **[1]**.

In Africa in particular, the notion of climate change is primarily attributed to a decrease in precipitation, which has been established as the key climatic factor in many studies **[2][3]**. In recent decades, precipitation has varied considerably, contributing to droughts and occasionally floods. The occurrence of these extreme events impacting agriculture, human health and ecosystems.

Algeria experiences diverse precipitation patterns across its various regions. The northern coastal areas typically receive the most rainfall due to the Mediterranean climate influence. In the last decades especially from 1970s the area has been facing a significant precipitation problem, with a decrease in average annual rainfall by over 30٪ **[4]**. This decline is attributed to climate change and has led to several consequences.

Analyses of precipitation over long series using statistical methods allows for a better understanding of drought and flood risks. It helps identify emerging trends and breaks. Those breaks can be indicators of drought periods or simply natural variations in rainfall patterns. By detecting breaks in rainfall series researchers can gain valuable insights into drought monitoring, climate change analysis, water resource management.

The main objective of the present study is to detect break in precipitation series between 1960 and 2013 for 15 rainfall stations in the Soummam basin located in the north eastern Algeria by using khronostat software. The study is organized as follows:

Chapter one: A bibliographical study relating to climate and its elements, the importance of studying precipitation, detecting breaks and trend around the world.

Chapter two: we present Soummam basin, particularly from point of view of location, relief and climate.

Chapter three: We talk about data, software and methods that can help detecting break.

Chapter four: Aims to analyze the break of annual rainfall series of 15 stations in the Soummam basin from 1960 to 2013.

Conclusion, a summary of the main results obtained.

Chapter 01: Bibliographic review.

Introduction:

Understanding the complexities of our climate system is paramount for anticipating and addressing its wide-ranging impacts. Through meticulous data collection and analysis, scientists can discern patterns, forecast future changes, and formulate strategies to confront the challenges posed by a shifting climate.

I.1. Climate:

The term "climate," derived from the Greek word "klima," refers to the long-term weather patterns observed in a specific region, typically averaged over a period of 30 years **[5][6]**. It encompasses various meteorological variables such as temperature, humidity, atmospheric pressure, wind, and precipitation.

According to the Intergovernmental Panel on Climate Change (IPCC), climate is defined as the average weather or statistical description of relevant quantities over a 30-year period **[7]**. Climate change denotes significant and enduring alterations in these patterns, often attributable to human activities. The repercussions of climate change manifest in diverse environmental phenomena, including escalating global average surface temperatures and intensified occurrences of extreme weather events.

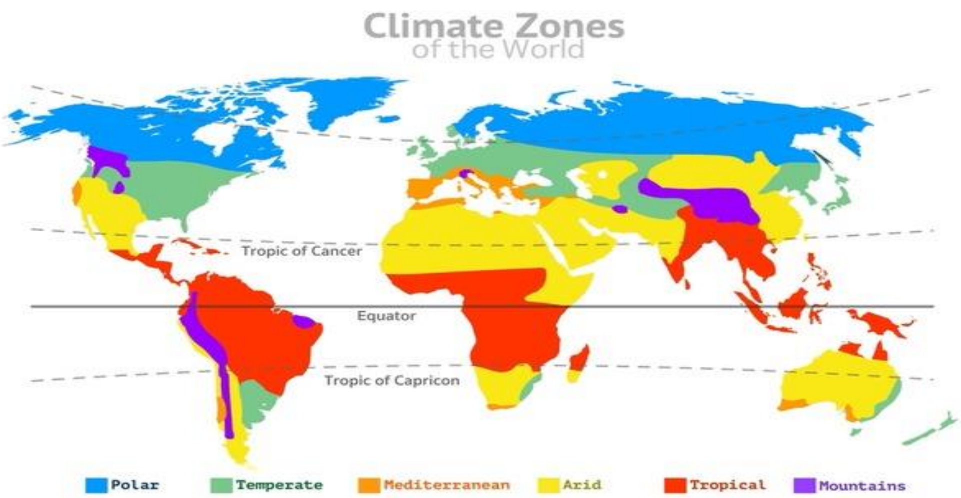

Figure I.01: Climate zones of the world **[8]**.

I.2. Elements of Climate:

Elements of climate are not merely atmospheric features but integral components of the intricate system that shapes the long-term weather patterns of a region. Analysing these elements forms the foundation for weather forecasting and understanding climate.

These elements are crucial for deciphering climate patterns, mitigating climate impacts, and devising strategies to adapt to changing weather conditions. They originate either directly from data collected by measuring devices like thermometers and rain gauges or from visual observations coded by observers.

While numerous elements contribute to defining climate, the following are among the most significant:

I.2.1. Temperature:

Temperature, a fundamental physical quantity representing the degree of heat or cold, stands as the foremost determinant of weather and climate. Its fluctuations influence other weather elements profoundly. Temperature forecasts offer insights into expected high and low temperatures for specific locations over defined periods.

The current rise in global average temperature is primarily caused by humans burning fossil fuels **[9][10]**. Higher temperatures are causing more intense storms, droughts and other weather extremes **[11]**. It can disrupt agriculture patterns, reduce crop yields, and increase the pests and diseases. This can lead to food insecurity.

I.2.2. Wind:

Wind plays a pivotal role in shaping weather and climate. It denotes the natural movement of air from regions of high pressure to those of low pressure.

Figure I.02: the wind **[12]**.

Wind patterns, or large-scale atmospheric movements, arise due to solar energy and variations in air temperature, which influence air densities and pressures. The ascent of warmer, less dense air and the consequent influx of cooler air create wind patterns **[13]**.

- **Impacts of the wind:**

Wind exerts significant influence on weather patterns, shaping regional climates and daily weather phenomena. Its impacts are multifaceted, encompassing various aspects such as the transport of heat and water vapour, redistribution and concentration of clouds, modulation of ocean surface currents, facilitation of erosion and sediment transport, creation of rain shadow effects, and modification of air masses. These effects collectively contribute to the dynamic and ever-changing nature of weather systems across the globe.

I.2.3. Evaporation:

Evaporation is the process by which a liquid transforms into a gaseous state at its surface, occurring at a temperature below its boiling point **[14]**. This physical phenomenon involves the gradual transition of a substance from liquid to gas, resulting in the production of water vapour and atmospheric moisture.

Figure I.03: Evaporation **[15]**.

Changes in evaporation rates can exert significant impacts on climate dynamics. For instance, heightened evaporation rates due to increasing temperatures can amplify precipitation intensity and exacerbate drought conditions in specific regions. Such alterations in the hydrological cycle can lead to complex interactions within Earth's climate system, influencing weather patterns and atmospheric circulation on both local and global scales.

- **The factors that affect the rate of evaporation:**

Several factors significantly influence the rate of evaporation:

- Temperature.
- Surface area.
- Humidity.
- Wind speed.

- Atmospheric pressure.
- Liquid properties.

I.2.4. Evapotranspiration:

Evapotranspiration is all the phenomena and flows of physical evaporation and biological transpiration, in particular of vegetation, which are involved in the water balance of a territory. It is most generally expressed as the average height evaporated on the surface considered over a defined period of time **[16]**.

Potential evapotranspiration (ETP) increases from north to south unlike actual evapotranspiration (ETR) which evolves in parallel with increasing temperatures and precipitation, the highest ETR values are reached in the lower basin where all the favourable conditions are met: high temperatures, precipitation, abundant and dense forest cover.

Evapotranspiration data provides valuable insights into the water cycle, the ecosystems and agricultural practices. By studying this data, it can make informed decisions about water resources management, land use planning, and adaptation to climate change.

Evapotranspiration data were mapped to identify areas in Soummam basin with high or low values of ETP in chapter 04.

I.2.5. Precipitation:

Precipitation refers to any product of the condensation of atmospheric water vapour that falls from clouds due to gravitational pull **[17]**. As a major component of the water cycle, it plays a crucial role in depositing fresh water on the planet **[18]**.

Figure I.04: Precipitation **[19]**.

This natural process is integral to the global climate system and is essential for sustaining life on earth while maintaining atmospheric balance.

Moreover, precipitation significantly influences various earth system processes and phenomena, including regional temperature patterns, terrestrial ecosystem productivity, and the distribution of pollutants and airborne particles.

I.2.5.1. The different forms of precipitation:

All forms of precipitation stem from the water cycle, the continual movement of water between the earth and the atmosphere **[20]**.The diverse temperatures and atmospheric conditions within clouds and at the earth's surface contribute to the formation of various precipitation forms. Rain, snow, drizzle, sleet, and hail are among the most prevalent forms of precipitation.

Each form has distinct characteristics dictated by factors such as temperature, humidity, and atmospheric dynamics. Understanding the processes behind precipitation formation is essential for meteorologists to forecast weather accurately and adapt to changing atmospheric conditions.

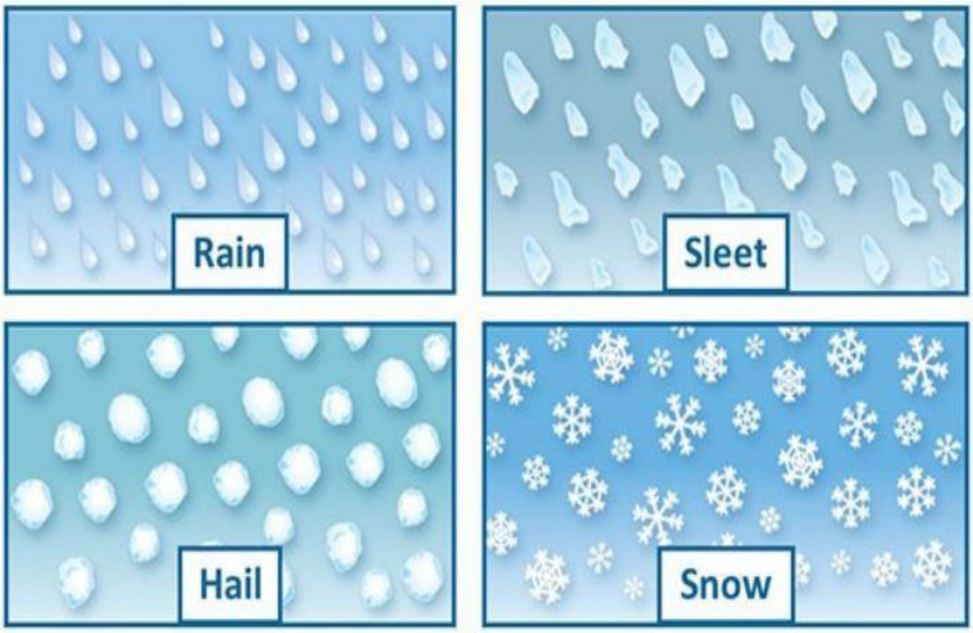

Figure I.05: Forms of precipitation **[21]**.

I.2.5.2. Types of precipitation:

There are three different types of precipitation which are as follows:

Convectional precipitation:

Convection arises when the Earth's surface becomes warmer than its surroundings, prompting substantial evapotranspiration. This phenomenon generates convective rain and light precipitation through large convective clouds, resulting in brief showers characterized by rapidly fluctuating intensities, commonly observed in tropical regions**[22]**.

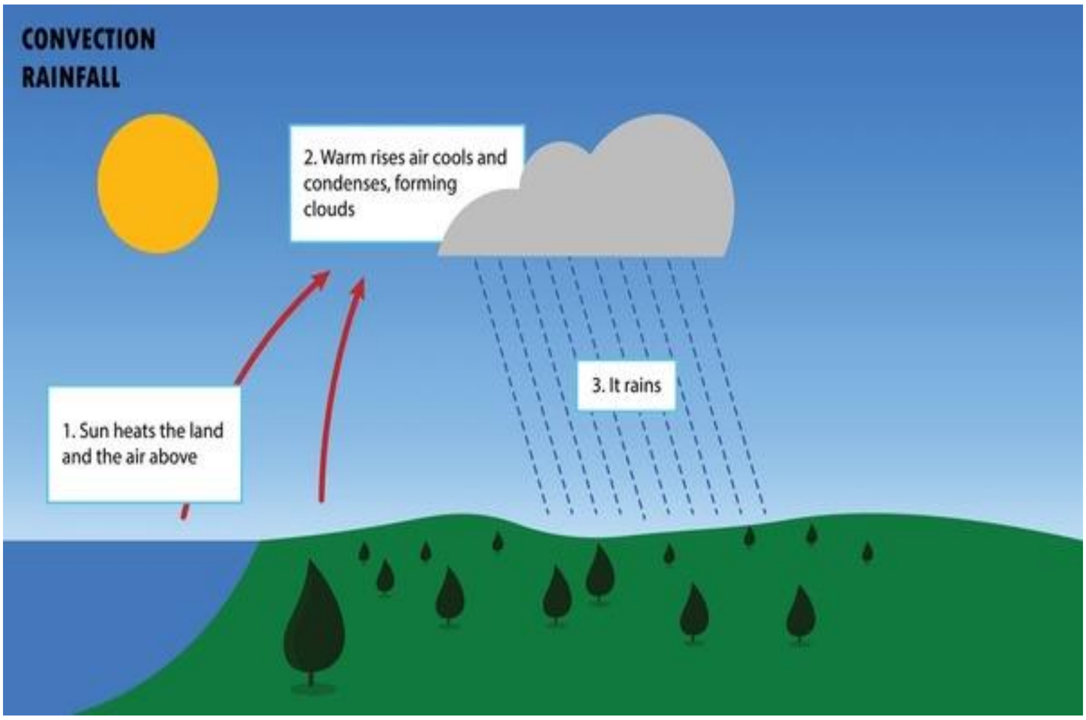

Figure I.06: Convectional precipitation **[23]**.

Cyclonic:

Frontal precipitation occurs when warm, tropical air encounters cooler, sub-polar air in frontal systems surrounding extra-tropical cyclones or lows. This collision of air masses, with different densities and characteristics, leads to the warmer, less dense air rising over the colder, denser air. If conditions permit, this rising air undergoes saturation and condensation, resulting in precipitation typically falling from nimbostratus clouds **[24]**.

Furthermore, precipitation can intensify the temperature and dew point contrast along the frontal boundary, perpetuating the precipitation process. Passing weather fronts often induce abrupt environmental changes, including fluctuations in temperature, humidity, and air pressure at ground level, as different air masses influence local weather patterns

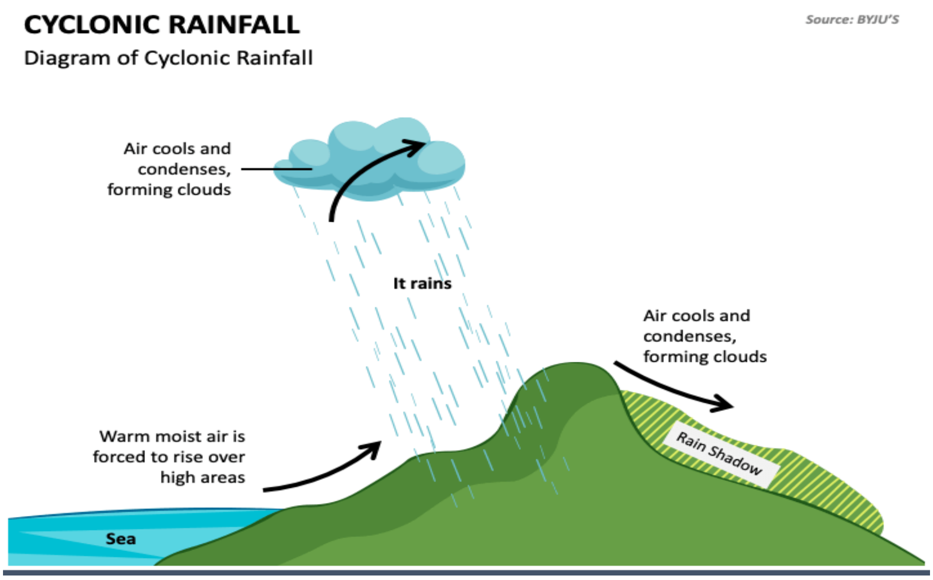

Figure I.07: Cyclonic rainfall **[23]**.

- **Orographic:**

Orographic or relief rainfall occurs when air masses are compelled upward along elevated land formations like mountains or plateaus, a phenomenon known as the upslope effect. As the air ascends, it experiences adiabatic cooling, leading to condensation and precipitation. In regions with consistent winds, such as the trade winds, the windward side of the mountain typically receives more precipitation due to orographic lift, while the leeward side experiences drier conditions and a rain shadow effect as moisture is depleted by precipitation on the windward side **[25]**.

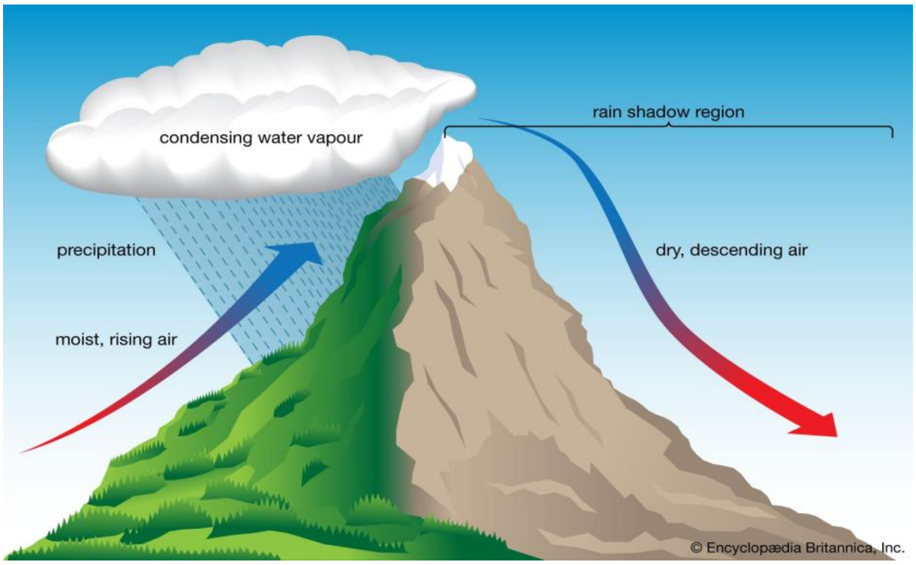

Figure I.08: Orographic precipitation **[26]**.

I.2.5.3. Measurement of precipitation:

Precipitation is quantified by measuring the amount of water that reaches the horizontal ground or its projection plane. The primary instrument for this purpose is a rain gauge, typically a cylindrical bucket that collects rainfall. Solid precipitation, like snow and hail, is measured differently, it's melted using a known amount of warm water, and the total is measured with a graduated cylinder. The initial warm water amount is then subtracted to determine the precipitation. Alternative methods for measuring precipitation include radar disdrometers and optical laser disdrometers **[27]**.

I.2.5.4. Factors affecting precipitation:

Precipitation patterns are influenced by various factors, resulting in complex interactions. Climate models and meteorological observations aid in understanding and predicting these patterns, benefiting water resource management, agriculture, and disaster preparedness.

These factors fall into three main categories: atmospheric conditions (moisture content, air masses, fronts, orographic uplift), geographical factors (topography, proximity to water bodies), and global climate patterns (El Niño, La Niña, monsoons, climate change) **[28]**.Understanding these influences is crucial for accurate prediction and management of precipitation variations.

I.2.5.5. Annual global precipitation:

The yearly precipitation averaged over the entire Earth is approximately 100 cm (39 inches), although this distribution varies significantly. According to our world in Data, the global average annual precipitation is reported to be 990 mm per year. However, data from Global Economy.com suggests a slightly higher average of 1168 mm per year based on 178 countries in 2020 **[29]**.

It's important to note that precipitation values can vary widely by location, with Colombia experiencing the highest average precipitation at 3240 mm per year and Egypt the lowest at 18 mm per year **[29]**.These variations may be influenced by factors such as geographic location, elevation, and local climate conditions.

I.2.5.6. Distribution of precipitation:

Regions across the Earth experience diverse rainfall patterns influenced by geography and seasons. Generally, precipitation declines from the equator to the poles. Coastal areas receive more rainfall due to proximity to water bodies. Between latitudes 35° and 40° north and south, eastern coasts receive heavier rainfall diminishing towards the west.

Conversely, between latitudes 45° and 65° north and south, precipitation is first received on the western margins of continents due to westerly winds, decreasing towards the east. Additionally, where mountains parallel the coast, rainfall is higher on the windward side and diminishes towards the leeward side

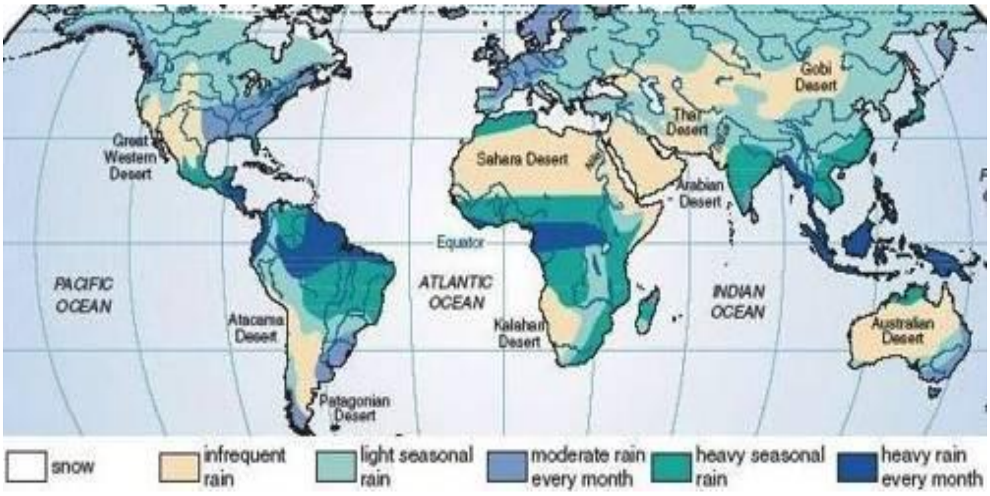

Figure I.09: Distribution of precipitation around the world **[30]**.

- **In Algeria:**

The amount of precipitation a watershed receives directly affects the stream flow in its waterways. Higher precipitation leads to more water flowing through streams and rivers. Conversely, lower precipitation can result in reduced stream flow or even dry periods in some streams. By studying precipitation, it can develop better strategies for managing water resources.

Seltzer (1946)**[31]**,Chaumont and Paquin (1971)**[32]** studied rainfall in Algeria and showed that the country is subject to the combined influence of the sea, relief, and altitude.

Seltzer (1946)**[31]** demonstrated that the distribution of rainfall in Algeria follows the following three laws:

• Rainfall increases with altitude but is higher on slopes exposed to humid winds than on leeward slopes.

• It increases from west to east.

• It decreases as one move away from the coast.

Precipitation data were mapped in chapter 04.

I.2.5.7. Extreme precipitation:

A) Floods:

Extreme precipitation is primarily caused by rising global surface temperature, which lead to increased evaporation rates and added water vapour to the atmosphere. This, in turn, results in more intense and frequent precipitation events.

The increase in extreme precipitation is one of the clearest changes in climate observed, with the amount of precipitation falling in the most intense events having increased significantly **[33]**.

As the planet warms the air's capacity for water vapour also increases leading to more intense precipitation events. These events have been observed to have increased in frequency and intensity in the United States and across many regions of the world since the 1950s **[34]**.

Figure I.10: Extreme rainfall **[35]**.

- **Threats posed by heavy precipitation:**

a) Storm water management:

- Increasing heavy rain events contribute to storm water problems **[36][37][38]**.
- Intense precipitation overwhelms sewage systems and water treatment facilities, raising the risk of waterborne disease outbreaks **[33]**.
- Urbanization exacerbates flooding by channelling storm water into fast-moving flows**[39]**.
- Poor storm water management in certain areas could lead to greater damage from heavy rains **[40]**.

b) Water quality and public health:

- Heavy rainfall leads to contaminated runoff and mobilizes pollutants stored in sediment, contaminating fish **[38][39][41]**.
- Floods increase the likelihood of waterborne diseases and lake contamination **[33][42][38]**.
- Warmer temperatures, combined with stronger storms and nutrient loading, may escalate toxic algal blooms and oxygen-depleted dead zones **[38]**.

c) Transportation:

- Increased extreme precipitation impacts transportation infrastructure, causing risks like traffic accidents **[43]**.
- Extreme precipitation can erode the base of bridges , leading to increased maintenance costs for bridges, the annual cost of maintaining Midwestern bridges may reach 400 million by the year 2050 **[44]**.

B) Drought:

Drought, a complex natural event, can significantly impair various societal activities, including social, economic, and agricultural sectors. It is characterized by a temporary lack of precipitation.

- **Types of Drought:**

Four primary categories of drought have been identified **[45][46]**:

- Meteorological drought, determined by the number of rain-free days and specific thresholds for each region.
- Agricultural drought, linked to water demand for crop growth.
- Hydrological drought, affecting surface and underground reservoir recharge
- Socio-economic drought, concerning supply-demand dynamics, alongside the emerging concept of ecological drought.

Figure I.11: Drought in California **[47]**.

- **Impacts of drought:**

Droughts have far-reaching impacts on both surface and groundwater resources, leading to reduced water supply and quality, diminished range productivity, and disruptions in power generation and recreation activities. They also affect various economic and social aspects **[48]**.

I.3. Importance of Studying Precipitation Data:

Accurate prediction of precipitation is crucial for a wide range of applications, from agricultural planning to flood control. Precipitation data analysis influences climate studies, water resource management, and ecosystem modelling.

I.3.1. For agriculture:

Extreme weather conditions, like heavy rainfall and drought, pose significant challenges to agriculture. Heavy rainfall at the end of the crop cycle can damage crops, leading to financial losses for farmers. Drought often results in decreased grain yields and economic losses on farms **[49]**.

The benefits of studying precipitation are also:

a) Short-terme impact:

- Crop growth and yield.
- Soil erosion and fertility.
- Pest and disease management.

b) Long-term planning:

- Water resource management.
- Climate change adaptation.
- Economic planning.
- Developing new agricultural technologies.
- Conservation and sustainability.

Figure I.12: Agricultural drought **[50]**.

I.3.2. For extreme event:

Studying precipitation in extreme events is crucial for understanding, predicting, and mitigating their impacts. By studying these events, it can improve forecasting, build resilience, and adapt to a changing climate, ultimately saving lives and protecting communities.

Studying precipitation in extreme events is critically important for several reasons:

a) **Understanding and predicting events:**
   - Flood forecasting.
   - Drought mitigation.

b) **Risk assessment and adaptation:**
   - Vulnerability mapping.
   - Climate change adaptation.

c) **Scientific understanding and societal impact:**
   - Attribution of events.
   - Improving weather models.
   - Societal impact assessment.

I.3.3. For water management:

Studying precipitation plays a vital role in effective water management by providing the knowledge base for informed decision-making, promoting efficient resource utilization, and building resilience to climate change. It ensures sustainable water use for various sectors, contributing to economic development and environmental protection.

The benefits of studying precipitation data:

a) **Resource assessment and planning:**
   - Estimating water availability.
   - Planning for droughts and floods.

b) **Efficiency and conservation:**
   - Demand forecasting.
   - Promoting water conservation.

c) **Infrastructure development and maintenance:**
   - Designing water storage and distribution systems.
   - Maintaining water quality.

d) **Climate change adaptation:**
   - Adapting to changing precipitation patterns.

I.3.4. For construction of network:

When annual rainfall increases or there is a shift to higher intensity events, the impacts on sanitation may be more profound. And the risks are primarily related to flooding and may have very serious public health implications.

Studying precipitation is vital for:

- Drainage Capacity.
- Pipe Sizing and Design.
- Storm water Management.
- Cost Optimization.

I.4. Precipitation data studies:

Modification in climate as a result of both natural and anthropogenic processes have raised considerable concerns such as more frequent and intense rainfall, droughts, dry spells, violent winds, as they induce adverse impacts on several development sectors **[7]**.

Ouarda and al., (1999) indicate that the adapted variables to the climate monitoring are: river flows, lake levels, rainfall, temperature, the groundwater level according to Doumouya and al.,(2016) among these variables rainfall represents the most important climate factor for population, environment and ecosystems **[51][52]**. Halmstad and al., (2012) Yao and al., (2012) reveal that rainfall plays a key role in the planning and management of sustainable water resources **[53][54]**.

Analysing precipitation data using statistical tests is crucialfor describes precipitation characteristics, identify trends, and predict potential environmental changes. Detecting trends and breaks are important for understanding climate patterns and potential shifts.

I.4.1. Studying breaks and trends in the world:

One of the major challenges in climate change studies is identifying and quantifying trends and structural breakpoints in long-term time series of climatic data, such as rainfall **[55]**. Understanding these patterns helps improve ecological and socioeconomic aspects of rain-fed agricultural regions **[56]**.

In recent years, various approaches have been employed to detect trends and breakpoints in time series data. Alijani (1997) utilized Pettitt test and the Mann-Kendall rank test to analyze annual and seasonal climatic data from 39 stations in Tabriz, Iran, spanning from 1950 to 2007 **[57]**. Mirza et al. (1998) employed the Mann-Kendall test and the Pettitt test for trend analysis using time series of annual rainfall data from 16 meteorological stations in India **[58]**.

Gallagher and Land (2013) utilized the mean shift cumulative sum method to detect trends or structural breakpoints in climate data time series from 1812 to 1999 in Jacksonville, USA **[59]**. Similarly, Agbazo et al. (2019) identified trends and breakpoints in long-term from 1951 to 2010 daily rainfall data from synoptic stations in Benin, West Africa, using statistical methods **[60]**.

Sabrina Taibi et al. (2013) employed statistical tests for detecting breaks or trends in the north of Algeria using data from 1936 to 2009, and the study shows that a significant drop in precipitation is observed from the mid-1970s **[61]**. Hind and Mohamed Meddi (2007) identified ruptures in long-term (1951-2010) rainfall data from 10 stations in the northwest of Algeria using statistical methods. It revealed thatan increasing trend in rainfall spanning the 1930s and 1950s, the decline in precipitation is marked in the early 1940s and mid-1970s**[62]**.

Conclusion:

Climate change can impact precipitation patterns on a global scale. Rising temperature can affect the water cycle, altering evaporation rates, atmospheric moisture content, and precipitation patterns. Changes in precipitation can lead to more frequent or intense rainfall events in some regions and drought conditions in others.

Studying precipitation is essential for informed decision-making in agriculture. It allows farmers to optimize crop production, manage resources effectively, and adapt to changing weather patterns.

The study of precipitation patterns is integral to understanding climate change and its impacts on various sectors. Precipitation data analysis allows for the identification and quantification of trends and structural breakpoints in long-term time series, aiding in informed decision-making and adaptation strategies.

The challenges in climate change studies, including the detection of trends and breakpoints, are addressed through various statistical methods employed by researchers worldwide.

Chapter 02: Study area.

Introduction:

Watersheds play a critical role in hydrology due to their ability to regulate water flow, maintain ecosystems, and support sustainable water resource management.

In this chapter we present our study area, particularly from point of view of location, relief and climate.

The Soummam basin is named after the Soummam River, which runs through it. The word Soummam is a distortion of the Kabyle word assemmam, which means acid. The reason it was called by that name is due to the plants that growing on its banks, which gave a slightly acid taste to the water **[63]**.

II.1. Geographic location:

The Soummam basin bearing the number 15 in accordance with the nomenclature adopted by the National Water Resources Agency (in French: Agence Nationale des Ressources Hydrauliques "ANRH"). It consists of 10 sub- watersheds, equipped with 34 rainfall stations.It is located in the north-eastern part of Algeria, between 3, 38° and 5, 38° east and 35, 45° and 36, 45° north **[60]** and it is 100 Km south and 200 east away from the capital Algiers.

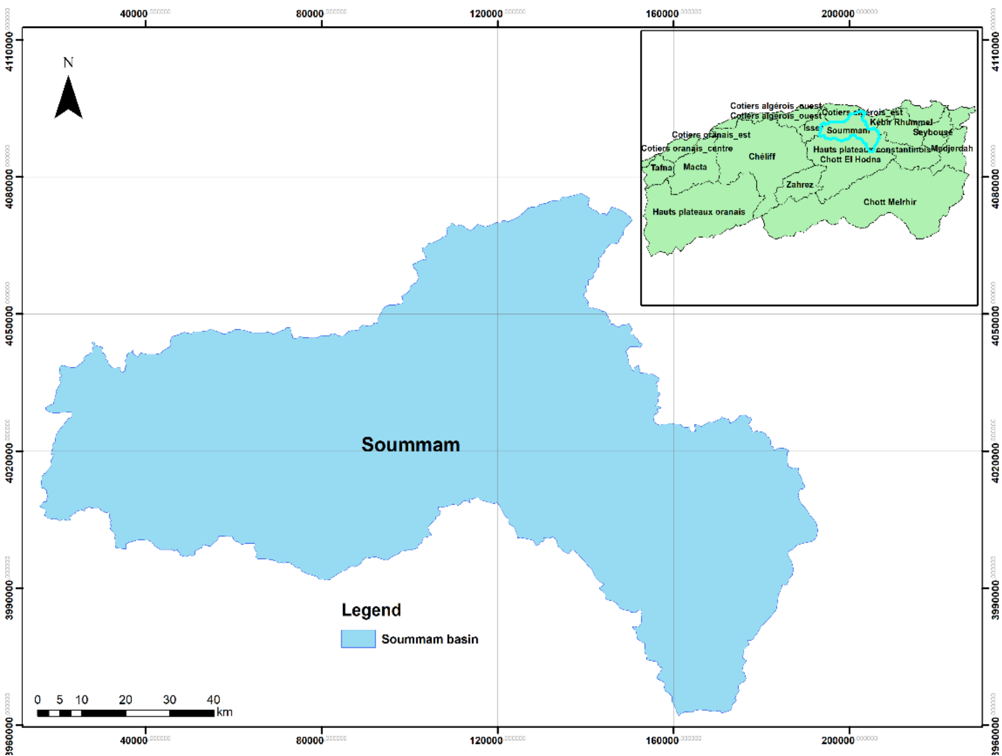

Figure II.01: Geographical location of watershed.

The basin covers an area of 9125 km^2 with an irregular shape stretched in the East-West direction and accesses the Mediterranean via the Gulf of Bejaia.

The Soummam watershed is limited to the north by the Algerian coastal watershed and to the south by the Chott El Hodna watershed. To the east by the Constantinois coastal watersheds, Kébir Rhumel and Constantinois highlands. To the west by the Isser watershed.

II.2. Basin parameters:

The different types of parameters aim to quantify the characteristic factors of the physical environment of a watershed which are of decisive importance on the water flow of the regime.

II.2.1.Surface:

The nature of the basin surfaces has an important role on their hydrological behaviour. The parameters involved are lithology, vegetation cover and slope. These parameters greatly influence the permeability and roughness of the surface, which in turn determines the runoff speed. For the watershed of Soummam we have: **S** = 9125 Km^2.

II.2.2.The perimeter:

The perimeter represents all the irregularities of the contour or the limit of watershed, it is expressed in km. The contour of the basin is made up of a line joining all the highest points. It can be measured using a curvimeter or automatically by mapping software **[64]**.

The perimeter of the Soummam watershed is **P**= 633.8 km.

II.2.3. Compactness or the Graveliusindex (GI):

There are different morphological indices making it possible to characterize the environment, and to compare watersheds with each other.

The Gravelius compactness index (GI) is in fact the ratio of the perimeter of the basin to the circumference of the circle having the same surface area. $GI = 0.28P/\sqrt{S}$

With:

GI: the compactness index

S: watershed surface (km^2)

P: basin perimeter (km)

This index is determined from a topographic map by measuring the perimeter of the watershed and its surface area.

For the Soummam watershed: **GI** = 1.86 .Which means that our basin has an elongated shape.

II.3. Relief:

The influence of relief on flow is easily understood, because many hydro meteorological parameters vary with altitude (precipitation, temperature, etc.) and the morphology of the basin. Additionally, the slope affects the flow velocity.

The relief of Soummam has a fairly irregular shape, near Maillot, that the highest point (Lalla Khadîdja) of the Soummam (2308 m) is located.

The altitude gradually decreases as you advance from Akbou towards the sea. The mountains of Little Kabylia are also pronounced in terms of altitude, their highest peak reaching 2004 m at Jebel Babor. Likewise, the southern mountain ranges do not remain orthographically behind the massifs mentioned above, the peaks are reached at Bibans 1832 m and Djebel Mansourah 1836 m **[63]**.

II.3.1. The major morphological traits:

The relief of Soummam is very varied and the main morphological units from North to South **[61]**.

- **The Djurdjura chain:**

It is a significant chain in the structure of upper Kabylia. It rises abruptly to the north of Bouira to the height of 2123m to reach its maximum height near M’Chedellah, (Lala Khadîdja 2308m). It ends with the Gouraya range and its picturesque Cap Carbon in the Bejaïa golf course.

- **The Soummam valley:**

The Soummam valley is a vast flat-bottomed corridor located between the Djurdjura and the Bibans in the upper course, and between the upper and lower Kabylie in the lower course.

- **The Bibans chain:**

With a general East-West orientation, this chain enters the Soummam basin near Sour El Ghozlane and extends towards Dj. Anechar (1415m) via Azerou N'Said (1283m). An important branch of the chain separates near Guenzat in the direction of Es-Sarsara, (1487m) to reach Anini (1596m).

- **The lower Kabylie chain:**

To the east of the basin, a considerable mountain range appears; it is the lower Kabylie chain. This range is located to the North-East of the downstream course of the Bousselm and is made up of a series of differently oriented ridges. Its average height varies between 1200 and 2000m and reaches its maximum at Babors (2004m).

- **The southern chain:**

These are small ridges which separate the mountainous terrain of the Tell Atlas from the Hodna plain.

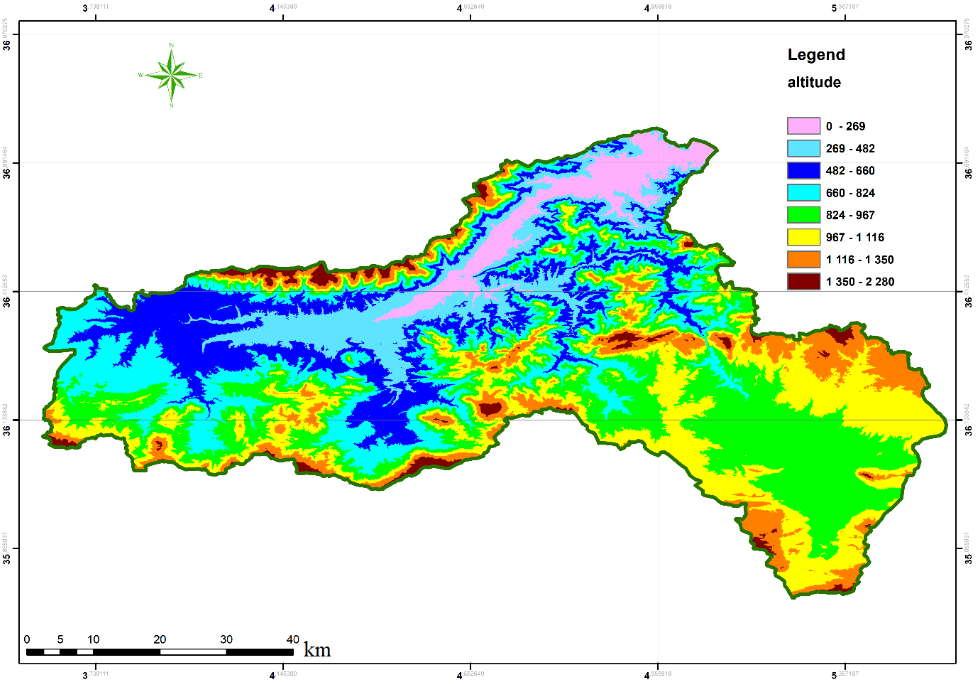

Figure II.02: Relief map.

The relief is also determined by the following characteristics:

- **Hypsometric curve:**

The hypsometric curve provides a synthetic view of the slope of the basin, and therefore of the relief. This curve represents the distribution of the surface of the watershed as a function of its altitude. It shows on the abscissa the surface (or the percentage of surface) of the basin which is above (or below) the altitude represented on the ordinate **[64]**.

Table II.01: The hypsometry of the Soummam basin **[65]**.

Class of altitudes (m)	Surface elementary (km²)	Surface Cumulative (%)	Average altitude (m)
2-200	379	100	100
200-400	724	95,85	300
400-600	1425	87,91	500
600-800	1825	72,30	700
800-1000	3119	52,30	900
1000-1200	1105	18,12	1100
1200-1400	274	6,01	1300
1400-1600	174	3.00	1500
1600-1800	50	1,10	1700
1800-2000	0	0,55	1900
2000-2200	0	0,55	2100
2200-2400	50	0,55	2300

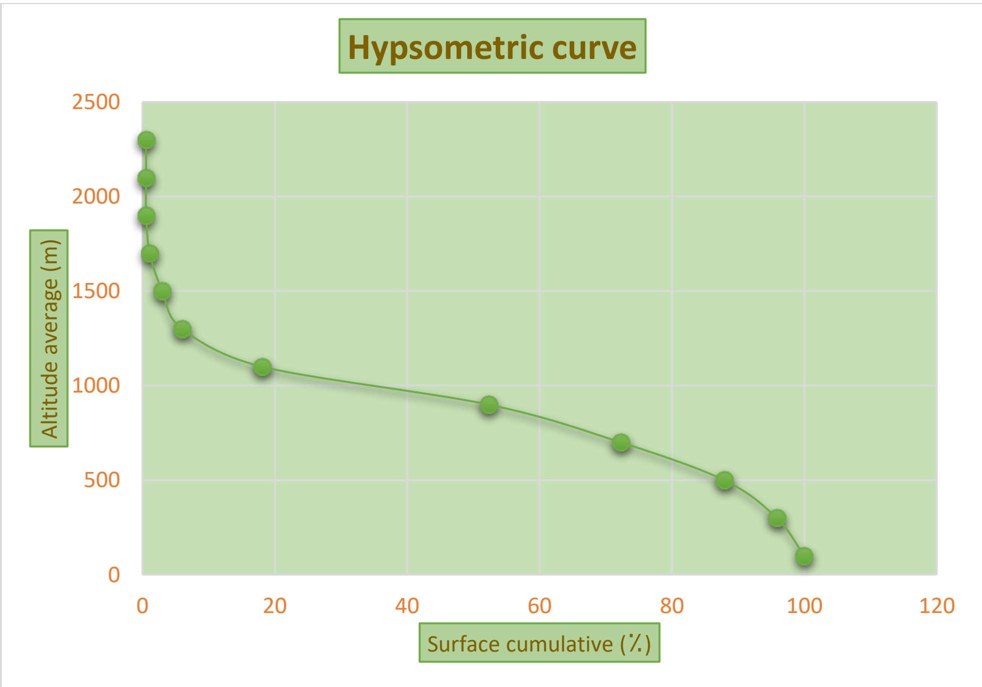

Figure II.03: Hypsometric curve.

We note that the altitude range above 1400 m, corresponds to significant mountain ranges and only the mountain ranges of Djurdjura exceed 2300 m. The altitudezones between800 and 1000 m cover 3119 km2, or 52.30% of the total area, they are distributed in the South and South-East of the basin. The altitude range below 200 m corresponds to the Soummam valley.

From the hypsometric curve, we can determine:

H 95% = 300m.

H 50% = 900m.

H 5% = 1300m.

So the Soummam watershed is a mature basin.

- **Altitude characteristics:**

- **Minimum and maximum altitudes:**

The minimum and maximum altitudes of the Soummam watershed are read directly from the topographic map. The minimum altitude is that which corresponds to the outlet of the basin near the sea, while the maximum altitude is found on the Djurdjura Mountains such as:

HMIN = 2 m.

HMAX = 2308 m.

- **Average altitude:**

The average altitude is deduced directly from the hypsometric curve. It is defined as follows: H average = $\sum \boldsymbol{Hi} / \sum \boldsymbol{Si}$

With:

H average: average altitude of the watershed.

Si: area between two level curves.

Hi: average altitude between two contour lines.

For our watershed **H average** = 785 m.

- **Median altitude:**

The median altitude corresponds to the altitude read at the point of abscissa 50% of the total surface of the basin, on the hypsometric curve. This quantity is close to the average altitude in the case where the hypsometric curve of the basin concerned presents a regular slope **[66]**.

For the Soummam basin **H median**= 900m.

We notice that the median altitude is higher than the average altitude, which means that the basin presents a slight asymmetry towards higher altitudes.

- **Slope indices:**

The purpose of these indices is to characterize the slopes of a basin and to allow comparisons and classifications. The slope indices are determined from knowledge of the hypsometric distribution over the basin **[62]**.

- **Global slope index:**

It is determined from the slope of the hypsometric curve. It is the ratio of the difference in frequency altitudes of 5% and 95% to the equivalent rectangle length.**GS**=H/L, with:

- H: height difference.
- L: length of the equivalent rectangle.
- H: is determined from the hypsometric curve such that:
- H = H 5%- H95% = 1300-300 = 1000 m
- H (5% and 95%) is the altitudes between which 95% of the watershed surface.

II.4. Hydrography study:

II.4.1.Hydrographic network:

The hydrographic network is defined as all the natural or artificial watercourses, permanent or temporary, which participate in the flow. The wadis and their tributaries constitute its fundamental hydrographic skeleton **[67]**.

The hydrographic network of the Soummam basin is very developed and has 9 main wadis totaling a length of 726 km. The longest is 226 km (Oued Soummam) and the shortest is 23 km (Oued O'Khriss). The main drainage system of the Soummam basin includes, to the west, the Oued Sahel and its tributaries, and to the east, the Oued Bousselm and its tributaries. These two wadis come together near Akbou to form Oued Soummam which flows into the Mediterranean.

At its confluence with Oued Bousselm, Oued Sahel drains a basin of 3,750 km². It is formed by the meeting of Oueds Eddous and Zaiane with drainage basins of 940 km² and 970 km² respectively. The Oued Sahel valley is relatively narrow and extends more or less from Bouira to Akbou. Oued Boussellem joins Oued Sahel to form Oued Soummam, at the entrance, the watershed of Oued Boussellem is 4500 km².The upper course of Oued Bousselm is on the Setif plateau and for most of its course, once past the plateau, it crosses very rugged mountainous regions following gorges or very narrow valleys.

From Akbou to Bejaïa, the Oued Soummam crosses a relatively narrow but fertile valley, before flowing into the sea. The drainage area of the lower Soummam (not counting the watersheds of the Oueds Sahel and Bousselm) is 1150 km² at its entrance **[68]**.

- **The sub-basins:**

The Soummam watershed is made up of 10 sub-basins corresponding to hydrological units, these sub-basins have different surface areas, some of which are controlled by hydrometric and rainfall stations.

We can say that the Soummam watershed is made up of 3 large sub-basins **[61]**.

- Bousselam sub basin.
- Edous Esahel sub basin.
- Soummam sub basin.

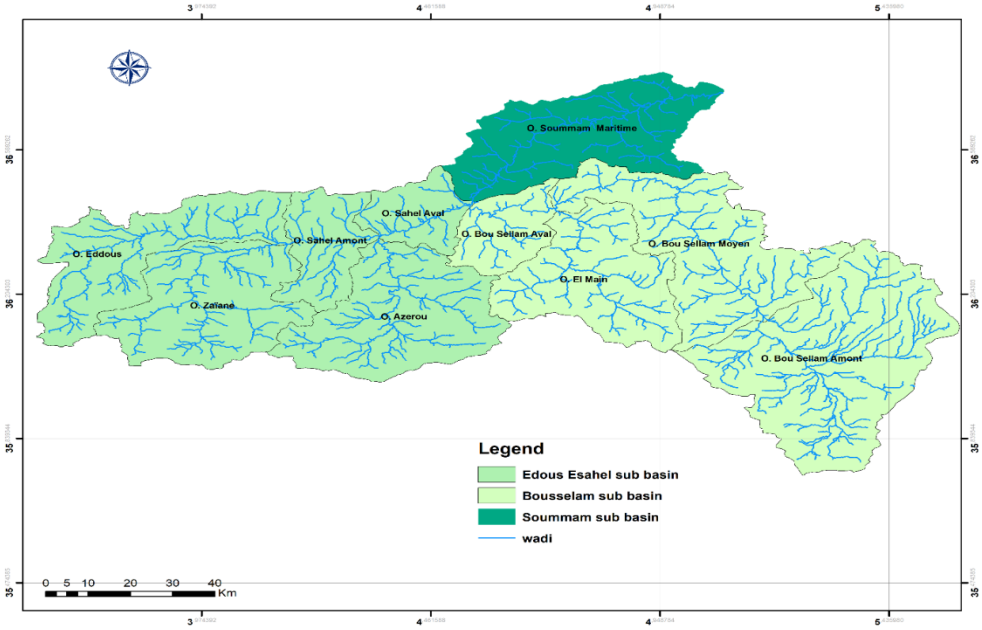

Figure II.03: Hydrographic network of Soummam watershed.

II.4.2. Characteristics of the drainage network:

II.4.2.1 Drainage density:

It is the quotient of the sum of the lengths of all the watercourses to the surface area of the drained basin: $Dd = \sum Li / S$

With:

- Dd: drainage density [Km/Km²)].
- Li: cumulative total length of watercourses of order (i) in [Km].
- S: surface area of the watershed (Km²).

The drainage density will therefore be**: Dd** = 0.62 Km / Km².

II.4.2.2 Hydrographic density:

Hydrographic density is defined as the number of basin drains per unit area:

Hd= Ni*S, where:

- Hd: hydrographic density [Km^{-2}]
- Ni: number of rivers
- S: area of the basin [km²].

For the Soummam watershed: **Hd**= 0.20 $Km^{-2.}$

II.4.2.3 Torrentiality coefficient:

The torrentiality coefficient is obtained using the following relationship:

Tc = (N1/S) Dd.

- Tc: torrentiality coefficient
- N1: number of thalwegs of order 1
- S: area of the basin in km²
- Dd: drainage density in km/Km²

We obtain for the Soummam watershed: Tc = 0.089.

II.5. Water resources in the Soummam watershed:

II.5.1. Assessment of water potential:

• Evaluation of surface water potential:

The surface water potential of the Soummam basin is estimated at 465.1Hm^3/year, or 16% of the water potential of the Algiers-Hodna-Soummam hydrographic basin of which the Soummam basin is a part **[69]**.

Surface water potential is illustrated in the following table.

Table II.02: Surface water potential **[69]**.

Subbasin	Code	Surface (Km^2)	Annual contribution(Hm^3)
Boussellem	150401	4.309	165,4
Eddous–Sahel	150302	3.755	167,0
Soummam	151001	1.061	132,7
Total		9.125	465,1

- **Assessment of groundwater potential:**

The hydrogeological units of the basin are distributed as follows:

- Aquifer of the upper and middle Soummam.
- Lower Soummam tablecloth.
- El Asnam tablecloth.
- Tablecloth of the high Setifian plains.

The estimate of groundwater resources in the Soummam basin, based on the results of the National Water Plan (NWP) is given in following table.

Table II.03: Water potential per hydrogeological unit **[69]**.

Hydrogeological unite	Nature of reservoirs	Potentialities (Hm^3 per year)
Soummam	WadiSoummamand miocene alluvium	100
CapAokas	Alluviumand dune sand	3
ElAsnam platter (Bouira)	Quaternary gravels and clays and miocene	15
Coastal plains of Bejaia	Quaternary	35
Total		153

The water potential of the Soummam hydrogeological unit is 153 Hm^3/year, or 65% of the groundwater resource in the Soummam watershed.

II.5.2 Mobilization of water resources:

- **Mobilization of surface water:**

- **Dams:**

The Soummam basin currently has 2 dams in operation, namely: Lekhal and Ain Zada, totaling a capacity of 155 Hm^3 **[70]** and regulating a volume of 67 Hm^3 per year.

Furthermore, we note the existence of two other dams recently in operation; Tichy Haf and Tilesdit totaling a capacity of 247 Hm^3.

- **Lekhal Dam:**

It is located 5 km from Ain Bessem in the wilaya of Bouira. It is located at the confluence of Oueds Lekhal and Fahem. The contributions from Oued Lekhal amount to 22 Hm^3/year for a catchment area of 189 km^2. It is intended for the irrigation of the Aribs perimeters and the water supply of Ain Bessem, Sour El Ghozlane and the industrial zone.

- **Dam tilesedit:**

This dam is located approximately 18 km east of the town of Bouira. With a capacity of 167 Hm^3 and a regulated volume of 73 Hm^3/year. The Tilesdit dam is intended to strengthen the supply of drinking water to the town of Bouira and its neighboring communes, the industrial zone of Sidi Khaled as well as the irrigation of the planned areas: El Esnam plateaus and valley of Sahel and Bled El Madjen, Hamza and El Hachimia.

- **Hill reservoirs:**

Across the territory of the Soummam basin, 73 hill reservoirs have been identified (table II.04) according to the DMRE of the Ministry of Water Resources and Environment **[71][69]**.

Table II.04: Hill reservoirs and their capacities by wilaya **[71]**.

Wilaya	Hill collinaires	
	Number	Capacity×1000m^3
Bejaia	29	1,15
Bouira	33	4,62
Setif	9	5,83
BordjBouArreridj	2	0,80
Total	73	12,4

The total capacity of these reservoirs is 12.4 Hm^3, including 47% and 37% respectively in the wilayas of Setif and Bouira (33 hill reservoirs).

- **Mobilization of groundwater:**

The mobilization of groundwater resources is done through fodder, wells and springs which capture the main aquifers of the basin.

According to the wilaya water management department Bejaïa, Setif, Bordj Bou Arreridj and Bouira, the Soummam watershed has 310 forages, 259 of which are in operation. The volume exploited is 179.30 Hm^3/year distributed as follows **[70]:**

- 170 fodder allocated to drinking water supply, using 88.30 Hm^3/year;
- 69 fodder allocated to irrigation using 75 Hm^3/year;
- 20 fodder used for industry, producing 16 Hm^3/year;
- 24 are stationary, including 12 abandoned and 27 unequipped.

II.6. Plant covers:

The vegetation in the Soummam watershed significantly influences its hydrological dynamics. It varies in type, density, and distribution across different regions, shaped by climatic conditions. From oak groves in the alluvial areas to olive groves and vineyards in the lower and middle regions, the vegetation diversifies. However, forest loss, exacerbated by insufficient reforestation and fire prevention measures, threatens the ecosystem, impacting both hydrology and the timber industry **[68]**.

II.7. Climate:

Figure (II.07) illustrates that the basin exhibits four distinct climate types. Bejaia experiences a humid climate, whereas the middle and portions of the upper Soummam basin have a sub-humid climate. The eastern and southern sides of the basin display sub-arid conditions, indicating an arid climate.

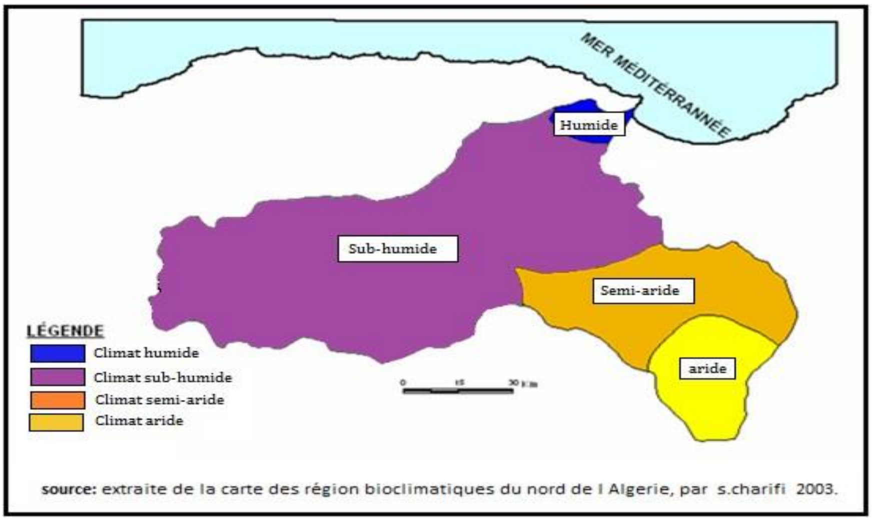

Figure II.04: Type of climate **[63]**.

II.8. Environmental challenges faced by Soummam watershed:

The Soummam watershed faces several environmental challenges, including soil erosion, surface water pollution, and the impact climatic changes and irregular demographic growth that could negatively affects its ecosystem and water resources.

Soil erosion is a significant problem in the region, affecting a large part of the land in northern Algeria. Furthermore, research has been conducted to map the surface water erosion potential in the area, aiming to estimate annual soil loss and understand the extent of this environmental challenge **[74]**.

The Soummam River showed a strong pollutant load, which was organic in origin and expressed by mean concentrations in suspended matter. This load is the result of the significant volume of urban and industrial emissions in the river, the high temperature during low water level periods, and flood events **[74]**.

Figure II.05: Ecological disaster of wadi Soummam**[75]**.

Conclusion:

The second chapter was devoted to the collection of all descriptive data in the study area. The Soummam basin consists of 10 sub- watersheds, it covers an area of 9125 km^2 stretched in the East-West direction and accesses the Mediterranean via the Gulf of Bejaia.

The relief of Soummam has a fairly irregular shape. The hydrographic network of the Soummam basin is very developed and has 9 main wadis totaling a length of 726 km. The longest is 226 km (Oued Soummam) and the shortest is 23 km (Oued O'Khriss).

The Soummam basin generally experiences a Mediterranean climate, hot dry summers and mild wet winters.

Chapter 03: Data and methods.

Introduction:

By meticulously collecting and analyzing data on precipitation, evapotranspiration rates and other factors, scientists are able to progressively construct a comprehensive understanding of earth's climate system.

In this chapter we will talk about data, software and methods that can help detecting breaks.

III.1. Data:

Climate data is a vital resource for understanding our planet's weather patterns and trends, utilized in diverse fields such as meteorology, climatology, agriculture, and water resources management. Once collected, climate data undergoes analysis by scientists employing various statistical methods.

The precipitation data collected from the stations in the Soummam basin has been utilized for various analyses, including statistical modeling of monthly rainfall variability, ensuring the control and homogeneity of annual precipitation data, and characterizing and predicting meteorological droughts **[78]**. In this study, rainfall data from 15 rainfall stations is provided by the National Water Resources Agency (in French: Agence Nationale des Ressources Hydrauliques "ANRH"). The precipitation series are complete, with no gaps **[79]**.

III.1.1. Data observed:

Observational data provide a historical record of past precipitation events, obtained through direct rainwater catchment in rain gauges or with technical instruments from a distance.

This historical record of precipitation is valuable for examining changes and trends in day-to-day climate. However, observed precipitation data are specific to the sampling location and range of detection, which can lead to gaps in the spatial and temporal resolution of the dataset. Nevertheless, observational systems offer an accurate depiction of the amount of rain produced by extreme events such as hurricanes or monsoons.

III.1.2. Precipitation data limitations:

It's impossible to precisely determine the exact weather conditions at every point in space, leading to limitations in all datasets. Observational data often contain missing values due to station maintenance or equipment malfunctions, while error sources may stem from sampling errors, calibration uncertainty, or random errors. Instrument and calibration uncertainty can introduce biases.

Additionally, some radar and satellite data lack records old enough for climatological research, which typically requires at least 30 years of historical data. Simulated outputs from mathematical equations may not capture precipitation events with the same level of detail as observed datasets. Many researchers rely on reanalysis data, but accurately simulating precipitation patterns, seasonal variations, and characteristics with mathematical models remains an area of active research **[80]**.

Moreover, Harmel et al. (2002) highlighted the difficulty in predicting weather variability, especially in extreme events, as these events often don't conform to common mathematical distributions **[81]**. Combining different output datasets can improve the accuracy of regional and global precipitation data **[82][83][84]**.

III.2. Climate:

III.2.1. Type of climate:

By looking at climate data for specific location, we can determine its climate type. There are many different ways to classify climate and for this study we use the aridity index.

- **Aridity index:**

Aridity is a climatic phenomenon based on the average climatic conditions of a region, defined by the scarcity of humidity **[85]**. The aridity index (AI) classifies the type of climate in relation to water availability. It is an estimate of the average water available in the soil. This index is usually defined as the ratio between mean annual precipitation (P) and mean annual potential evapotranspiration (ETP). $AI = P / ETP$.

Table III.01: The different classes of aridity **[86]**.

Classification	Aridity index
Hyper arid	$AI < 0.08$
Arid	$0.08 < AI < 0.20$
Semi-arid	$0.2 < AI < 0.5$
Dry sub humid	$0.5 < AI < 0.65$
Sub humid	$0.65 < AI < 1$
Humid	$1 < AI$

The higher the aridity index of a region the greater the water resources variability and scarcity over time.

The results of the aridity index were mapped to show the different types of climate existing in the Soummam basin in the chapter 04.

III.3. Rainfall stations:

Rainfall stations are ground based facilities equipped with instruments to measure and record the amount, type, and intensity of precipitation at a specific location. They play a crucial role in weather monitoring, climate research, and water resource management.

The following table represents the code, longitude, latitude, and altitude for fifteen stations.

Table III.02: Inventory of the rainfall stations used in this study **[79]**.

Name	Code	Longitude °	Latitude°	Altitude (m)
Sour El Ghozlane	150101	3.704342	36.14322	866.32
Bordj Okhriss	150202	3.971244	36.08164	737.98
El Esnam	150204	4.038449	36.31172	433.90
Bouira	150208	3.9897	36.32803	506.63
Ben Daoud	150402	4.184069	36.08776	931.57
Tizi Nslib	150504	4.505616	36.49902	1056.09
Ain Arnat	150607	5.311788	36.18416	1018.8
Bouira Coligny	150608	5.278535	36.21174	1001.86
Tixter	150614	5.084451	36.04936	956.1
Bir Kasdalli	150707	5.026109	36.14249	978.94
Sidi Embarek	150801	4.90994	36.1032	1011.19
Bordj Zemmorah	150802	4.833994	36.26859	939.10
Sidi Yahia	150904	4.617067	36.42111	229.24
Sidi Aich	151001	4.682016	36.60806	101.79
Domaine Maouchi Ah	151004	4.848431	36.63857	60.62

The following map represents the position of fifteen stations in Soummam basin.

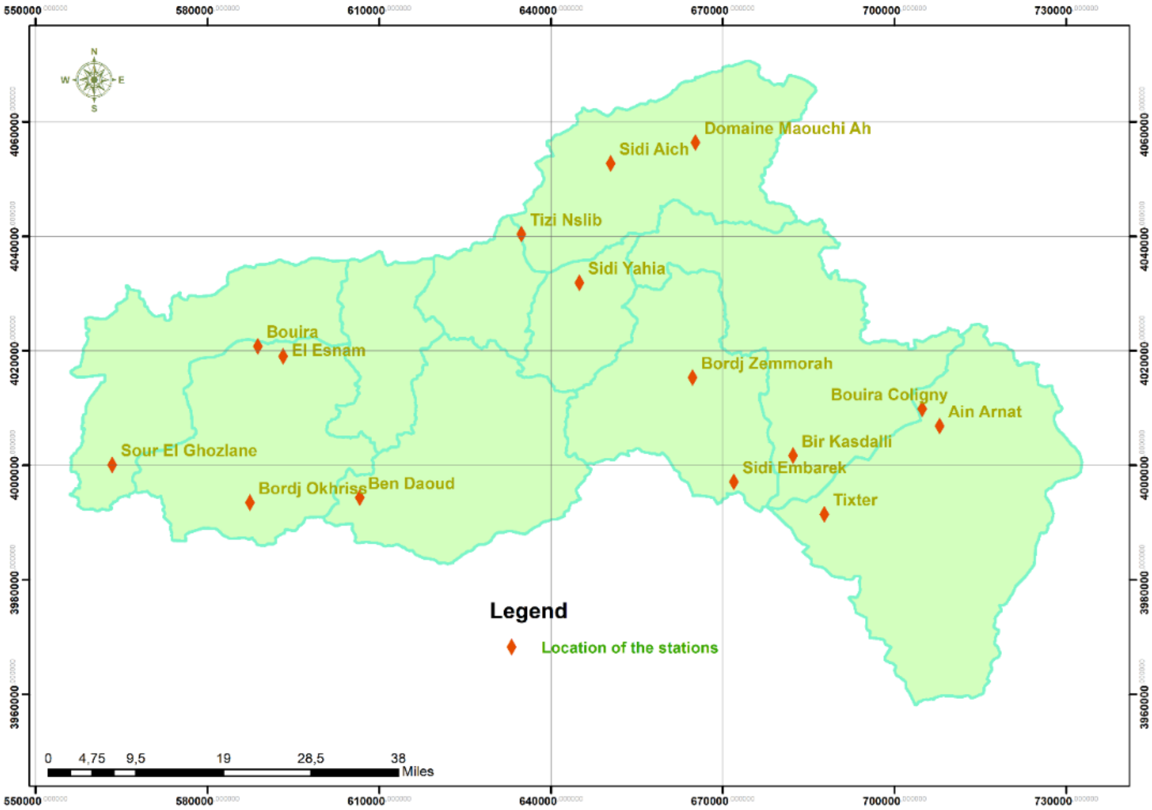

Figure III.01: Location of the rainfall stations in the Soummam basin.

In this study, all of the 15 rainfall stations were particularly selected as having no missing value.

- **Characteristics of precipitation data:**

The average precipitation represents the typical amount of precipitation received at a station over a specific period. It provides a central tendency value, a baseline for comparing precipitation with other periods or locations.

Standard deviation of precipitation represents the amount of variation in precipitation data compared to the average.

A high standard deviation signifies significant deviations from the average, while a low standard deviation suggests more consistent precipitation patterns.

The following table represents characteristics of precipitation data.

Table III.03: Characteristics of precipitation data **[79]**.

Name	Min (mm)	Max (mm)	Average (mm)	Standard deviation (mm)
Sour El Ghozlane	255(1983)	840 (2002)	437	436
Bordj Okhriss	46 (1974)	568 (1971)	286	109
El Esnam	98(2001)	592 (1969)	336	109
Bouira	209 (2001)	816 (1971)	437	117
Ben Daoud	31 (1983)	725 (1969)	274	151
Tizi Nslib	269 (1996)	778 (2002)	526	97
Ain Arnat	136 (1977)	573 (2002)	347	94
Bouira Coligny	202 (2001)	577 (1991)	409	98
Tixter	77 (2001)	543 (2008)	269	107
Bir Kasdalli	157 (1987)	734 (1969)	391	126
Sidi Embarek	193 (2001)	518 (1991)	323	79
Bordj Zemmorak	177 (2001)	885 (1972)	504	154
Sidi Yahia	93 (1974)	629 (2002)	382	108
Sidi Aich	249 (1996)	910 (1969)	494	127
Domaine Maouchi	222 (1964)	775 (2011)	470	127

III.4. Break detection methods:

The methodology presented in this study, applied to the Soummam basin, involves the identification of breaks in precipitation series. A break is defined as an abrupt change in the probability distribution of the series at a given time, typically unknown. It corresponds to a reversal in the trend of the time series **[87]**.

In order to determine breaks in the precipitation series over the period 1960–2013, several break tests are conducted. A low break indicates detection by a single test, suggesting a lower probability of a break. A probable break occurs when the break is detected by two or three statistical tests. A proven break indicates detection by more than three tests, signifying a significant probability of a break **[88]**.

The methods used to detect a break include the Pettitt test, Buishand test, ellipse of Bois, Lee and Heghinian test, and the segmentation procedure of Hubert. However, these statistical analysis methods are complex and require specialized software, therefore, we opted for Khronostat.

III.4.1. Description of Khronostat model:

Khronostat is a statistical model developed by the Research Institute for Development (RID) at the House of Water Science (HWS) in Montpellier. It was developed as part of a study on climate variability in West and Central Africa and is focused on the analysis of hydroclimatic series **[89]**. It can operate at annual, monthly, or daily scales depending on the needs expressed.

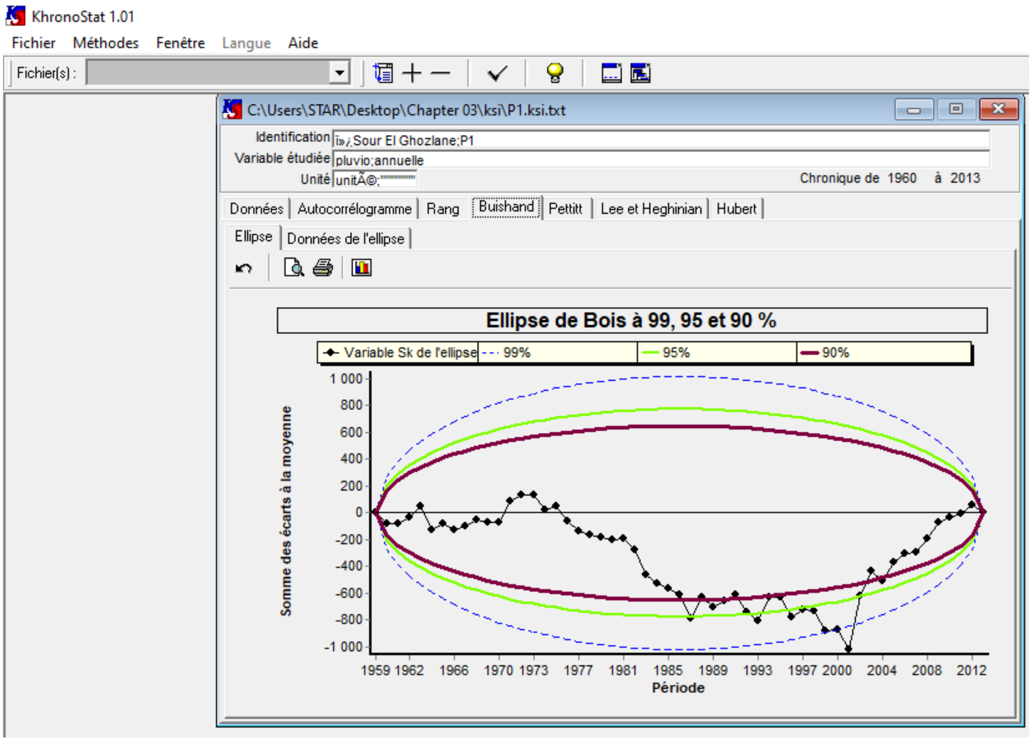

Figure III. 02: Khronostat software.

Khronostat is adaptable to all variables, including climatic, hydrological, and meteorological data. However, it requires complete series with no gaps. It is highly recommended by meteorologists and climatologists worldwide for drought surveillance or monitoring.

Khronostat incorporates various statistical tests:

•**The first test category**:

Concerns the randomness (or independence test) series (correlation test on the rank and autocorrelogram test), they carry to the constancy of the average of the series throughout its observation period. Autocorrelation is a statistical tool used to analyze time series data. It essentiality measures how similar a series is to a lagged version of itself.

•**The second test category**:

Concerns the homogeneous character of the series (Pettitt test, Buishand test, Hubert test, Bayesian methods or Lee and Heghinian test), they relate to the detection of breaks in a time series **[90]**. These tests typically do not have very strict application conditions.

❖ **Pettitt's test:**

The Pettitt's test is a non-parametric test that requires no assumption about the distribution of data. It is an adaptation of the tank based Mann Whitney test that allows identifying the time at which the shift occurs. It is used to detect changes in a time series, making it particularly useful for analysing environmental data such as rainfall, temperature, or river flow **[91]**.

The steps are: the studied series is divided into two sub-samples of sizes *m* and *n* respectively, than the values of the two samples are grouped and arranged by increasing order. The sum of the ranks of the components of each sub-sample in the total sample is then calculated. A statistic, U_t, is defined using the two sums thus obtained in order to assess whether the two samples belong to the same population **[89]**.

$$\text{Sgn}(x) = \begin{cases} 1, x > 0 \\ 0, x = 0 \\ -1, x < 0 \end{cases} \quad (1)$$

$$D_{i,j} = \text{sgm}(x_i - x_j) \quad (2)$$

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{i,j}, \quad (3)$$

$$K_N = \max_{t=1,N-1} |U_{t,N}| \quad (4)$$

If k is the value of K_N taken on the studied series, under the null hypothesis, then:

$$\text{Prob}(K_N > K) = 2\exp(-6 * K^2 / (N^3 + N^2)) \quad (5)$$

If Prob $(K_N > k) < \alpha$, for a significance level α, then the null hypothesis is rejected.

❖ **Buishand and Lee and Heghinian's tests:**

The Buishand and Lee and Heghinian tests are Bayesian procedures applied under the assumption that the studied series is normally distributed **[92]**.The tests are based on the following model, which supposes a change in the series mean:

$$x_i = \begin{cases} \mu + \varepsilon & ,i = 1,\ldots\ldots,m \\ \mu + \varepsilon + \delta, & i = m + 1,\ldots\ldots N \end{cases} \qquad (6)$$

Where ε_t are random variables, independent and normally distributed, with null expectance and a constant variance. The break point m and the parameters μ and δ are unknown.

The Buishand's test (1982) can be used on variables following any type of distribution. But its properties have been particularly studied for the normal case **[93]**.It is known for its sensitivity to changes in the middle of a series, making it particularly useful for detecting mid series shifts.

Lee and Heghinian is a statistical test used to detect changes in the mean level of sequences of independent normal random variables. It works in the hypothesis that $(X_i)_{i=1,N}$ is a series of independent variables, with a constant variance.

The method determines the a posteriori probability distribution function of the parameters μ and δ, considering their a priori distributions and supposing that the break time follows a uniform distribution. The range of the break time corresponds to the values of the modes of the a posteriori distributions of *m* and δ respectively **[92]**.

- **Ellipse of Bois:**

Ellipse of Bois test is a non-parametric test developed by French hydrologist Helene Buishand. It is based on the idea of comparing the distribution of data points within an ellipse to the distraction of points outside the ellipse. If there is a significant difference in the distributions, it suggests that there may be a breakpoint in the data **[94]**.

Ellipse of Bois test and the Buishand test are both effective methods for detecting breakpoints in the time series. However the ellipse of Bois test is more likely to detect a breakpoint if there are a few data points.

- **Hubert's test:**

Hubert's segmentation procedure detects the multiple breaks in time series. The principle is to cut the series into m segments (m >1) such that the calculated means of the neighbouring sub series significantly differ **[95]**.

To limit the segmentation, the means of two contiguous segments must be different to the point of satisfying Scheff's test **[95].**The procedure gives the timing of the breaks.

Also khronostat has the normality test, it determines whether a sample data has been drawn from a normally distributed population. It is generally performed to verify whether the data involved in the research have a normal distribution.

III.4.2. Principle of a statistical test:

A statistical test is to make decisions based on information collected on a sample **[96]**. The tests are to determine if a characteristic (average or standard deviation) taken from sample, is identical to a reference (standard) or that of another sample.

The choice of test depends on the specific research question and characteristics of data being analysed.

A statistical series can be characterized by two type of parameters:

- **Position parameters (median, average):**

They give the order of magnitude of the observations and are related to the central tendency of the distribution

- **Dispersion parameters (standard deviation, variance, coefficient of variation):**

They show how observations fluctuate around the central tendency **[97]**. Ordinarily, tests are ranged in two categories:

- **The parametric test:**

It is test the value of certain parameter, in this case, the characteristics of the data can be summarized using the estimated parameters of the sample, subsequent testing procedure bears then on these parameters.

- **Non parametric test:**

Non parametric test is test that do not involves parameters and make no hypothesis on the distribution of variables, the prior step is to estimate the parameters of the distributions before proceed the hypothesis test itself.

Whatever the test category used, the goal is to decide between two hypotheses, one called null or fundamental denoted by H0. A hypothesis is an attempt to explain how a phenomenon works or approach consisting of that assessment based on a data set (sample). In general, the null hypothesis corresponds to a stationary situation while the alternative hypothesis reflects a change (breaks or trend) **[98]**.

The fundamental notion on testing, the probability that one has to be wrong. There are two ways to go wrong in a statistical test:

-Wrongly reject the null hypothesis H0 when it is true.

- Accept the null hypothesis when it is false.

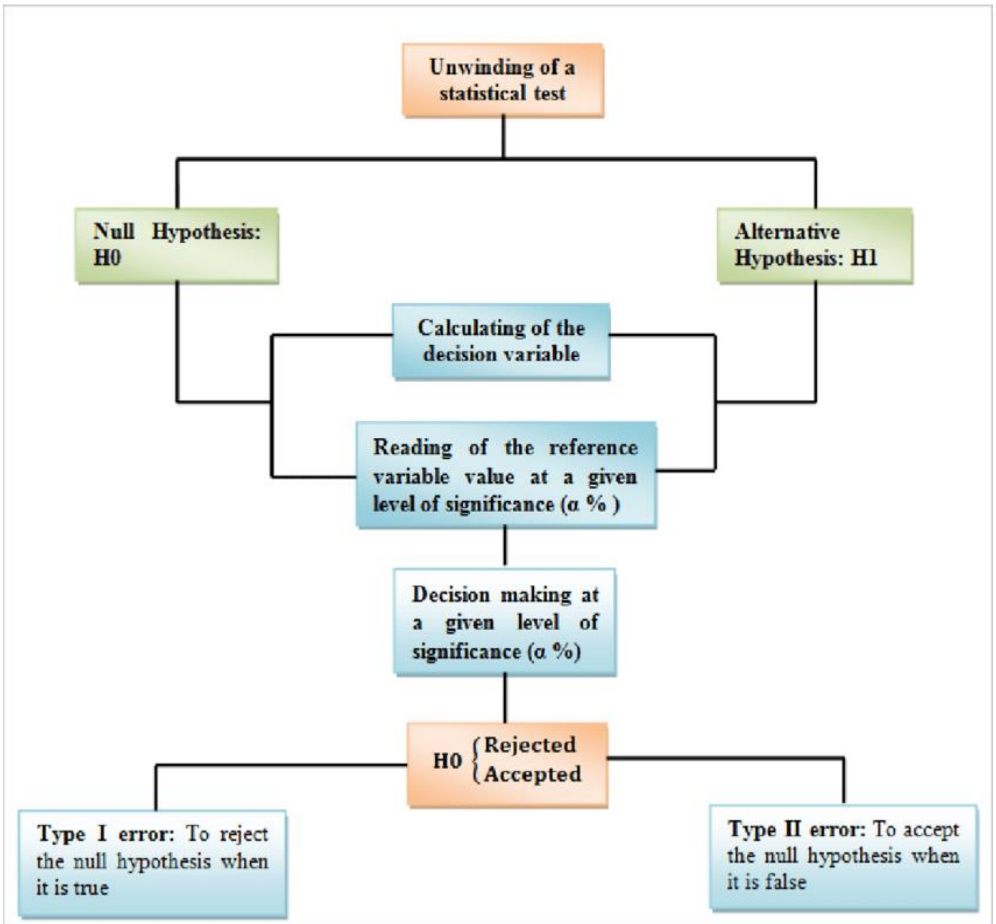

Figure III.03: Organization of statistical tests **[99]**.

III.5. The used method for trend detection:

The trend is a significant change over time exhibited by a random variable, detectable by statistical parametric and non-parametric procedures.

In this study, trend detection was carried out by R Studio software by using Mann Kendall test to see if the trend is significant or not.

III.5.1. Mann Kendall test:

The Mann Kendall (MK) test is a non-parametric test, commonly used to detect significant trends in hydrological and meteorological time series **[100][101][102][103][104]**. The test can cope with missing values and it is suitable for the data that do not follow a normal distribution **[105]**.

III.5.2. Sen’s slope:

Sen’s slope is the median of all slopes passing between pairs of distinct x and y coordinates. It is basically use to identify the magnitude of trend in a data series **[102]**.

Conclusion:

By analysing climate and precipitation data, it offers a powerful lens for understanding the planet’s climate, managing water resources effectively, and supporting sustainable agriculture.

Statistical tests are a fundamental tool in research, especially in analysing data and drawing conclusions from it. They provide a systematic way of uncovering hidden patterns and trends.

Employing statistical tests on the precipitation series can assess whether there have been breaks or not. The null hypothesis states no change in the underlying distribution of the data series, while the alternative hypothesis proposes a change point at some unknown time.

Chapter 04: Results and discussion.

Introduction:

The spatial analysis is a valuable approach to understanding how climate conditions have varied across different regions within the study area over distinct time periods. It helps identify localized climate trends, which can be vital for regional planning and resource management.

Detecting breaks in the precipitation series provides valuable information for understanding past climate changes, predicting future trends, and making informed decisions about water resource management.

This chapter aims to analyze the break of annual rainfall series of 15 stations in the Soummam basin from 1960 to 2013.

IV.1. Evolution of annual precipitation

IV.1.1. Under the influence of climate:

To better understand the relationship between climate type and precipitation, we conducted an analysis of the annual rainfall evolution curves for three stations: Ben Daoud, with a low aridity index value (0.29), Sidi Yahia, with an average value (0.50), and Bordj Zemmorah, with a high aridity index value (0.66).

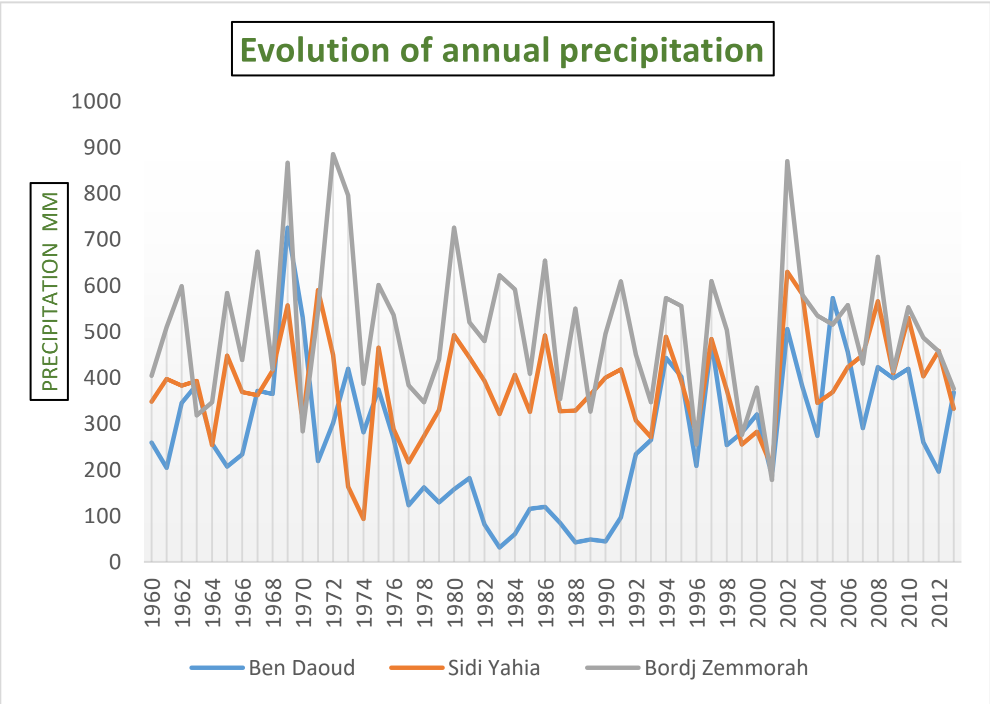

Figure IV.01: Evolution of annual precipitation of three rainfall stations from 1960 to 2013.

Figure IV.01 represent the evolution ofannual precipitation of three rainfall stations from 1960 to 2013. Bordj Zemmorah is characterized by periods of high rainfall in 1969, 1972, and 2002, with a peak value of 885.2 mm in 1972, and periods of low rainfall in 1971 and 2001, with a minimum value of 177.7 mm in 2001. Precipitation values at Sidi Yahia range between 93.2 and 629.4 mm. Ben Daoud is characterized by a period of low rainfall from 1975 to 1993, with a minimum value of 31.3 mm in 1983. The highest value (725.2 mm) was recorded in 1969.

The amount of precipitation received by stations is influenced by the climate of their respective regions. For instance, the Bordj Zemmorah station, located in a sub-humid climate, receives a higher amount of precipitation. In contrast, the Sidi Yahia station, situated in a dry sub-humid area, receives an average amount. Lastly, the Ben Daoud station, located in a semi-arid climate, receives the least precipitation among the three stations.

We conclude that a higher aridity index indicates a more humid climate, with higher precipitation compared to a lower aridity index, which indicates a drier climate with less precipitation.

IV.1.2. Threshold:

Threshold is a specific amount of precipitation used as a benchmark.

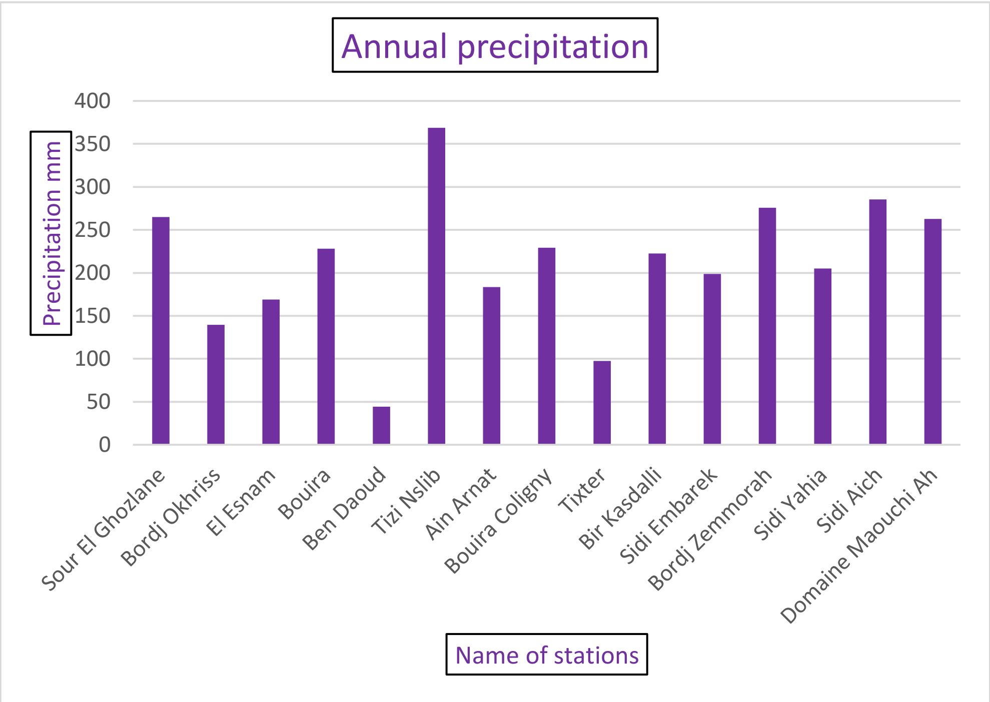

Figure IV.02: Threshold of annual precipitation.

Figure IV.02 can be divided into three categories. The first category includes two rainfall stations: Ben Daoud station with a threshold of 44.2 mm, and Tixter station with a threshold of 97.4 mm. These two stations have the lowest thresholds due to the semi-arid climate. The second category includes Bordj Okhriss, El Esnam, Ain Arnat, Sidi Embarek, Sidi Yahia, Bir Kasdalli, Bouira, and Bouira Coligny, with thresholds varying between 139.7 mm and 229.4 mm. The third category includes five stations: Domaine Maouchi (262.6 mm), Sour El Ghozlane (265.1 mm), Bordj Zemmorah (275.9 mm), and Sidi Aich (285.5 mm), with the highest threshold detected in the Tizi Nslib station at 368.7 mm.

IV.3. Mapping:

Mapping allows us to assess the spatial variability of the results coming from descriptive statistics **[106]**. For a better spatial representation of rainfall variability, interpolation is the best technical tool. It allows estimating the value of a variable at given area.

In this study we used the inverse distance weighting (IDW). It estimates unknown values with specifying search distance, closest points, power setting and barriers.

IV.3.1. Precipitation:

Isohyet is a line drawn on a map connecting points having equal rainfall at a certain time or for a stated period.

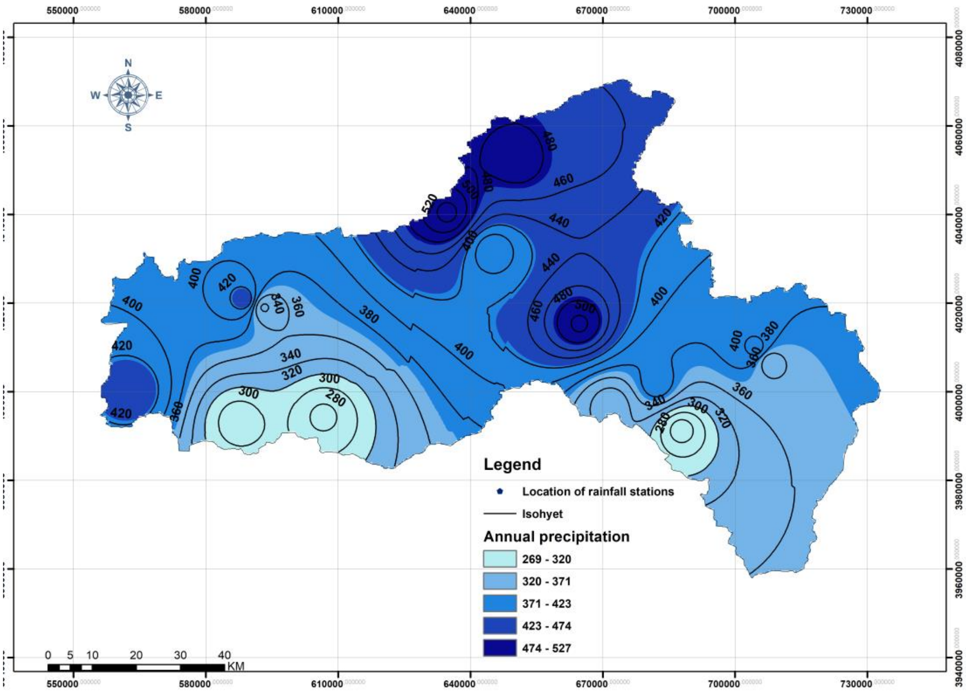

Figure IV.03: Precipitation isohyets in Soummam basin from 1960 to 2013.

Figure IV.03 represents isohyets from 1960 to 2013. Based on the map, the coastal zone in the north receives more rainfall than the central and southern parts, likely due to the proximity of the sea.

In the region where Domaine Maouchi, Bordj Zemmorah, Sidi Aich, and Tizi Nsilb are located, precipitation varies from 423 mm to 527 mm. For Bordj Okhriss, Ben Daoud, and Tixter, precipitation ranges between 269 mm and 320 mm, while for the rest of the watershed, precipitation varies from 320 mm to 371 mm. The lowest precipitation value (269.1 mm) is detected at the Tixter station, while the highest value (526.2 mm) is recorded at Tizi Nslib. This variation appears to be influenced by the climate of the zones where the two stations are located.

Isohyets ranging from 400 to 500 mm cover only a small area in the north, while weaker isohyets, such as those ranging from 280 to 400 mm, are located in the west and the south of the basin and cover a larger area.

IV.3.2. Evapotranspiration:

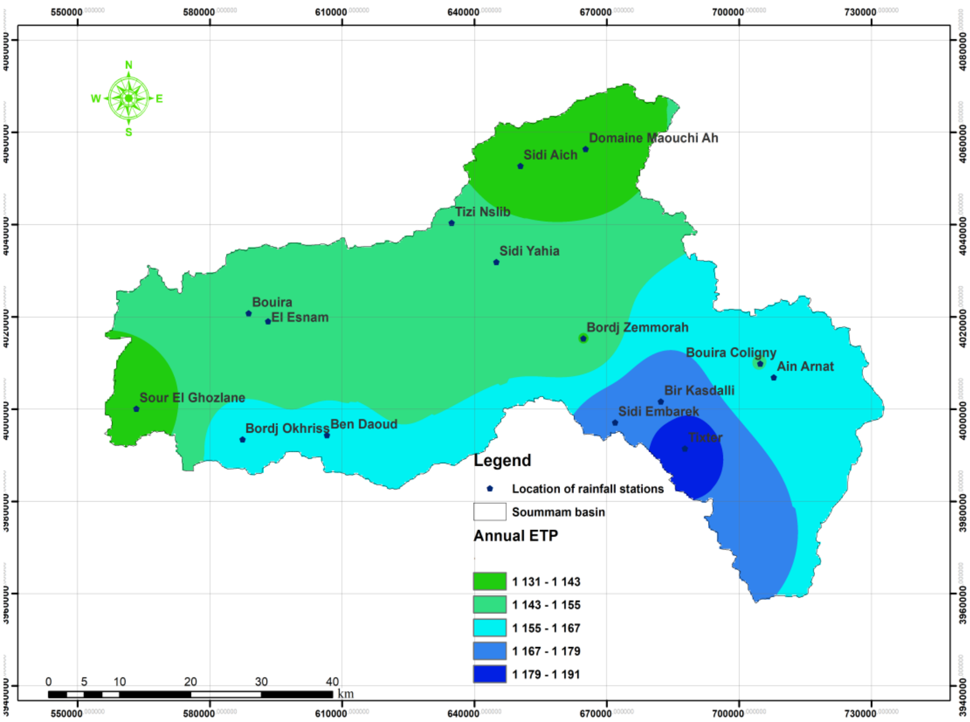

Figure IV.04: Annual ETP in Soummam basin from 1960 to 2013.

Figure IV.04 represents annual ETP in Soummam basin from 1960 to 2013. Hotter and drier climates generally have higher ETP rates due to increased evaporation driven by solar radiation and lower humidity. Conversely cooler and more humid climates will have lower ETP rates.

The annual evapotranspiration in the Soummam watershed varies between 1131 and 1191 mm. On the upper and western side of the Soummam basin, values range between 1131 and 1155 mm, this is attributed to lower temperatures. In contrast, values between 1167 and 1191 mm are detected in the eastern and southern parts of the watershed, where temperatures are higher than in the upper and western regions.The highest value of ETP is recorded at the Tixter station (1191 mm), which is situated in the lower basin where all favorable conditions are met, including high temperatures, lower precipitation, and abundant dense forest cover.

IV.3.3. Climate:

In this part we used our climate data to see the types of climate in our watershed.

The Soummam basin is characterized by three types of climates. In the upper and central parts of the watershed, the climate is dry sub-humid, except for the region where the Tizi Nslib and Bordj Zammorah stations are located, where the climate is sub-humid. In the west, east, and south of the basin, the climate is semi-arid, except for the region where the Bouira, Sour El Ghozlane, and Bouira Coligny stations are located, where the climate is dry sub-humid (Figure IV.05).

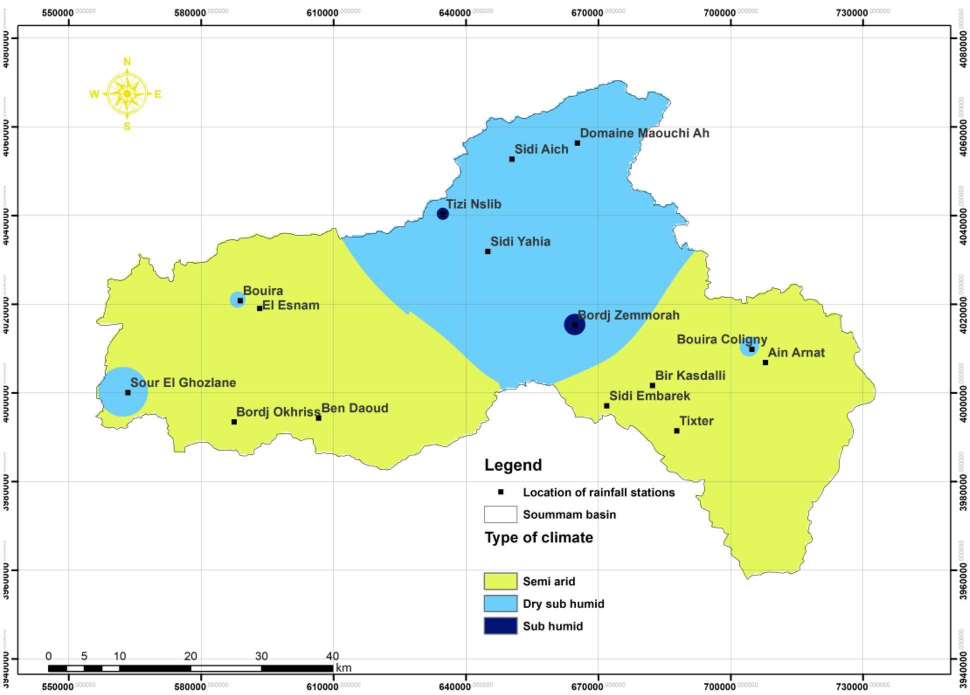

Figure IV.05: Type of climate in Soummam basin.

IV.4. Detecting break:

Fifteen rainfall stations were tested using five tests to detect breaks in rainfall series, and the results are summarized in the following table.

TableIV.01: Results of statistical tests.

Name of stations	Pettitt	Buishand	Ellipse of Bois	Lee and Heghinian	Hubert
Sour El Ghozlane	X	X	✓	✓	✓
Bordj Okhriss	X	X	X	✓	X
El Asnam	X	X	✓	✓	X
Bouira	X	X	✓	✓	X
Ben Daoud	✓	✓	✓	✓	✓
Tizi Nslib	X	X	✓	✓	X
Ain Arnat	X	X	X	✓	X
Bouira Coligny	X	X	✓	✓	X
Tixter	✓	X	✓	✓	X
Bir kasdalli	X	X	X	✓	X
Sidi Embarek	X	X	X	✓	X
Bordj Zemmorak	X	X	X	✓	X
Sidi Yahia	X	X	✓	✓	✓
Sidi Aich	✓	✓	✓	✓	✓
Domaine Maouchi	X	X	✓	✓	✓

We present in table (IV.01) the results of break detection tests Pettitt, Buishand, ellipse of Bois, Lee and Heghinian, at the 95% significance level, and Hubert at a significance level of p = 0.01 for 15 rainfall stations on an annual scale. The 'X' sign indicates no break, while the other sign indicates that there is a break.

IV.4.1 The Pettitt's test:

The results indicate that the Pettitt's test did not detect any breaks except for three stations. The rainfall series showed a probability of exceeding the critical value of the test, with values of $7.37*10^{-3}$in 1992 for the Ben Daoud station, $5.62*10^{-2}$in 1978 for Tixter, and $5.49*10^{-2}$ in 1975 for the Sidi Aich station, at the 95% confidence level.

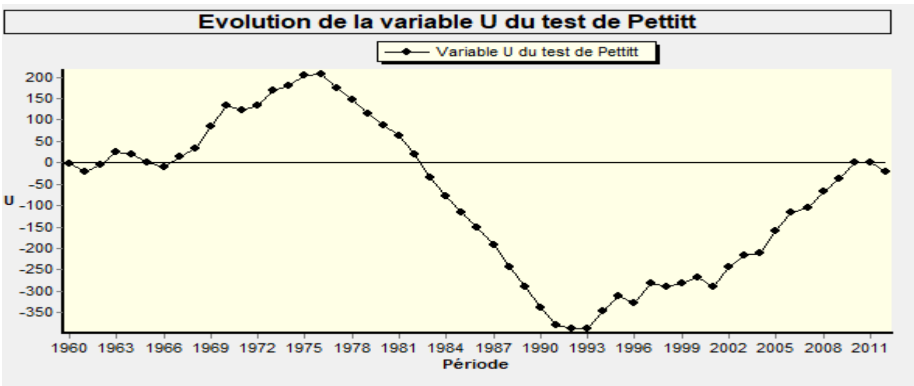

Figure IV.06: Result by the Pettitt test for the Ben Daoud station.

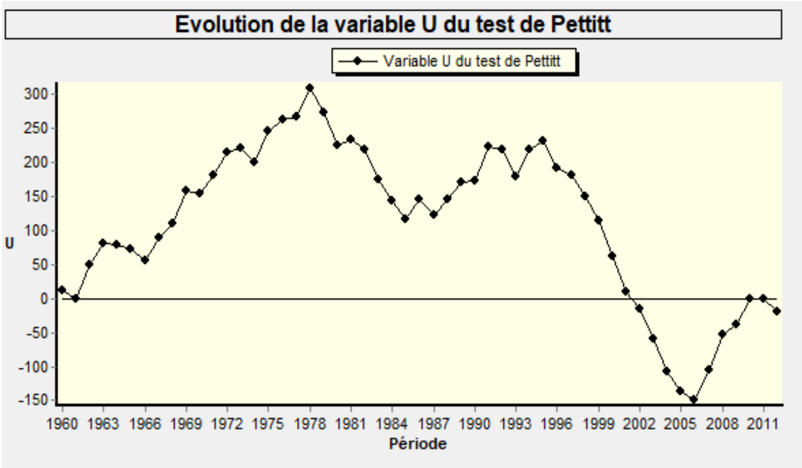

Figure IV.07: Result by Pettitt test for Tixter station.

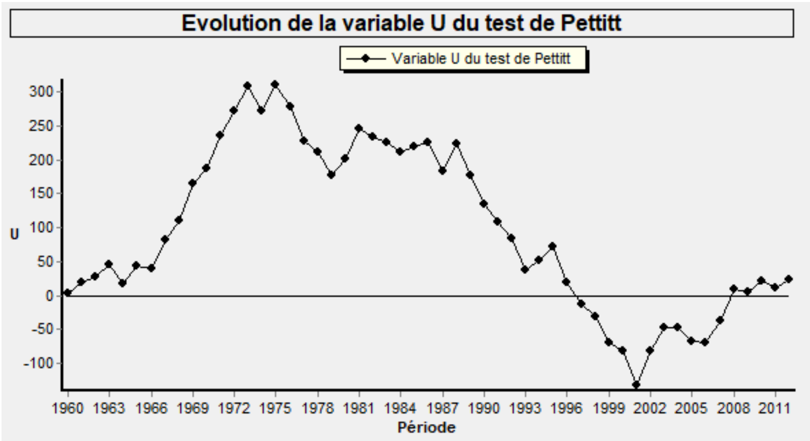

Figure IV.08: Result by the Pettitt test for the the Sidi Aich station.

IV.4.2. The Buishand test:

The Buishand test detected two ruptures: one for the Ben Daoud station, and the other for the Sidi Aich station, at the 95% confidence level. The null hypothesis was accepted for the other stations.

IV.4.3. Ellipse of Bois:

The Buishand test graphic led to the acceptance of the null hypothesis for five stations: Bordj Okhriss, Ain Arnat, Bir Kasdalli, Sidi Embarek, and Bordj Zemmorah stations at the 95% confidence level. However, the null hypothesis was rejected for the remaining stations, which experienced ruptures in different years (with the majority of stations detecting 2001 as the breaking year).

The results of some stations are in the following figures.

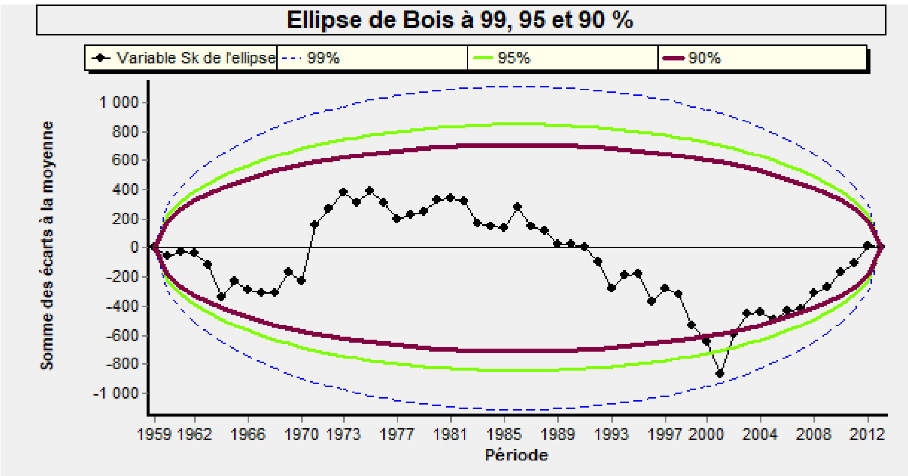

Figure IV.09: Result of the Bouira station by Ellipse of Bois.

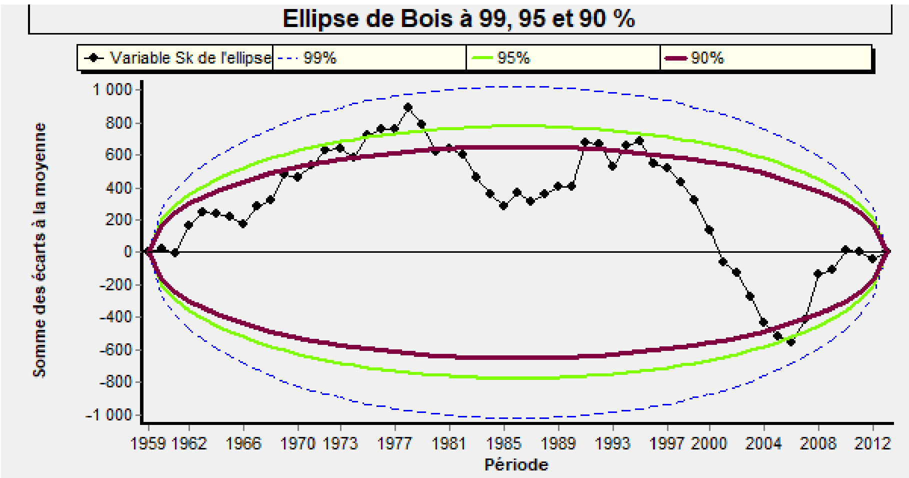

Figure IV.10: Result of the Tixter station by Ellipse of Bois.

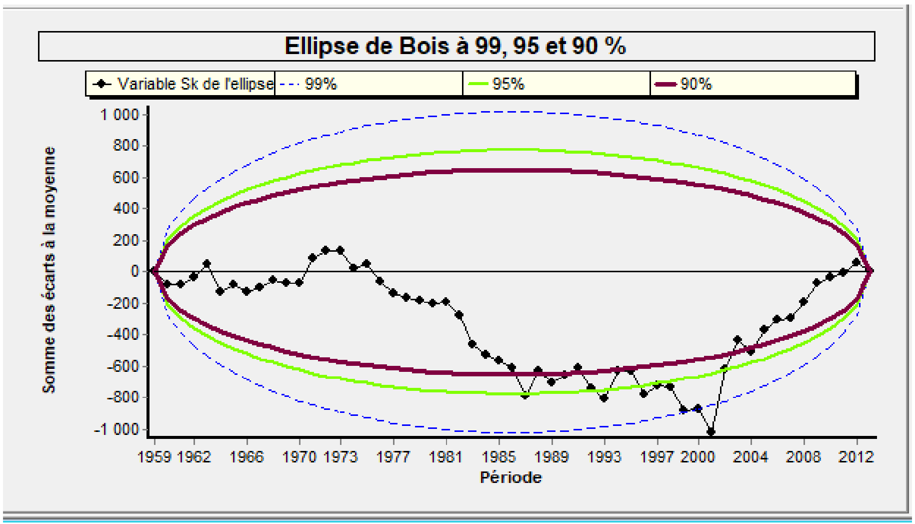

Figure IV.11: Result of the sour El Ghozlan station by Ellipse of Bois.

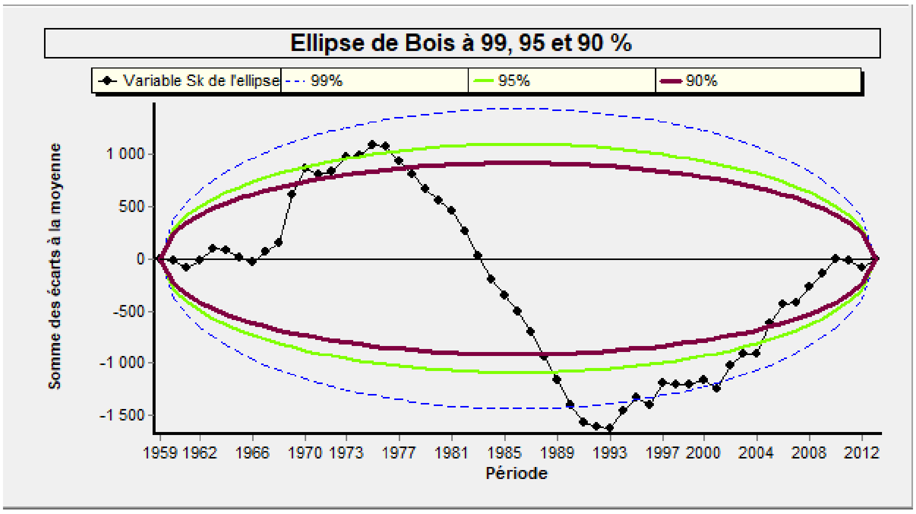

Figure IV.12: Result of the Ben Daoud station by Ellipse of Bois.

IV.4.4. The Lee and Heghinian test:

The Lee and Heghinian test rejected the null hypothesis for all stations, and showing the 2001 as the year of break for majority of the rainfall stations (Sour El Ghozlane, El Asnam, Bouira, Tizi Nslib, Ain Arnat, Sidi Yahia, and Domaine Maouchi).

The results indicate a significant shift in rainfall patterns at all monitored stations around the specified years. The posterior probability density function's mode offers further insight into the confidence level associated with these identified breakpoints.

The results of these tests are summarizing in the following table:

Table IV.02: Results of the Lee and Heghinian test.

Name of stations	Year of break	Mode of posterior probability density function.
Sour El Ghozlane	2001	0.4822
Bordj Okhriss	1971	0.1669
El Asnam	2001	0.0780
Bouira	2001	0.1826
Ben Daoud	1993	0.1669
Tizi Nslib	2001	0.1507
Ain Arnat	2001	0.0822
Bouira Coligny	1995	0.0836
Tixter	1978	0.0860
Bir kasdalli	1961	0.0923
Sidi Embarek	2012	0.0628
Bordj Zemmorak	2012	0.0537
Sidi Yahia	2001	0.2983
Sidi Aich	1973	0.1723
Domaine Maouchi	2001	0.1552

IV.4.5. The segmentation method of Hubert:

The application of the segmentation method of Hubert led to the rejection of the null hypothesis for five stations at the p = 0.01 significance level, while the null hypothesis was accepted for the remaining stations.

The lowest average rainfall values appear to have occurred between 1970 and 1990, with rainfall averages ranging between 98 and 600 mm. However, from 2002 to 2013, there seems to be an increase in the average rainfall compared to previous years. In 2002, the average rainfall reached its peak at 894.3 mm.

- **Sour El Ghozlane station:**

The results of the Hubert test for this station indicated three segments in the rainfall series. The first segment spanned from 1960 to 2001, with an annual average of 413.1 mm and a standard deviation of 89.2. The second segment was in 2002 with an annual rainfall of 840.1 mm. The third segment covered the period from 2003 to 2013, with a rainfall of 493.4 mm and a standard deviation of 80.5.

Segmentation de Hubert

Niveau de signification du test de Scheffé: **1%**

Début	Fin	Moyenne	Ecart type
1960	2001	413,105	89,201
2002	2002	840,100	0,000
2003	2013	493,382	80,469

Figure IV.13: The results of the Hubert test for the Sour El Ghozlane station.

- **Ben Daoud station:**

The test revealed that this station has five segments. The first segment lasted from 1960 to 1968, with a rainfall of 291.7 mm and a standard deviation of 73.9. The second segment spanned from 1969 to 1970, with an annual average of 628.1 mm and a standard deviation of 137.3. The third segment covered the period from 1971 to 1976, with a rainfall of 310.2 mm and a standard deviation of 73.7. The fourth segment extended from 1977 to 1991, with an annual average of 98.5 mm and a standard deviation of 47.7. The last segment spanned from 1992 to 2013, with a rainfall of 345.9 mm and a standard deviation of 109.1.

Segmentation de Hubert

Niveau de signification du test de Scheffé: 1%

Début	Fin	Moyenne	Ecart type
1960	1968	291,700	73,899
1969	1970	628,100	137,320
1971	1976	310,233	73,684
1977	1991	98,513	47,665
1992	2013	345,959	109,129

Figure IV.14: the results of the Hubert test for the Ben Daoud station.

- **Sidi Yahia station:**

The test showed three segments. The first segment lasted from 1960 to 1972, with a standard deviation of 92.1 and rainfall of 404.9 mm. The second segment covered the period from 1973 to 1974, with a standard deviation of 49.5 and an annual average of 128.2 mm. The last segment spanned from 1975 to 2013, with a standard deviation of 100.2 and a rainfall of 387.4 mm.

Segmentation de Hubert

Niveau de signification du test de Scheffé: 1%

Début	Fin	Moyenne	Ecart type
1960	1972	404,946	92,106
1973	1974	128,200	49,497
1975	2013	387,428	100,227

Figure IV.15: the results of the Hubert test for the Sidi Yahia station.

- **Sidi Aich station:**

The test detected four segments in the rainfall series. The first segment lasted from 1960 to 1973, with a rainfall of 573 mm and a standard deviation of 117.5. The second segment spanned from 1974 to 2001, with a standard deviation of 100.9 and an annual average of 433.6 mm. the third one was in 2002 with an annual rainfall of 894.3 mm. In this station and the Sour El Ghozlane station, the test identified 2002 as both the beginning and the end of the segment, if the data exhibits a significant shift within a single year compared to the previous and following years, the Hubert test is likely to recognize that year as a separate segment. The forth segment covered the period from 2003 to 2013, with a rainfall of 511.3 mm and a standard deviation of 70.8.

Segmentation de Hubert

Niveau de signification du test de Scheffé: 1%

Début	Fin	Moyenne	Ecart type
1960	1973	573,007	117,593
1974	2001	433,557	100,927
2002	2002	894,300	0,000
2003	2013	511,300	70,761

Figure IV.16: the results of the Hubert test for the Sidi Aich station.

- **Domaine Maouchi station:**

The Hubert test revealed two segments in the rainfall series. The first segment extended from1960 to 2001, with an annual average of 446.4 mm and a standard deviation of 116.3.

The second segment covered the period from 2002 to 2013, with a standard deviation of 132.2 and a rainfall of 554.4 mm.

Segmentation de Hubert

Niveau de signification du test de Scheffé: 1%

Début	Fin	Moyenne	Ecart type
1960	2001	446,419	116,254
2002	2013	554,400	132,231

Figure IV.17: the results of the Hubert test for the Domaine Maouchi station.

The results of the five tests indicate that breaks have occurred in the basin from 1973 to 2001, with the majority identified in 1973, 1975, 1978, 1992, and 2001 with decreasing of precipitation. In a study on the spatiotemporal analysis of precipitation and its relationship with climate indices in the Soummam Basin, Algeria, Fayrous Bahloul revealed that the basin experienced a 29-year drought from 1973 to 2001**[4]**. Detection of change points in historical precipitation series can unveil breaks associated with drought events. The Hubert test indicates the recovery of rainfall from 2002, a year characterized by significant precipitation, aligning with findings from other researchers regarding the increase in average rainfall in the Mediterranean basin during the last decade **[107][108][109]**.

The following map represents the distribution of breaks tests in the basin.

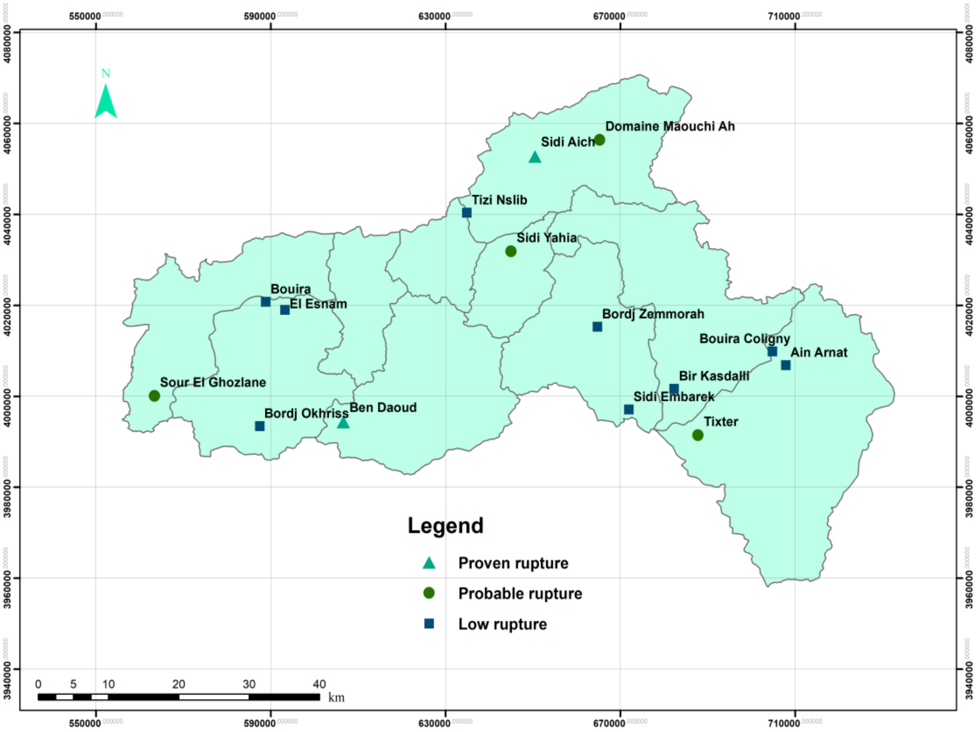

Figure IV.18: Distribution of break tests in Soummam basin.

The Lee and Heghinian test detected low ruptures for five stations: Bordj Okhriss, Ain Ahnat, Bir Kasdali, Bordj Zemmorah, and Sidi Embarek. The Ellipse of Bois, Lee and Heghinian tests identified probable ruptures for: El Esnam, Bouira, Tizy Nslib, and Bouira Coligny stations. Moreover, the Ellipse of Bois, Lee and Heghinian, and Hubert tests detected probable ruptures for Sour El Ghozlane, Sidi Yahia, and Domaine Maouchi stations. Lastly, the Lee and Heghinian, Ellipse of Bois, and Pettitt tests found proven ruptures for the Tixter station. The two stations, Ben Daoud and Sidi Aich, showed proven ruptures across all tests.

IV.5. Trend:

After applying the Mann-Kendall test at the significance level of α= 0.05 using R Studio on the rainfall series from 1960 to 2013, all stations accepted the null hypothesis. This suggests that the rainfall patterns have not exhibited a statistically significant trend, possibly due to the relatively stable average rainfall throughout the entire period or the influence of certain climatic factors leading to periods of increased or decreased rainfall without a discernible long-term trend. However, the absence of a significant trend does not imply the absence of change, it indicates that the change is not statistically detectable based on the available data.

We utilized Excel and R Studio (Sen's slope) to assess whether this change is increasing or decreasing. The two software showed the same results, and revealed that nine stations (Sour El Ghozlane, Bouira, Ben Daoud, Tizy Nslib, Ain Arnat, Sidi Embarek, Sidi Yahia, Bir Kasdalli, and Domaine Maouchi) detected a positive trend with increasing precipitation, while remaining rainfall stations showed a negative trend. The results of some stations are presented in the following figures.

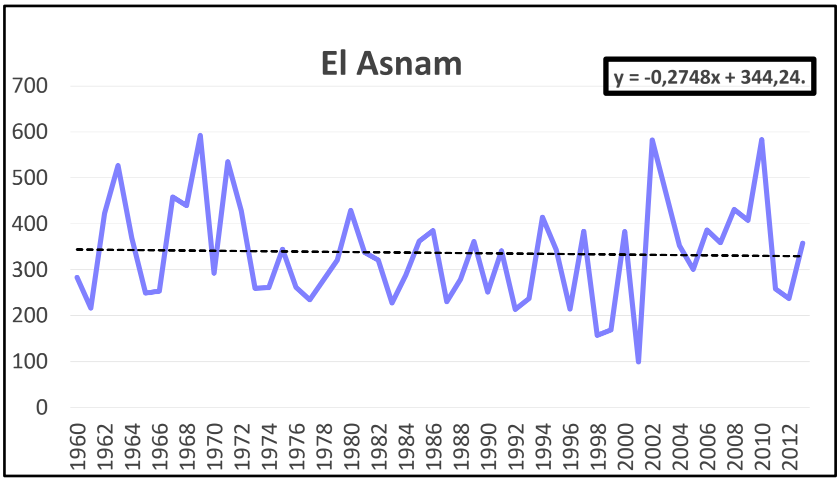

Figure IV.19: Trend graph of El Asnam station.

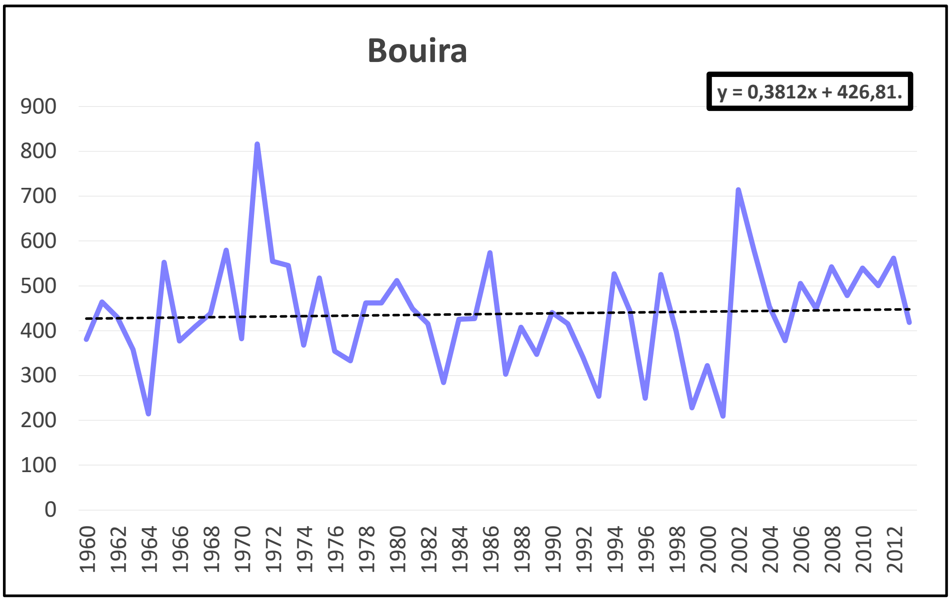

Figure IV.20: Trend graph of Bouira station.

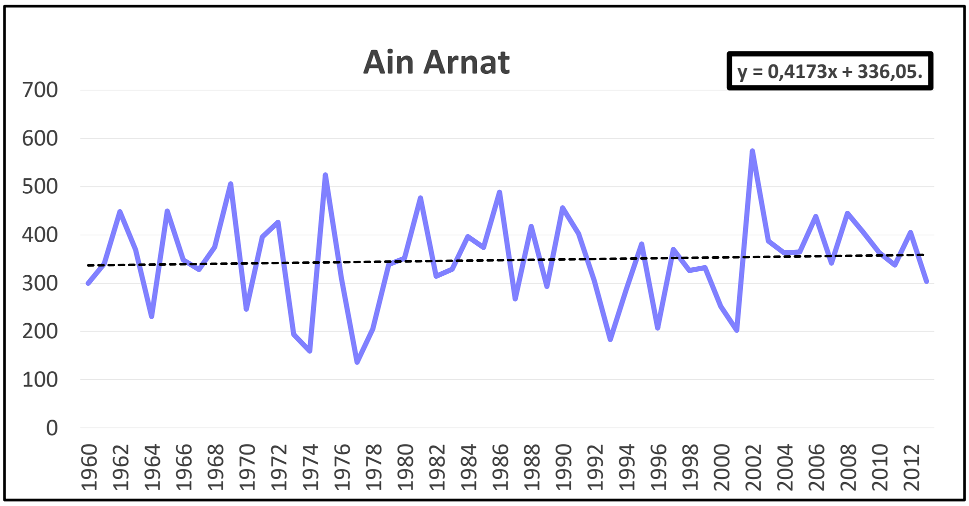

Figure IV.21: Trend graph of Ain Arnat station.

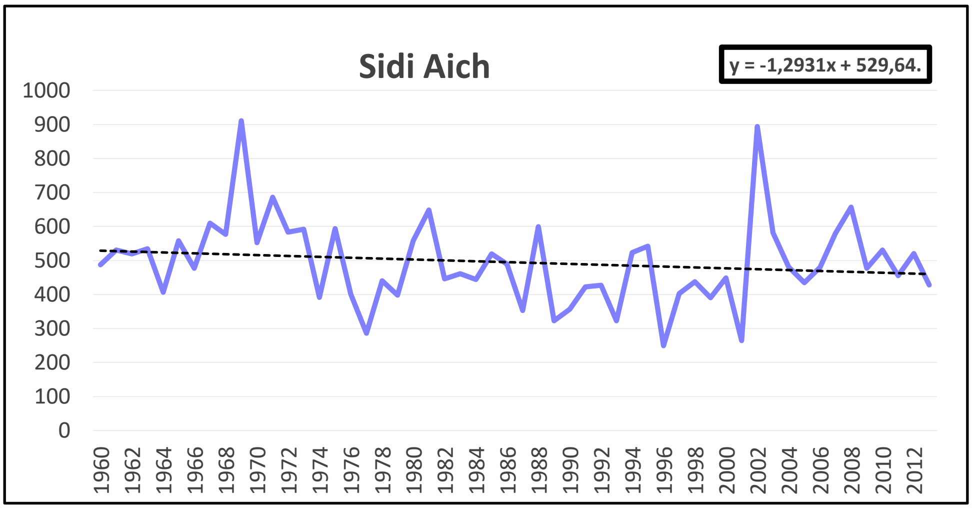

Figure IV.22: Trend graph of Sidi Aich station.

Table IV.03: Results of trend by R Studio.

Name of stations.	**Mann Kendall test.**	**Sen's slope.**
Sour El Ghozlane	0.3032	0.7826087
Bordj Okhriss	0.3472	-0.826087
El Asnam	0.8814	-0.1025571
Bouira	0.6544	0.4894737
Ben Daoud	0.3707	1.137757
Tizi Nslib	0.6224	0.346
Ain Arnat	0.6652	0.3592181
Bouira Coligny	0.4739	-0.7706452
Tixter	0.08086	-1.645
Bir kasdalli	0.9524	0.06977248
Sidi Embarek	0.9287	0.07142857
Bordj Zemmorak	0.6015	-0.7938904
Sidi Yahia	0.2445	1.143424
Sidi Aich	0.2445	-1.110521
Domaine Maouchi	0.1437	1.813048

Conclusion:

The amount of precipitation an area receives is a major factor in determining its climate type. Regions with humid climates receive more precipitation than those with arid climates.

The amount of precipitation in the Soummam basin decreases from north to south, while evapotranspiration increases in the same direction. The highest evapotranspiration value was detected at the Tixter station, whereas the lowest value was recorded at the Sidi Aich station.

Among the fifteen stations examined, two stations exhibited proven ruptures detected by all tests. Eight stations showed probable ruptures detected by two or three tests, while the Lee and Heghinian test identified lower levels of rupture for the remaining stations. The period from 1973 to 2001 experienced the most breaks with decreasing in precipitation due to the drought that affected the Soummam Basin. Rainfall began to recover from 2002, marked by an increase in precipitation.

The application of Mann-Kendall test at the significance level of $p = 0.05$ using R Studio on the rainfall series from 1960 to 2013, revealed that all stations accepted the null hypothesis. We utilized Excel and R Studio (Sen's slope) to assess whether this change is increasing or decreasing. The two software showed the same results, and revealed that nine stations detected a positive trend with increasing precipitation, while remaining rainfall stations showed a negative trend.

General conclusion.

General conclusion:

The main objective of the study was to detect break in precipitation in the Sommam basin on an annual scale from 1960 to 2013 by using Khronostat software.

The Soummam basin consists of 10 sub- watersheds, it covers an area of 9125 km2 stretched in the East-West direction and accesses the Mediterranean via the Gulf of Bejaia. In the upper and central parts of the watershed, the climate is dry sub-humid, in the west, east, and south of the basin, the climate is semi-arid. The amount of precipitation in the Soummam basin decreases from north to south, while evapotranspiration increases in the same direction.

Increased precipitation after a break can lead to floods, a decreased in precipitation can impact to availability of water resources. Precipitation data analysis allows for the identification and quantification of trends and structural breakpoints in long-term time series, aiding in informed decision-making and adaptation strategies. The challenges in climate change studies, including the detection of trends and breakpoints, are addressed through various statistical methods employed by researchers worldwide.

In this study, we employed various statistical methods (Pettitt, Buishand, Ellipse of Bois, Hubert, Lee, and Haghinian) within the Khronostat software to detect breaks in precipitation. For trend analysis, we utilized the Mann-Kendall test in both Excel and R Studio.

Among the fifteen stations examined, Ben Daoud and Sidi Aich stations exhibited proven ruptures detected by all tests. The Lee and Heghinian test identified lower levels of rupture for Bordj Okhriss, Ain Arnat, Bir Kasdalli, Sidi Embarek, and Bordj Zemmorah. The remaining stations showed probable ruptures detected by two or three tests.

The period from 1973 to 2001 experienced the most breaks with decreasing in precipitation due to the drought that affected the Soummam Basin. Rainfall began to recover from 2002, marked by an increase in precipitation.

The Mann-Kendall test at the significance level of $\alpha = 0.05$ using R Studio on the rainfall series from 1960 to 2013 showed that all stations accepted the null hypothesis. This suggests that the rainfall patterns have not exhibited a statistically significant trend.

The two software showed the same results, and revealed that nine stations (Sour El Ghozlane, Bouira, Ben Daoud, Tizy Nslib, Ain Arnat, Sidi Embarek, Sidi Yahia, Bir Kasdalli, and Domaine Maouchi) detected a positive trend with increasing precipitation, while remaining rainfall stations showed a negative trend.

References.

Reference:

[1] C. Huntingford, R.G. Jones, C. Prudhomme, R. Lamb, J..H.C. Gash, D.A. Jones, Regional climate— model predictions of extreme rainfall for a changing climate, Q. J. R. Meteorol. Soc., 129, 2003, pp. 1607– 1621.

[2] J. Bricquet, F. Bamba, G. Mahe, M. Toure, J Publisher, City, 1997.

[3] E. Servat, J. Paturel, H. Lubes-Niel, B. Kouamé, J. Masson, M. Travaglio, B. Marieu, De différents aspects de la variabilité de la pluviométrie en Afrique, Publisher, City, 1999.

[4] Fayrouz Bahloul Imp spatiotemporal analysis of precipitation and their relationship with climate indices (Soummam Basin, Algeria). International Journal Water Sciences and Environment Technologies Vol. (vii), Issue 1, March 2022, pp. 18-35.

[5] Matthews, J.B. Robin; Moller, Vincent; van Diemen Renee;Fuglestvedt, Jan S.;MassonDelmotte,Valerie;Mendez,,Carlos;Semenov,Sergey;Reisinger,Andy.2021:Annex VII.Glossary:IPCC_Intergovermental Panel on Climate Change(PDF).IPCC Sixth Assessment Report.P.2222.Archived(PDF) from the original on 2022_06_05.Retrieved 2022_05_18.

[6] Shepherd,J.Marshall;Shindell,Drew;O'Carroll,CynthiaM.1February2005 :"What's the Difference Between Weather and Climate?"NASA.Archived from the original on 22 September 2020. Retrieved 13 November 2015.

[7] IPCC 2017: Intergovermental Panel on Climate Change. AppendixI:Glossary. Archived 2017_01_26 at the Wayback Machine Retieved on 2007_06_01.

[8] Political Map of the World, November 2011.

[9] IPCC SR15 Ch1 2018,p.54: these global level rates of human driven change far exceed the rates of change driven by geophysical or biosphere forces that have altered the Earth System trajectory in the past(e.g., Summerhayes, 2015;Foster et al.,2017);even abrupt geophysical events do not approach current rates og human driven change.

[10] Lynas, Mark;Houlton, Benjamin Z.;Perry, Simon(19 October 2021)."Greater than 99% consensus on human caused climate in the peer reviewed scientific literature doi: 10.1088/1748-9326/ac2966.

[11] IPCC AR6 WG1 Ch11 2021,p.1517.

[12] Chip Somodevilla / Getty Images September 10,2017, in fort Lauderdale, Florida.

[13] Stringer 1972:20**:** Foundations of Climatology.W.H.Freeeman and Company, San Francisco.586 p.

[14] John P. Rafferty., 2021**:** Encyclopaedia Britannica.

[15] Buiten Beeld. 2024 Water evaporates from sugar beet in Borger, Netherlands.

[16] https://hydrologie.org/glu/FRDIC/DICEVAPO.HTM

[17] AMS.2009**:** Precipitation. Glossary of Meteorological Society.2009. Retrieved 2009_01_02.

[18] Ebert, 2007: Ebert, E. J., John; Kidd, Chris. (2007):Comparison of Near-Real-Time Precipitation Estimatesfrom Satellite Observations and Numerical Models. American Meteorological Society.doi:10.1175/BAMS-88-1-47.

[19] Gaby Pilson article 11 types of precipitation to know for your next outdoor adventure march 27,2023.

[20] D.M Gray and D.H.MALE. 2004: Handbook of snow: Principles, Processes, Management & Use 2004.

[21] Supriya N., 2019. Biology Reader.

[22] B. Geerts**:** Convective and stratiform rainfall in the tropics. Retrieved on 2007_ 11_27.

[23] Byju's 2024 Types of precipitation diagram.

[24] Glossary of Meteorology, 2009**:** "Stratiform precipitation area". American Meteorological Society. Archived from the original on 2011_ 06_06. Retrieved 2009_ 07_12.

[25] Physical Geography**:** Chapter 08: Introduction to the Hydrosphere (e). Cloud Formation Processes. Retrieved on 2009_ 01_01.

[26] Encyclopaedia Britannica 4 June 2024. Condenation, precipitation, and the rain shadow effect resulting from orographic lift.

[27] RolandStull**:**https://geo.libretexts.org/Bookshelves/Meteorology_and_Climate_Science/Practical_Meteorology_(Stull)/07:_precipitation_Processes/7.08:_Precipitation_Measurement

[28] HaseebJamal.2017:www.aboutcivil.org/precipitation_in_engineering_hydrology.html

[29] FAO. 2020**:** Food and Agriculture Organization of the United Nations.**www.fao.org/home/en.**

[30] Earth Forum, Houston Museum of Natural Science 2013.

[31] Seltzer P., (1946) — Le climat de l'Algérie, Alger, Institut de Météorologie et de Physique du Globe, Carbonnel, 219 p.

[32] CHAUMONT M., PAQUIN C., (1971) — Carte pluviométrique de l'Algérie, échelle 1/50000. Soc. Hist. Nat. Afrique du Nord, Alger.4 feuilles.1 notice.

[33] Thomas R. Karl, Jerry M. Melillo, and Thomas C.Peterson. 2009**:** Global Climate Change Impact in the United States. Cambridge University. Press.

[34] NCA. 2018**:** National Climate Assessment, U.S.Global Change Research Program.

[35] Route fifty July, 2022Article extreme rainfall will be worse than we thought.

[36] Changnon S.A., 2001:Causes for record high flood losses in the central United States. Water International 26:223_ 230.

[37] Changnon S.A., N.E. Westcott, 2002: Heavy rainstorms in Chicago: increasing frequency, altered impacts and future implications. Journal of the American Water Resources Association 38:1467_1475.

[38] Hayhoe K., weubbles D.J., 2008:Climate Change and Chicago: Projections and Potential Impacts. Report for the City of Chicago.

[39] IJC. 2009: The Impact of Urban Areas on Great Lakes Water Quality. International Joint Commision, Washington, DC, Ottawa, ON, and Windsor, ON.

[40] Hejazi M., 2009:Impacts of Urbanization and Climate Variability on Floods in Northeastern IIIinois. Jornal of Hydrologic Engineering 14:606.

[41] USEPA. 2011:Great Lakes_ Basic Information, in: USEPA (Ed.), USEPA.

[42] Melillo J.M.,A.C.Janetos T.G.Karl, R.Corell,E.JBarron, V. Vurkett, T.E. Cecich, K.Jacobs, L.Joyce,B. Miller,M.G.Morgan, E.A.Parson, R.G.Richels,D.S. Schimel, 2000:The Potential Consequences of Climate Variability and Change_ Introduction. National Assessment Synthesis Team. USGCRP.

[43] Lead,B., and K.Roth, 2016:Weather, Traffic Accidents and Exposure to Climate Change. RFF DP 15_19_REV. Resources for the Future, Washington. DC, resourcesmag.org/archives/how_climate_change_affects_traffic_accidents/.

[44] EPA,2017:Multi_model Framework for Quantitative Sectoral. Impact Analysis: A Technical Report for the Fourth National Climate Assessment. EPA 430_R_17_001.U.S. Environmental Protection Agency (EPA), Washington, DC, 271 pp.cfpub.epa.gov/si/si_public_record_Report_Lab=OAP&dirEntryld=335095.

[45] D.A. Wilhite, M.H. Glantz, Understanding: the drought phenomenon: the role of definitions, Publisher, City, 1985.

[46] Shelley D. Crausbay, S.D. ; Ramirez, A.R.; Carter, S.L.; Cross, M.S.; Hall, K.R.; Bathke, D.J.; Betancourt, J.L.; Colt, S.; Cravens, A.E.; Dalton, M.S.; Dunham, J.B.; Hay, L.E.; Hayes, M.J.; McEvoy, J.; McNutt, C.A.; Moritz, M.A.; Nislow, K.H.; Raheem, N.; Sanford, T. (2018) : Defining Ecological Drought for the Twenty-First Century. Bulletin of the American Meteorological Society, 98, 12,

[47] Rachel Ramirez October 14, 2021 Drought in California.

[48] Riebsame,W.E.,S.A.Chagnon, Jr., and T.R.Karl (1991). Drought and Natural

Resources Management in the United States: Impacts and Implications of the 1987_89 Drought.Westview Press, Boulder, CO, 174pp.

[49] Schmitt,J.,Offermann,F.,SODER,M.,Fruhauf,C.,Finger,R.2022,October:Extreme weather events cause significant crop losses at the farm level in German agriculture. Food Policy, 112. https://doi.org/10.1016/j.foodpol.2022

[50] Ayse Calik May ,2019. Agricultural drought.

[51] Ouarda, T.B.M.J., Rasmussen, P.F . , Cantin, J.F. , Bobee, B., Laurence, R., Hoang, V.D., Barabe, G., 1999:Identification d'un réseau hydrométrique pour le suivi des modifications climatiques dans la province du Québec.Rev.Sci.Eau, 12(2),425_448.

[52] Doumouya, F.R., Traore, V.B., Sadio, M., Sambou, H., Issaka Ali, A.H., Diaw, A.T., Sambou B., Beye, A.C., 2016:RainfallVariability in Sine Saloum River Basin in a Context of Climate Change and Variability. Advances in Research 6(6), 1_12. Article noAIR.25349ISSN:2348_0394, NLM ID:101666096.SCIENCEDOMAINinternationalwww.sciencedomain.org.

[53] Halmstad , A. Najafi, M.R., Moradkhani, H., 2012Analysis of precipitation extremes with the assessment of regional climate models over the Willamette River Basin U.S. Ydrol; Precess 27, 2579e2590.

[54] Yao, A.B., Goula, B.T.A., Kouadio, Z.A., Kouakou, K.E., Kane, A., Sambou, S., 2012:Analysis Of Climate Variability And Quantification Water Resources in Tropical Wet Zone: From Watershed Case Of LABO In Central West Of Ivory Coast.Rev.ivory.Sci.Technol.19,136_157.

[55] Fankhauser, S. and Tol, R.S., 1997. The social costs of climate change: the IPCC second assessment report and beyond. Mitigation and Adaptation Strategies for Global Change, 1 (4), 385–403. doi:10.1007/BF00464889.

[56] Nema, M.K., et al., 2018. Spatio-temporal analysis of rainfall trends in Chhattisgarh State, Central India over the last 115 years. Journal of Water and Land Development, 36, 117–128. doi:10.2478/jwld-2018-0012.

[57] Alijani, B., 1997. Some statistical characteristics of temperature variations in Iran. Journal Research Geography, 31, 24–33.

[58] Mirza, M.Q., et al., 1998. Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. Hydrological Sciences Journal, 43 (6), 845–858. doi:10.1080/02626669809492182.

[59] Gallagher, C. and Lund, R., 2013. Changepoint detection in climate time series with long-term trends. Journal of Climate, 26, 4994–5006. American Meteorological Society,

2013. doi:10.1175/JCLI-D-12-00704.1.

[60] Agbazo, M.N., et al., 2019. Fractal analysis of the long-term memory in precipitation over Bénin (West Africa). Advances in Meteorology, 2019, 12. Article ID 1353195.doi:10.1155/2019/1353195.

[61] Sabrina Taibi, mohamed Meddi, Doudja Souag, Gil Mahé : évolution et régionalisation des précipitations au nord de l'Alérie (1936_2009). Climate and land surface changes in hydrology, IAHS Publ 359,191_197, 2013.

[62] Hind Meddi, Mohamed Meddi. Variabilité des précipitations annuelles du Nord Ouest de L'Algérie. Sécheresse 20 (1), 57_65, 2009.

[63] Yusuf Aliwi, Book of the tribes of the region.

[64] Benhamiche, N. Modélisation de la relation pluie – relief en vue de la cartographie par Kriageage: cas de basin versant de la Soummam. Thèse de magister: université d'INA El –Harrach. 158p.

[65] Melle Hamenni Nassima,15/05/2011, Etude des ressources en eau du bassin versant de la Soummam par l'utilisation du sig, Mémoire présentée pour obtenir le titre de Magister, L'école national superieur d'agronomie, Alger.

[66] DubreuilP.L.,(1974)—Initiationàl'analysehydrologique.Ed.MassonetCie ORSTOM,Paris,216p.

[67] CharifiS,2006 :Applicationdu modèlehydrologique GR2Msurles bassinsversants delaSoummam etdel'Isser.Mémoiredemagistère. EcoleNational polytechnique.Alger.

[68] Remenieras, G. 1980. L'hydrolyse de l'ingénieur. Ed Eyrolles. Tome2. 565p.

[69] DHWB, 2006 : Etude de la protection de la ville de Bejaia contre les inondations (Rapport de la mission C « Hydrologie »).Bureau d'étude : INGEROP.

[70] https://echo2.epfl.ch/e-drologie/chapitres/chapitre2/chapitre2.html.

[71] LabordeJ-P.,(2000)— Elémentsd'hydrologiedesurface.CoursUniversitédeNiceSophiaAntipolis,192p.

[72] BECHROUNEAbdelhakim,2009/2010,Elaborationd'unebasededonnéesHydrologiqued uBassinVersant dela Soummam viale modèle hydrologique HEC-HMS,Mémoirede Magister, Faculté deTechnologie,Départementd'Hydraulique,Bejaia

[73] P.N.E., Groupement Bceom-Bg-Sogreah, (2004) — Etude d'actualisation et definalisationduPNE-CentreetEst.Mission2-Mai2004,Volet4-Hydrologie.

[74] ANRH,(1974)—Hydrologiedesnappesalluvialesdel'OuedSoummam.

[75] MRE-Bceom-Bg-Sogreah., (2004) — Etude d'actualisation et de finalisation du PlanNationaldel'Eau volet4et 6.

[76] Chafika Allili Ailane, Benoit Laignel, Nawel Adjeroud, Hassiba Bir, and Khodir Madani. Particule Flow at the Mouth of the Soummam Watershed (Algeria) Université of Bejaia, Bejaia 06000, Algeria.

[77] Le Matin Algérie 02-08-2016.

[78] Merabti Abdelaaziz, 26/04/2018, Caractérisation, variabilité et prévision de la sécheresse dans le Nord est Algérien. Mémoire présentée pour obtenir le grade de docteur de l'ecole nationale superieure d'hydraulique.

[79] National Water Resources Agency (NWRA). Rainfall data 1960_2013.

[80] Eyring.,V.,Bony,S.,Meehl,G.A.,Senior,C.A.,Stevens,B.,Stouffer,R.J.,&Taylor,K.E. 2016 : Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6)experimental design and organization. Geoscientific Model Development, *9*(5), 1937-1958.doi: 10.5194/gmd-9-1937-2016.

[81] Harmel, R. D., Johnson, G., & Richardson, C. W. 2002: The GEM experience: Weathergenerator technology development in the USDA. Bulletin of the AmericanMeteorologicalSociety,83(7),954-957.doi:Doi10.1175/1520 0477(2002)083<0954:Tgewgt>2.3.Co;2.

[82] Ebert, 2007: Ebert, E. J., John; Kidd, Chris. (2007):Comparison of Near-Real-Time Precipitation Estimatesfrom Satellite Observations and Numerical Models. American Meteorological Society.doi:10.1175/BAMS-88-1-47.

[83] Huffman, G. J., Adler, R. F., Rudolf, B., Schneider, U., & Keehn, P. R. 1995:GlobalPrecipitation Estimates Based on a Technique for Combining Satellite-Based Estimates,Rain-Gauge Analysis, and Nwp Model Precipitation Information. JournalofClimate,8(5),1284-1295.doi:Doi10.1175/1520-0442(1995)008<1284:Gpeboa>2.0.Co;2

[84] NOAA.2017: National Oceanic and Atmospheric Administration. National Centers for Environmental Information. Data Access.Retrieved 04/20, 2017, from https://www.ncdc.noaa.gov/data-access.

[85] Raziei T, Saghafian B, Paulo AA, Pereira LS, Bordi I (2009) Spatial patterns and temporal variability of drought in Western Iran. Water ResourManag 23:439–455

[86] Armon Rezai, Lancer Taylor, Reinhard Mechler., 2013: Ecological macroeconomics: An application to climate change https://doi.org/10.1016/j.ecolecon.2012.10.008.

[87] Traore, V.B., Soussou, S., Cisse, M.T., Seni, T., Sidy, F., Diaw, A.T., Hyacinthe, S., Malanda, E.N., 2014:Trends and shifts in time series of rainfall and runoff in the Gambia Riner watershed. International Journal of Environmental Protaction and Policy. 2(4), 138_146.

[88] Boyer, J.F .,2002:Software Khronostat chronological series of statistical analysis. IRD UR2, Program 21 FRIEND AOC, Team UMRGBE Hydrology, University of Montpellier II, Ecole des Mines de Paris.

[89] Paturel, J.E., Servat, E., Kouame, B., Boyer, J.F., Lubes Niel, H., Masson, J.M., 1995:Identification Procedures "breaks" in time series_ changing rainfall patterns in Africa not Sahelian West.IAHS Publ. no.238,99_110.

[90] A.Pettitt, A non parametric approach to the change point problem, Publisher, City, 1979.

[91] T. A Buishard, Tests for detecting a shift in the meanof hydrological time series, Journal of Hydrology, 58,1984,pp.51-69.

[92] A. F. S. Lee, M.S. Heghinian, A Shift of the MeanLevel in a Sequence of Independent Normal Random Variables-ABayesianApproach,*Technometrics*,19(4), 1977,pp. 503-506

[93] Wijnagaad J.B., Klein Tank, A.M.G. and Konnen, G.P. 2003: "Homogeneity of 20th century European daily temperature and precipitation series", International Journal of Climatology, Vol. 23,No.6, pp. 679-692.

[94] Bois P. 1986. Controle des series chronologiques corrélées par étude du cumul des résidus. In Deuxiéme journées hydrologiques de l'Orstom. Orstom Publication: Montpellier: 89_100.

[95] P.Hubert,J.P.Carbonnel,A.Chaouche,Segmentation des séries hydrométéorologiques. Application à des séries de précipitations et de débitsde l'Afrique de l'Ouest, *Journal of Hydrology*, 110,1989,pp. 349-367.

[96] Lemaitre, F., 2002:Stationary study hydrometric series. Comparative study of the performance of some stationary tests. Graduation report. Montpellier University, 94p.

[97] Mestre, O., 2000:Statistical methods for homogenization long climate series. Thesis in Applied Mathematics statistics. Paul Sabatier University of Toulouse 226p.

[98] Lubes Niel, H., Masson, J.M., Paturel, J.E., Servant,E., 1998:climate variability and statistics. Simulating the power and robustness of some tests used to check the homogeneity of chronic. Journal of Water Sciences, 11(3),383-408.

[99] Vieux Boukhaaly Traore, Mamadou Lamine Ndiaye, Cheikh Mbow, Giovani

Malomar, Joseph Sarr, ABoubaker Chedikh Beye, Amadou Tahirou Diaw .,2017: Khronostat Model as Statistical Analysis Tools in Low Casamance River Basin, Senegal.

[100] Cannarozzo, M., Noto, L.V., Viola, F., 2006. Spatial distribution of rainfall trends in Sicily (1921–2000). Phys. Chem. Earth. 31 (18), 1201–1211.

[101] Modarres, R., da Silva, V.P.R., 2007. Rainfall trends in arid and semi-arid regions of Iran. J. Arid. Environ. 70, 344–355.

[102] Partal, T., Kahya, E., 2006. Trend analysis in Turkish precipitation data. Hydrol. Process. 20, 2011–2026.

[103] Tabari, H., Hosseinzadeh Talaee, P., 2011a. Recent trends of mean maximum and minimum air temperatures in the western half of Iran. Meteorol. Atmos. Phys. 111, 121–131.

[104] Yue, S., Hashino, M., 2003b. Temperature trends in Japan: 1900–1996. Theor. Appl. Climatol. 75, 15–27.

[105] Tabari, H., Nikbakht, J., Shifteh Some'e, B., 2011e. Investigation of groundwater level fluctuations in the north of Iran. Environ. Earth Sci., http:// dx.doi.org/10.1007/s12665-011-1229-z.

[106] Berthelot M (2008) Spatial dynamics of rainfall in the Centre Region according to climate normal 1971-2000.ESRI, Francophone Conference, October,1st and 2ad 2008,Varsailles,Frence.(In French)

[107] W. Khoualdia, Y. Djebbar, Y. Hammar, Caractérisation de la variabilité climatique: cas du bassin versant de La Medjerda (Nord-Est algérien), Publisher, City, 2014.

[108] M. Ramos, J. Martinez-Casasnovas, Nutrient losses by runoff in vineyards of the Mediterranean Alt Penedès region (NE Spain), Publisher, City, 2006.

[109] Z. Nouaceur, vers un retour des pluies sur la rive sud du bassin mediterraneen occidental: analyse et evaluation de la tendancepluviométrique sur plus d’un demi siecle en algerie, Publisher, City, 2011.