PEOPLE’S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education and Scientific Research

University of Blida - Saad Dahlab

Faculty of technology
Department of Water Science and Environment

Final Year Project
To obtain a Master's degree in Hydraulics resources
Topic:

Performance of SPI Index to assess drought in the Coastal Constantine watershed

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Academic year: 2024-2025

Dedications

Although sometimes words are never enough to thank some people, I try to express my gratitude through this work to:

My dear parents who have always watched over me and supported me throughout my studies, and I wish them health and happiness.

My dear sister.

And all my classmates.

All my friends.

All those who are near and dear to me.

Acknowledgements

First and foremost, I want to thank Allah for giving me the strength to finish this endeavor.

I would like to express my sincere gratitude to the jury members for their constructive feedback and the time, care, and attention they gave to the review proces. It has been a privilege to have my work reviewed by such knowledgeable and dedicated scholars.

I want to express my gratitude to Dr. Merabti Abdelaaziz, my supervisor, for his assistance from the start of this research, his time, his insightful counsel, and most importantly, his patience.

Lastly, I would want to express my gratitude to my instructors in the Department of Water Science and Environment for effectively sharing all of their knowledge with us students.

Abstract

Globally, drought is one of the most important natural disasters affecting ecosystems, agricultural output, and socioeconomic stability. The purpose of this study is to use the Standardized Precipitation Index (SPI) to assess temporal dynamics of drought in the Coastal Constantine Basin in northeastern Algeria. This study evaluates drought severity and events at multiple time scales (1, 3, 6, 9, and 12 months) using precipitation data from twelve meteorological stations gathered during a 54-year period (1960–2014). Significant differences in annual precipitation are seen throughout the basin, according to the results, suggesting that some regions experience recurrent and ongoing droughts. In this situation, the SPI has shown itself to be a reliable and flexible instrument for drought monitoring, enabling the detection of both extended hydrological and agricultural droughts as well as short-term meteorological droughts. The results highlight how urgent it is to improve adaptive water resource management techniques and put localized drought mitigation policies into action, particularly in light of climate change estimates for the Mediterranean region.

Keywords: Standardized Precipitation Index (SPI) - Drought - Coastal Constantine watershed

ملخص

على الصعيد العالمي، يُعد الجفاف أحد أهم الكوارث الطبيعية التي تؤثر على النظم البيئية والإنتاج الزراعي والاستقرار الاجتماعي والاقتصادي. والغرض من هذه الدراسة هو استخدام مؤشر هطول الأمطار القياسي **(SPI)** لتقييم الديناميكيات الجغرافية والزمنية للجفاف في حوض قسنطينة الساحلي في شمال شرق الجزائر. تُقيّم هذه الدراسة شدة الجفاف وأحداثه في فترات زمنية عديدة (1 و3 و6 و9 و12 شهرًا) باستخدام بيانات هطول الأمطار من اثنتي عشرة محطة أرصاد جوية جُمعت خلال فترة 54 عامًا (1960-2014). وتُلاحظ اختلافات كبيرة في هطول الأمطار السنوي في جميع أنحاء الحوض، وفقًا للنتائج، مما يشير إلى أن بعض المناطق تشهد جفافًا متكررًا ومستمرًا. وفي هذه الحالة، أثبت مؤشر هطول الأمطار القياسي أنه أداة موثوقة ومرنة لرصد الجفاف، مما يتيح اكتشاف كل من الجفاف الهيدرولوجي والزراعي الممتد بالإضافة إلى الجفاف الجوي قصير المدى. وتسلط النتائج الضوء على مدى الحاجة الملحة إلى تحسين تقنيات إدارة الموارد المائية التكيفية ووضع سياسات التخفيف من آثار الجفاف المحلية موضع التنفيذ، وخاصة في ضوء تقديرات تغير المناخ في منطقة البحر الأبيض المتوسط.

كلمات مفتاحية: مؤشر هطول الأمطار الموحد **(SPI)** – الجفاف - حوض قسنطينة الساحلي

Résumé

À l'échelle mondiale, la sécheresse est l'une des catastrophes naturelles les plus importantes affectant les écosystèmes, la production agricole et la stabilité socio-économique. L'objectif de cette étude est d'utiliser l'indice standardisé de précipitations (IPS) pour évaluer la dynamique géographique et temporelle de la sécheresse dans le bassin côtier de Constantine, dans le nord-est de l'Algérie. Cette étude évalue la gravité et les événements de sécheresse à de nombreuses périodes (1, 3, 6, 9 et 12 mois) à l'aide des données de précipitations de douze stations météorologiques recueillies sur une période de 54 ans (1960-2014). D'après les résultats, des différences significatives dans les précipitations annuelles sont observées dans l'ensemble du bassin, suggérant que certaines régions connaissent des sécheresses récurrentes et continues. Dans ce contexte, l'IPS s'est révélé un instrument fiable et flexible pour la surveillance de la sécheresse, permettant de détecter à la fois les sécheresses hydrologiques et agricoles prolongées ainsi que les sécheresses météorologiques de courte durée. Les résultats soulignent l'urgence d'améliorer les techniques de gestion adaptative des ressources en eau et de mettre en œuvre des politiques localisées d'atténuation de la sécheresse, notamment à la lumière des estimations du changement climatique pour la région méditerranéenne.

Mots-clés: Indice de précipitations standardisé (SPI) - Sécheresse - Bassin côtier de Constantine

Summary

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SPI: Standardized Precipitation Index

IPCC: Intergovernmental Panel on Climate Change

ET: evapotranspiration

RDI: The Reconnaissance Drought Index

SPEI: Standardized Precipitation Evapotranspiration Index

PET: potential evapotranspiration

NWRA: National Water Resources Agency

General introduction

General introduction

Drought is a natural danger, but it is different from other natural hazards in a number of ways [42] .Almost every climatic zone has droughts, including regions with high and low rainfall, and they are mostly caused by a decrease in the quantity of precipitation obtained over a prolonged duration, like a year or a season. Droughts are caused by a number of factors, including temperature, high winds, low relative humidity, and the timing and features of precipitation, such as the distribution of wet days during crop growth seasons, the intensity and duration of the rain, and its start and end represent a vital part in the occurrence of droughts. [41]

The Mediterranean region is suffering from a protracted and severe drought, with major precipitation deficiencies in places ranging from southern Europe to North Africa [36] . Algeria is in a particularly dire situation, there have been severe and protracted drought occurrences throughout the nation, which have hampered vegetation growth and caused water shortages. Agriculture, ecosystems, the availability of drinking water, and the production of energy are all already being negatively impacted by the current drought [17] . Forecasts show that precipitation will significantly decrease and drought severity will grow in the region, which has been designated as a climate change hotspot [19] . Research has evaluated the Constantine region's agricultural drought, emphasizing the decline in vegetation health and weather patterns from 2021 to 2023 [3] .

Numerous studies on the Mediterranean region's drought have been carried out, including one for Algeria [21] . Utilizing multiple standardized drought indices, especially the standardized precipitation index (SPI) Since it simply needs precipitation data and may be used to detect droughts in meteorology, agriculture, and hydrology across a variety of time periods [23] .

In this study, 54 years of precipitation data spanning from 1960 to 2014 from 12 rainfall stations around the Coastal Constantine watershed are used to apply the standardized precipitation index (SPI) at five different time scales (1, 3, 6, 9, and 12 months). Identifying the most vulnerable regions, assessing the temporal and spatial variability of droughts, and examining long-term climate trends are the main goals.

Chapter I: Literature review

I-Literature review

I-01-Introduction

One of the biggest environmental hazards that has posed a significant challenge to human societies and ecosystems for many generations is drought [40] . Evaluating droughts is crucial for managing and planning freshwater resources. Understanding previous droughts in the area as well as the effects of droughts when they occur is necessary for this. Consequently, it will be beneficial to comprehend various drought ideas in order to create models that examine various drought characteristics [25] .

I-02-Definition and Categorization of the Drought Phenomenon

I-02-1-Definition

Both conceptual and operational definitions of drought can be distinguished; conceptual definitions are those that are developed in broad strokes to delineate the parameters of the idea of drought [40] . For instance, a drought is described as "a long period with no rain, especially during a planting season" in the American Heritage Dictionary [2] . Another definition of it is "an extended period of dry weather, especially one injurious to crops," according to the Random House Dictionary [30] . Conceptual definitions don't offer much help to people who want to use them for current drought evaluations, or real-time assessments [40] .

The goal of operational definitions is to pinpoint the beginning, intensity, and end of drought episodes. There are operational definitions that contain estimates of possible effects. To assess the rate of soil moisture depletion, for instance, an operational definition may relate daily precipitation values to evapotranspiration (ET) rates. These relationships would then be expressed in terms of how dryness affects plant behavior at different phases of crop growth. Over the course of the growing season, agricultural experts would regularly reevaluate how these climatic factors affected plant growth [40] .

Analysis of drought frequency, severity, and duration during a specific historical period can also be done using operational definitions. However, these definitions need information on yield deviations from "normal" (i.e., expected) or moisture deficiencies on an hourly, daily, monthly, or seasonal basis in order to pinpoint the exact time of drought. Drought probabilities with different intensity, duration, and spatial characteristics can be computed using these definitions [40] .

I-02-2-Categorization

Various drought kinds have been identified and categorized from a disciplinary perspective. The four categories into which the definitions were divided were hydrological, agricultural, socioeconomic, and meteorological. These four categories can be divided into two groups: the first three methods focus on quantifying drought as a physical phenomenon, while the fourth one examines drought in terms of water supply and demand, tracking the effects of water scarcity as it permeates socioeconomic sectors [31] .

a) Meteorological Drought

The most widely used definitions of drought are meteorological. Frequently, they define drought based only on the length of the dry period and the level of dryness [40] . A meteorological drought is characterized by a significant decrease in the normally anticipated rainfall across a large area. It is typically used to quantify the extent to which precipitation deviates from average over time [7] . Due to the extreme global variability of the meteorological conditions that cause drought, definitions developed for one location and applied to another can lead to issues. There is also variation in how these conditions are perceived. When identifying the features of drought and comparing different places, both of these factors need to be considered [40] . Several definitions of meteorological drought have been created for use in different nations worldwide, including:

- ✓ The United States: less than 2.5 mm of precipitation in 48 hours [7] .
- ✓ Britain: 15 days, with no one receiving more over 0.25 mm [6] .
- ✓ Libya: when the yearly precipitation is less than 180 mm [14] .
- ✓ India: seasonal rainfall falls more than twice short of the mean deviation [29] .
- ✓ Bali: six days in which there is no rain [14] .

b) Agricultural Drought

Drought in agriculture is influenced by rainfall and water use efficiency. During crucial crop stages, a lack of water can significantly reduce agricultural productivity. Agricultural drought specifically affects plants that are grown, as opposed to wild vegetation [9] . The current weather, the biological traits of the particular plant, its growth stage, and the physical and biological qualities of the soil all affect how much water a plant needs. The varying susceptibility of crops at different stages of crop growth should be taken into consideration in an operational definition of agricultural drought. For instance, if topsoil moisture is adequate to meet early growth requirements, then inadequate subsurface moisture during an early growth stage will not significantly affect the final crop output. However, there would be a significant yield loss if the subsurface moisture deficit persisted [40] .

c) Hydrological Drought

The impact of dry spells on surface or subsurface hydrology is the focus of definitions of hydrologic drought, not the meteorological cause of the phenomenon. Its impact on river basins is frequently used to determine the frequency and intensity of hydrologic drought. Hydrologic droughts frequently occur at a different time than both agricultural and meteorological droughts [40] . Hydrologic drought is said to be underway if the actual flow for a chosen time period drops below a certain threshold. Nonetheless, it is arbitrary to specify the number of days and the probability threshold that must be met in order to identify a hydrologic drought period [20] . Because there is a lag between a lack of rainfall and a shortage of water in rivers, lakes, and dams, hydrological data are not the first indicators of drought. A decline in above- and groundwater levels is one way that scarcity shows up when rainfall is minimal or nonexistent for an extended length of time [26] .

d) Socioeconomic Drought

A shortage of water starts to negatively impact civilization on a personal and societal level by decreasing the supply of products that rely on precipitation. When lakes, rivers, or ponds have less water, fish may die or have their ability to reproduce greatly reduced. Farmers are also unable to get water to irrigate their fields and gardens. For example, Texas experienced a severe drought in 2011 that cost the state's agriculture industry $7.62 billion [45] . Additionally, the lack of adequate water supply paralyzes industry and other activity. Consequently, when water resources are insufficient to meet water demand, a socioeconomic drought occurs [44] . Typically, they are linked to the supply and demand of a certain economic commodity. In certain cases, land use practices can exacerbate an existing drought condition or cause a new one (such as an agricultural or hydrologic drought). Examples of the symbiotic relationship between drought and human activity are frequently given, including the 1930s dust bowl years in the US

Great Plains, the early 1970s Sahelian drought in West Africa, and the most recent Ethiopian drought [40] .

e) Ecological Drought

The term "ecological drought" refers to a recurring scarcity of water that causes ecological systems to beyond their thresholds of sensitivity, impacts ecosystem services, and generates feedback loops in both human and natural systems. Because of the close connection between the ecological environment and human development and survival [39] . In recent years, ecological drought has gained significant attention, and a new ecological drought index has been created [16] .

f) Groundwater Drought

A brief decline in subsurface water availability that persists for a long period of time is known as a groundwater drought. Groundwater drought was a specific type of drought that was thought to be caused by a decline in groundwater recharge [12] . Drought can affect groundwater storage due to a variety of causes, including hydrological, climatic, and agricultural droughts [10] . Both natural and man-made factors can cause groundwater drought [34] .

g) Flash Drought

Flash drought is characterized by an unusually rapid onset, which is followed by weeks of rapid intensification, which has an impact on one or more sectors. It happens everywhere in the world, and in recent years, a lot of researchers have been interested in it [27] [28] .

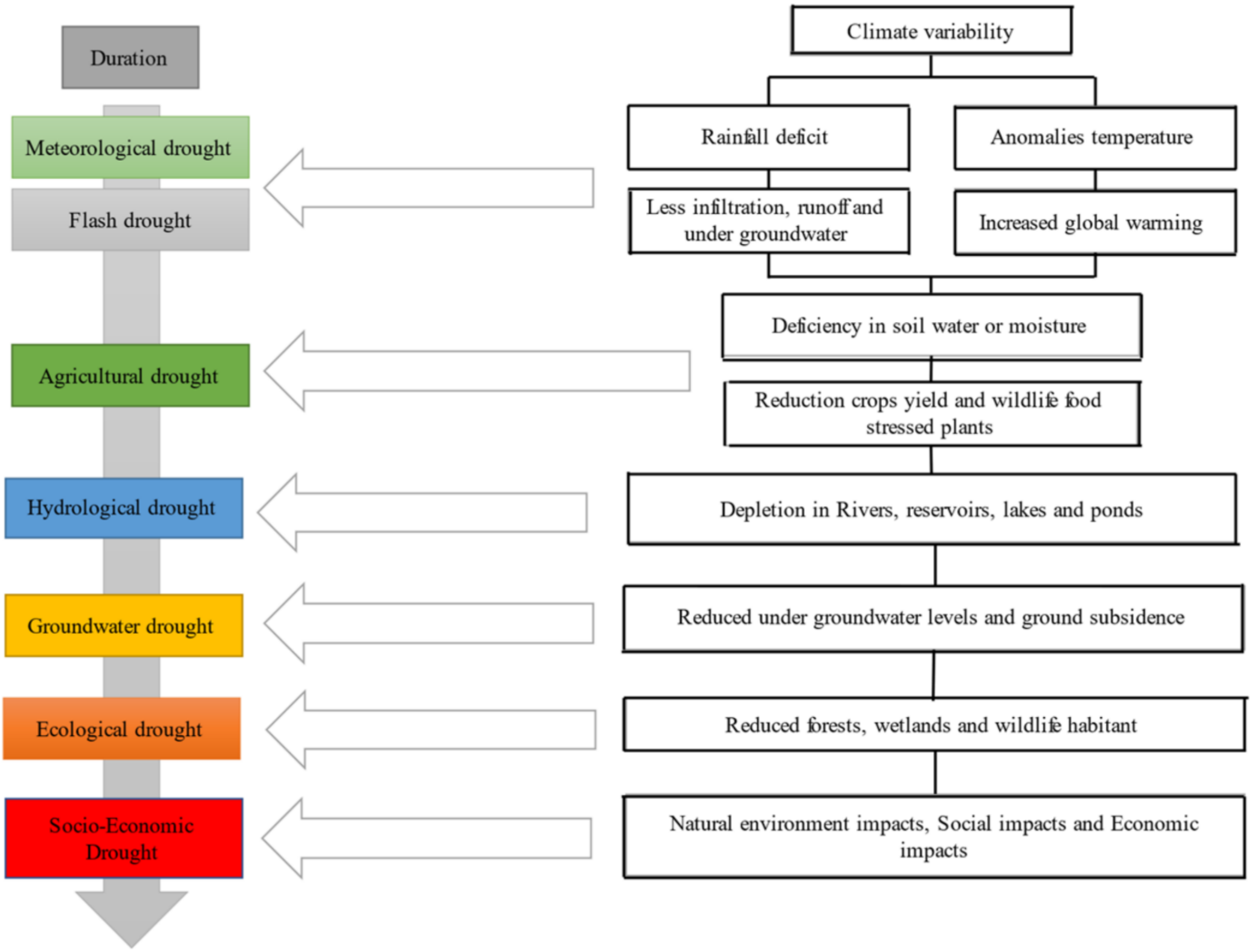

Figure I-1: Different classification of drought [26]

I-03-Drought Causes and Impacts

I-03-1-Drought Causes

Weather patterns are one of the natural causes of droughts. But more and more, human action is to blame:

a) Human Factor

- Extreme weather is becoming increasingly often due to global warming. It can increase evaporation, which can make areas drier. Flash flooding can occasionally happen because when the soil gets so dry, an impervious crust forms, causing water to flow off the surface when it rains.

- Water is captured and released into the atmosphere by plants and trees, causing clouds and eventually rain. Scientists have found a connection between drought and deforestation.
- In addition to initially contributing to deforestation, intensive farming can also alter the soil's absorbency, causing it to dry out considerably faster.
- Intense agriculture and population growth are two factors that could cause the demand for water to exceed the availability. In lower, downstream regions, dryness may also result from increased demand upstream in rivers (for irrigation or dams) [52] .

b) Natural Factor

- Climate patterns known as El Niño and La Niña have the potential to produce drought in some regions of the world. Drought in the southwestern United States and southern Africa can result from El Niño, which is defined by warmer-than-normal water temperatures in the Pacific water. Drought in Australia and Indonesia may result from La Niña, which is defined by Pacific Ocean temperatures that are lower than usual.
- A group of powerful winds that go high in the atmosphere is known as the jet stream. By bringing in dry air from other regions of the earth, changes in the jet stream can contribute to dryness in some regions [52] .

I-03-2-Drought Impacts

a) Risk of Famine

When crops fail due to drought, food poverty results. Famine occurs when a significant portion of the population is unable to obtain food, leading to acute hunger, illness, and mortality throughout the impacted area. Millions of children under the age of five are suffering from severe acute malnutrition as a result of the present widespread food shortages and near-famine in East Africa [52] .

b) Malnutrition

Food shortages result in a shortage of nutrient-dense food, which causes acute malnutrition. Children who are malnourished are at a heightened risk. Without the vital vitamins and minerals needed for healthy growth, babies are more likely to get sick, experience significant developmental delays, or even pass away. There is effective treatment for malnourished children, but it frequently lacks access to the most vulnerable. For the purpose of reaching more children at a lesser cost, the IRC has created a streamlined procedure for treating malnutrition [52] .

c) Diseases

Essential access to safe drinking water is impacted by drought. People may end up drinking tainted water as a result, which can cause cholera and typhoid outbreaks. Another consequence of not having clean water is that these illnesses might spread in areas with inadequate sanitation [52] .

d) Wildfires

Homes may be at risk from wildfires that burn the last of the vegetation when circumstances are dry. In addition to affecting air quality, fires can make long-term lung diseases worse [52] .

e) Displaced People

To find clean water, people have to travel farther. Usually, women and children are left to perform this extremely physically demanding chore at the expense of other jobs and education. Many have to leave their houses permanently to survive because they lack access to food or clean water. As many as 700 million people could face displacement due to drought by 2030, according to the World Health Organization, and 40% of the world's population is affected by water scarcity [52] .

f) Conflict

Studies have shown that drought intensifies already-existing conflicts. Because there is more competition for resources when people migrate in large numbers from hunger and drought-stricken countries, political tensions and war may rise. For instance, there is proof that the Syrian conflict was exacerbated by drought [52] .

g) Flash flooding

The same regions that experience drought may also be at danger for flooding. Although it seems like rain should be beneficial during a drought, unexpected, intense rainfall can cause dangerous flash flooding, as was the case in Pakistan, following a protracted dry spell. This is because droughts prevent rain from soaking the land since they leave it hard and baked, with little or no plant cover and poor soil quality. Rather, it flows across the arid terrain when it falls quickly and in enormous quantities, as in a rainstorm [52] .

I-04-Drought and Climate Change

Many times, attribution studies that demonstrate how climate change affects extreme events have already demonstrated how climate change contributes to the frequency or intensity of droughts. Naturally, not all droughts may be attributed to climate change, and droughts did exist before human activity altered the environment. However, 71 of the 103 droughts that have been examined so far have been made more severe or likely by climate change [24] . "We can attribute an increase in the severity and likelihood of droughts in the Mediterranean, South Africa, Central and East Asia, southern Australia, and western North America to global warming with a high degree of confidence," summarizes the World Weather Attribution group, which is responsible for these attribution studies [8] .

In its broadest definition, droughts are characterized by a shortage of water or by conditions that are drier than usual in a particular area, and they can last for a variety of lengths of time. Vegetation and human activities, such as irrigation and soil artificialization, can increase or decrease the severity of drought and its socio-economic impact. Meteorological droughts are marked by a deficit in rainfall (of varying duration); they can also be hydrological, with reduced levels in rivers or water tables (sometimes for several years) and agricultural, with soil drought having a potential impact on crops and natural vegetation. The effects of human activity on drought are also indirect. Changes in the climate are one example. The water cycle is becoming more intense due to climate change, for every degree that the atmosphere heats, its maximum water content rises by an average of 7% [13] .

This has multiple drought-related effects. First, there is a shift in the seasonality and intensity of precipitation. Climate change is causing, for instance, an increase in intense rainfall and a decrease in wet days in Europe. More surface runoff results from this less frequent but heavier rain, which also generally does a worse job of replenishing the water tables. In certain areas, rising global temperatures are also decreasing snow supplies, which has an impact on the flow of rivers that get water from springtime snowmelt. Lastly, the IPCC predicts that subtropical areas—which include the Amazon basin, South Africa, South-West Australia, South America, Central America, and West Africa—will likewise see a sharp decline in yearly precipitation [13] .

A significant factor contributing to agricultural drought is the rise in surface evapotranspiration brought on by climate change, in addition to rainfall. Evaporation from the soil and the surface of rivers and lakes, as well as the movement of water from the soil to the atmosphere through plant transpiration, are all considered forms of evapotranspiration on the continents. On the other hand, surface temperatures are increasing more across continents than across oceans. As a result, droughts become more severe since there is more energy available for water to evaporate. This effect is partially countered by the way CO2 affects plants, which can make them more efficient at using soil water. However, evapotranspiration has risen since the 1980s, so this is insufficient [13] .

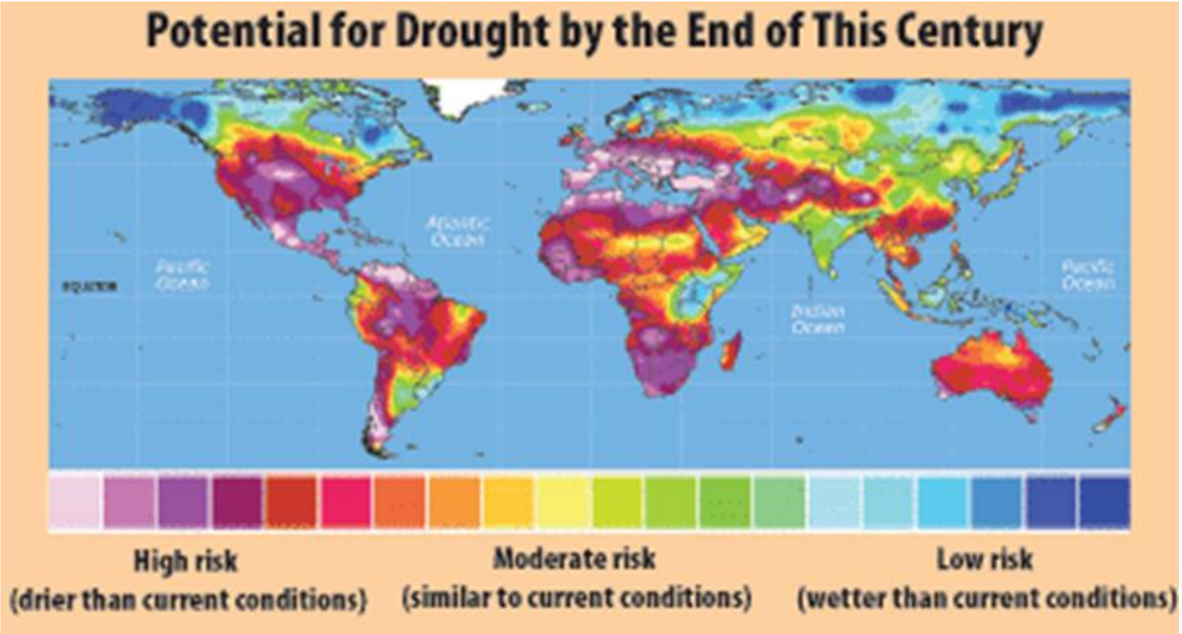

Figure I-2: Drought under global warming [46]

I-05-Drought Monitoring and Indices

Based on climatic or hydro-meteorological inputs, drought indices are numerical representations of the severity of drought. The size, location, timing, and durability of drought episodes are all measured using drought indicators. The severity is the amount that an index deviates from its normal. Drought indicators can facilitate the composite correlation process by offering practitioners, the general public, and several interested parties helpful information tools [18] .

One such index is well-known as the Standardized Precipitation Index (SPI):

a) Standardized Precipitation Index (SPI)

One method for estimating the likelihood of precipitation shortfalls on useable water sources is the Standardized Precipitation Index (SPI). It is computed by creating a monthly precipitation data set for months, preferably for a minimum of 30 years. The time spans of months (e.g.1,3,6,9,12 months), which indicate arbitrary time scales for precipitation deficiencies, are determined by choosing a set of averaging periods [23] .

- **Advantages:**

It is simple and widely used since it only requires precipitation data, which makes it simple to compute and apply across different geographies. Also, SPI may be calculated for a variety of durations (such as 1, 3, 6, 9, and 12 months), it can be used for several types of droughts, including meteorological, agricultural, and hydrological droughts. makes it possible to compare different climates and it is useful for identifying brief droughts in the weather [23] .

- **Limitations:**

SPI's capacity to depict drought severity in warming environments is limited by its failure to take temperature and potential evapotranspiration into consideration. And in regions with naturally low precipitation SPI has the potential to overestimate or underestimate the severity of the drought [23] .

b) The Reconnaissance Drought Index (RDI)

RDI is a widely used indices due to its high resilience and sensitivity. It measures the ratio of precipitation and potential evapotranspiration (PET) for a specific period, aiming to accurately assess water deficit as a balance between input and output in a water system [35].

- **Advantages:**

In light of climate change, RDI is better suited for identifying drought because it makes use of precipitation and potential evapotranspiration (PET). Improved in spotting dryness in arid areas where water balance is vital and Similar to SPI, RDI can be used across a variety of time periods [35].

- **Limitations:**

increases complexity by requiring temperature or more factors to calculate PET. Results may vary depending on the method used for PET estimate. Comparability is limited because it is not widely well-known and less commonly utilized than SPI [35].

c) Standardized Precipitation Evapotranspiration Index (SPEI)

A basic multiscale drought index (the SPEI) that integrates temperature and precipitation data is what we present here. The original SPI calculation process serves as the foundation for the SPEI, which is incredibly simple to compute. The SPI is computed using precipitation data, either weekly or monthly. Monthly (or weekly) precipitation and PET differences are used by the SPEI. This is an example of a basic climatic water balance that is computed to determine the SPEI at various time scales [38] .

- **Advantages:**

enhances the Standardized Precipitation Index (SPI) for long-term trend investigations by combining data on evapotranspiration with multi-timescale components of the SPI. Also, the statistically based index does not assume anything about the properties of the underlying system and simply needs climatological data [48].

- **Limitations:**

More information is needed than the precipitation SPI. And its Sensitive to how potential evapotranspiration (PET) is calculated. Furthermore, A long base period (30–50+ years) that captures the natural fluctuation should be employed, just like with other drought indices [48].

Table I-1: Classification of drought conditions according to the SPI, RDI, and SPEI [43]

SPI values	Classification
2.00 +	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and less	Extremely Dry

i-06-Conclusion

Drought is a complex and devastating natural disaster with significant impacts on ecosystems, agriculture, water resources, and human societies. Climate change is expected to increase drought frequency, intensity, and duration, exacerbating vulnerabilities in mediterranean regions like Algeria's Coastal Constantine Basin. The Coastal Constantine Basin faces escalating drought risks, threatening water security, food production, and social stability. Integrating advanced monitoring systems, and using indexes like SPI can help prepare and prevent future droughts from happening or enhance resilience against already existing ones to ensure a sustainable future.

Chapter II: Study area, data and method

II-Study area, data and method

II-01-Geographical Location

North-east Algeria is home to the Constantine Coastal watershed. The three large basins that comprise it are the East, Central, and West Constantine Coastal watersheds. This watershed, which is 11,119 km² in size, is bounded to the north by the Mediterranean Sea, to the south by the Kebir Rhumel Basin, the Seybouse and Medjerda watershed, to the west by the Soummam watersheds, and to the east by the borders with Tunisia. The 10 wilayas that make up the Constantine Coastal Basin are Bejaia, Jijel, Skikda, Annaba, El Tarf, Setif, Mila, Constantine, Guelma, and Souk Ahras (Abdeddaim H, 2018).

This watershed's territory consists of the massifs of Cap Bougaroune, Skikda-Jijel, and Edough, as well as the plains of Collo and Azzaba at the level of the Central Coastal Constantine, and the plains of Tichy and the Babors extension at the level of the West Coastal Constantine watershed. We can recognize the plains of Annaba, OumTboul, and El Tarf on the eastern edge of this watershed [1] .

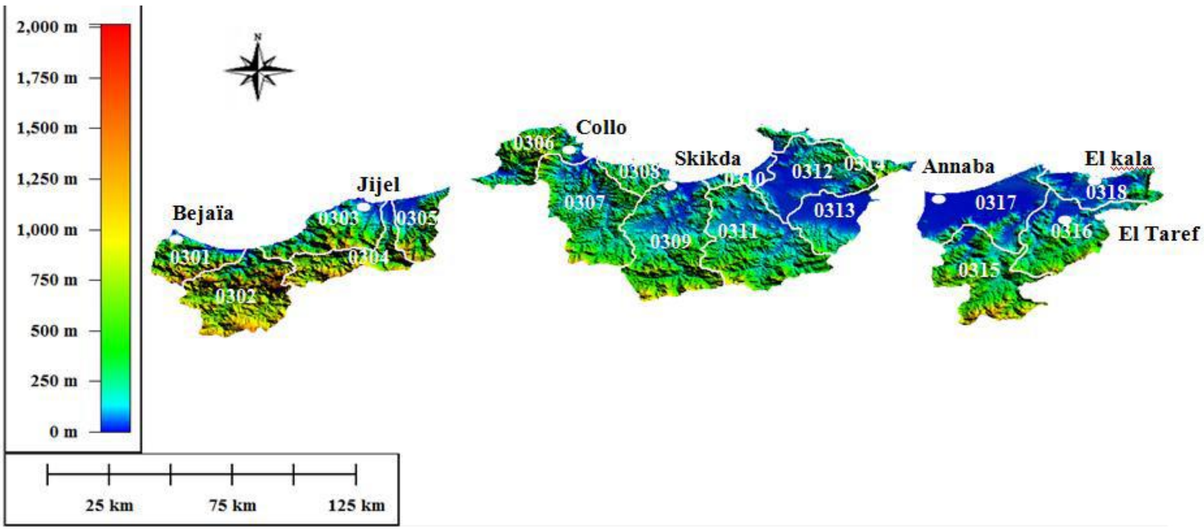

Figure II-1: The Coastal Constantine watershed [1]

II-02-Climatic Conditions

According to Köppen-Geiger, the Constantine Coastal watershed enjoys a hot-summer Mediterranean climate (Csa). January has an average maximum temperature of 9°C, while July has an average temperature of 36°C [51] . The moderate, rainy winters and hot, dry summers define this environment [47] [49] .

The annual precipitation varies significantly according on elevation and sea proximity [51] :

More than 1,200 mm/year in Séraidi (altitude 900 m), 1,600 mm/year in Zitouna-Collo (altitude 620 m), and 1,280 mm/year in Erraguene (Jijel region; altitude 680 m) are examples of coastal mountainous terrain (clicours.com).

Between 500 and 900 mm/year in the high plains and mountainous areas of Tell and Medjerda, examples include 880 mm/year in Ain Seynour (altitude 904 m), 590 mm/year at Souk Ahras (altitude 790 m), and 560 mm at Constantine (altitude 595 m) [50] .

The high plateaus of Constantine and the region south of the Medjerda basin are examples of low rainfall locations, with an annual rainfall of less than 500 mm/year [50] .

In the Constantine coastal watershed, the annual number of rainy days varies as well, ranging from 65 to 100 days [50] .

From 15 to 18°C is the average annual temperature. The coldest month's average minimum temperatures in coastal zones range from 0 to 9°C, while in semi-arid regions, they range from -2 to 4°C. August has average high temperatures between 28 and 40°C, making it the hottest month, The temperature can rise to 40°C along the coast and 33–38°C on the upper steppe plains on Sirocco days [50] [49] .

The average monthly temperature of some the wilayas that are part of the coastal Constantine watershed:

Table II-1: Climate data for some wilayas in the coastal Constantine watershed [51] .

State	Jan	feb	mar	apr	may	jun	jul	aug	sept	oct	nov	dec
Constantine	13°	14°	17°	21°	25°	31°	36°	35°	30°	24°	18°	14°
Setif	12°	12°	16°	20°	24°	30°	35°	34°	28°	23°	16°	13°
Annaba	16°	16°	17°	20°	23°	28°	31°	32°	29°	25°	20°	17°
Jijel	15°	15°	17°	19°	22°	26°	30°	31°	28°	24°	20°	16°
Skikda	15°	15°	16°	18°	21°	25°	29°	29°	27°	24°	20°	17°
EL tarf	15°	15°	17°	20°	23°	28°	31°	32°	29°	25°	20°	17°
Mila	13°	14°	17°	21°	25°	31°	36°	35°	30°	25°	18°	15°

Climate change poses a serious threat to the Mediterranean region, which includes northeastern Algeria. With consequences including decreased freshwater availability, harsh weather, and rising sea levels, it is warming up 20% more quickly than the rest of the world. By the middle of the 21st century, these catastrophes may become 10% to 30% more frequent and intense, according to forecasts [37] [36] .

II-03-Hydrological characteristics

Nine of the 18 sub-watersheds of the Coastal Constantine watershed are part of the Central watershed, five are part of the Coastal Constantine East, and the remaining four sub-watersheds are in the western portion. These units feature an extremely dense and branching hydrographic system, Djendjen, Guebli, Safsaf, Bounamoussa, Kebir, and Mafragh are the six large rivers that are part of the watershed, the Mediterranean Sea is where the outlet for these rivers. Examples of water bodies are Lake Fetzara, Tonga, Oubeira, and Mellah. This watershed's geography includes these bodies of water. It is a watershed in the north with an exoreic flow that is rather abundant [1] .

The following nine dams are operational in this watershed: Agrem, BeniZid, Cheffia, Emda, Erraguene, Ighil Guenitra, Mexa, Zardezas, Zit Emba [1] .

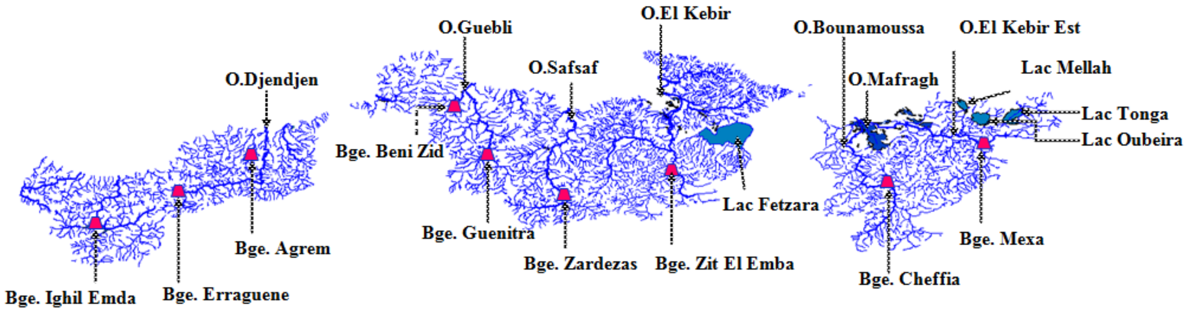

Figure II-2: Hydrographic network of the Coastal Constantine watershed [1]

II-04-Socioeconomic Context

The Coastal Constantine watershed supports a diverse range of socioeconomic activities:

- Olive trees in the Mediterranean watershed, including Algeria, are primarily cultivated under rainfed conditions, making them highly sensitive to rainfall variability. Despite being drought-tolerant, their distribution is limited in areas with annual precipitation below 350mm, necessitating water availability for optimal yields [11] .
- Constantine's industrial sectors, including manufacturing and services, heavily rely on water resources. Rapid urban growth has led to poor distribution, frequent interruptions, and deteriorating water quality. To address these issues, management has transitioned to a public-private partnership model, integrating foreign companies to improve water and sanitation services [4] .
- Constantine's rapid urban expansion, particularly in Ali Mendjeli, has put pressure on existing water infrastructure, necessitating improved planning and management to ensure sustainable urban development, as the city's population has grown from 64,483 in 2008 to 243,214 in 2020 [32] .

II-05-Data Collection

Utilized in a variety of disciplines, including meteorology, climatology, agriculture, and water resources management, climate data is an essential resource for comprehending the weather patterns and drought trends of our planet.

The National Water Resources Agency (NWRA) supplied rainfall data for this study with no gaps in the precipitation series from 12 rainfall stations.

Precipitation data was obtained from ground-based stations to guarantee analytical accuracy. Because of their thoughtful placement throughout the Coastal Constantine Basin, these stations are able to record the region's varied monthly rainfall data.

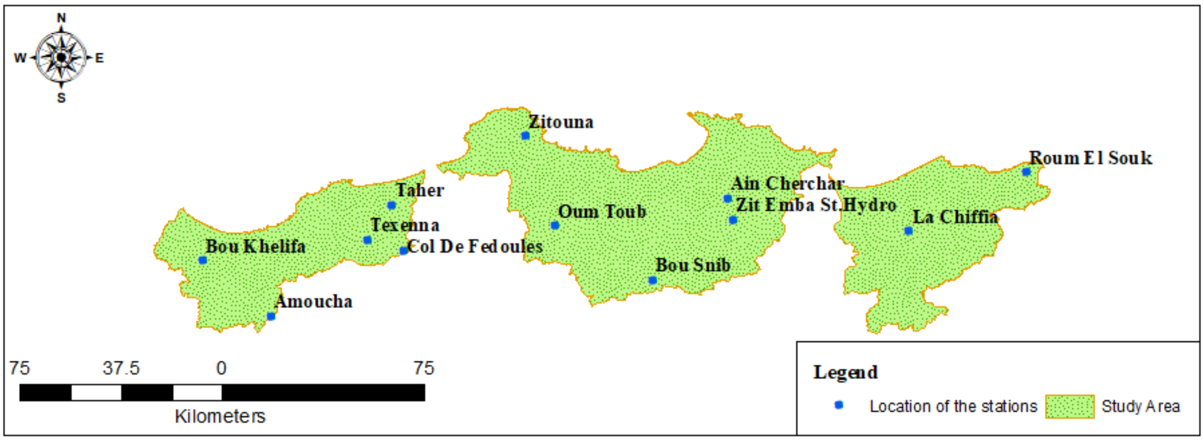

Figure II-3: Location of the rainfall stations in the Coastal Constantine watershed

II-06-Rainfall stations

Rainfall stations are installations on the ground that are outfitted with devices to measure and document the quantity, kind, and severity of precipitation at a particular place. They are essential to water resource management, climate research, and weather monitoring.

The analysis covers 54 years of monthly precipitation records, from 1960-1961 to 2013-2014 (Octobre-September). This long-time frame enables a thorough analysis of the region's drought trends as well as variations.

Table II-2: Coordinates of the stations

Name	Code	X (Lambert) m	Y (Lambert) m	Z (Altitude) m
Bou Khelifa	30101	715100	370250	160
Amoucha	30204	743600	346150	800
Texenna	30302	776200	377850	700
Col De Fedoules	30403	789800	367800	920
Taher	30504	785600	390500	56
Zitouna	30602	834690	416500	548
Oum Toub	30706	846150	383450	240
Bou Snib	30905	882100	362950	900
Zit Emba St.Hydro	31102	911400	385300	58
Ain Cherchar	31201	909500	393200	34
La Chiffia	31501	977150	381300	170
Roum El Souk	31602	1020700	402900	150

II-07-Temporal variations

The annual rainfall data from twelve stations over 54 years is crucial for assessing drought conditions, identifying periods of deficit rainfall and potential drought events. Understanding these trends is essential for early warning systems, mitigating drought impacts, and enhancing resilience in vulnerable areas.

The variation in annual precipitation for each station is represented by these charts:

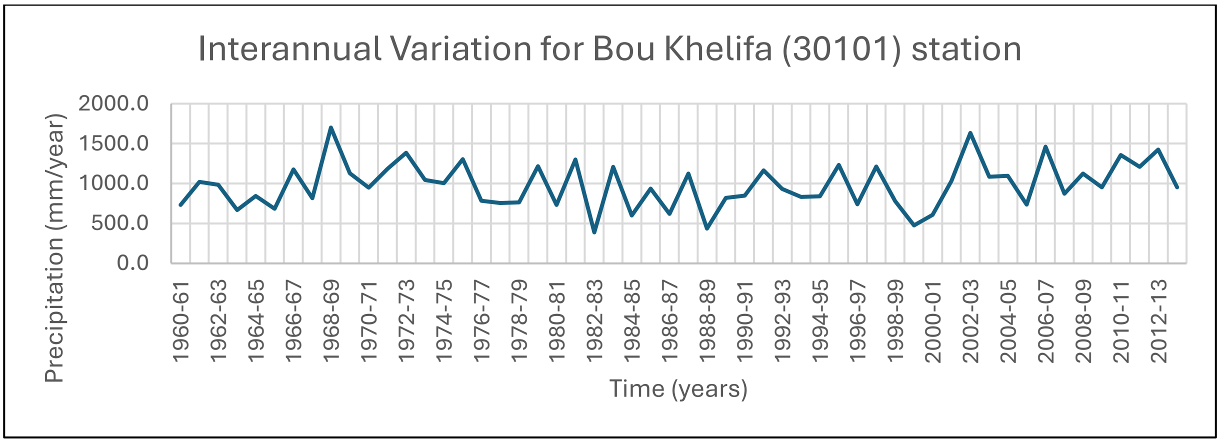

Figure II-4: Annual precipitation for Bou Khelifa (30101) station

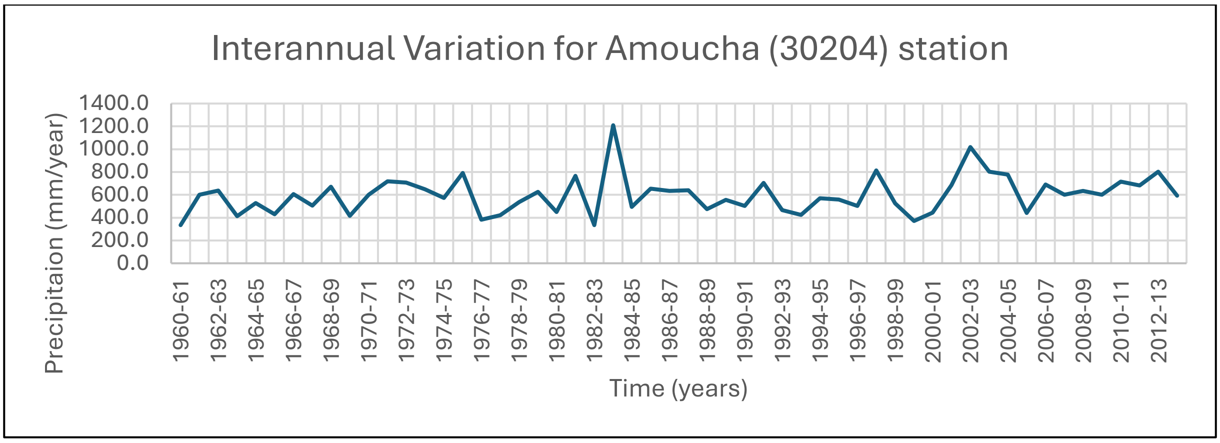

Figure II-5: Annual precipitation for Amoucha (30204) station

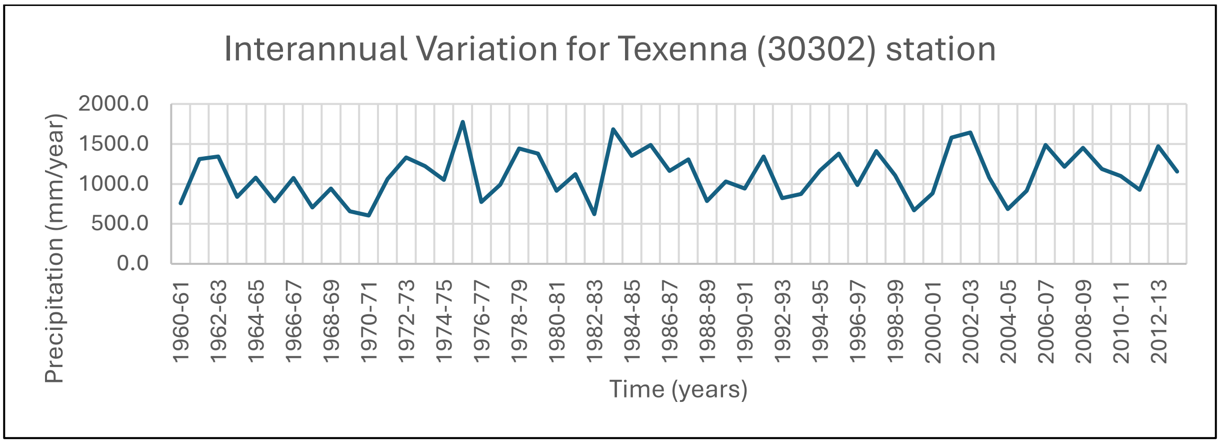

Figure II-6: Annual precipitation for Texenna (30204) station

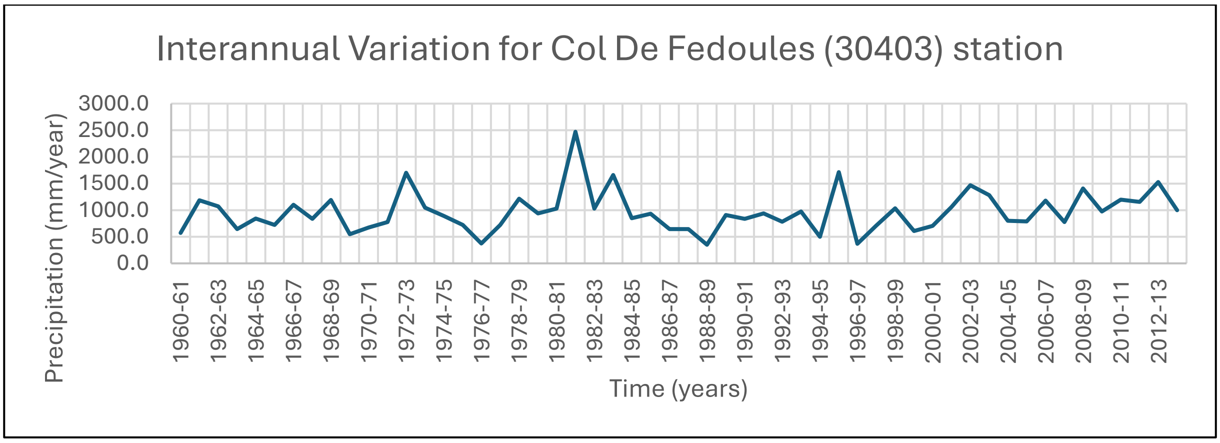

Figure II-7: Annual precipitation for Col De Fedoules (30403) station

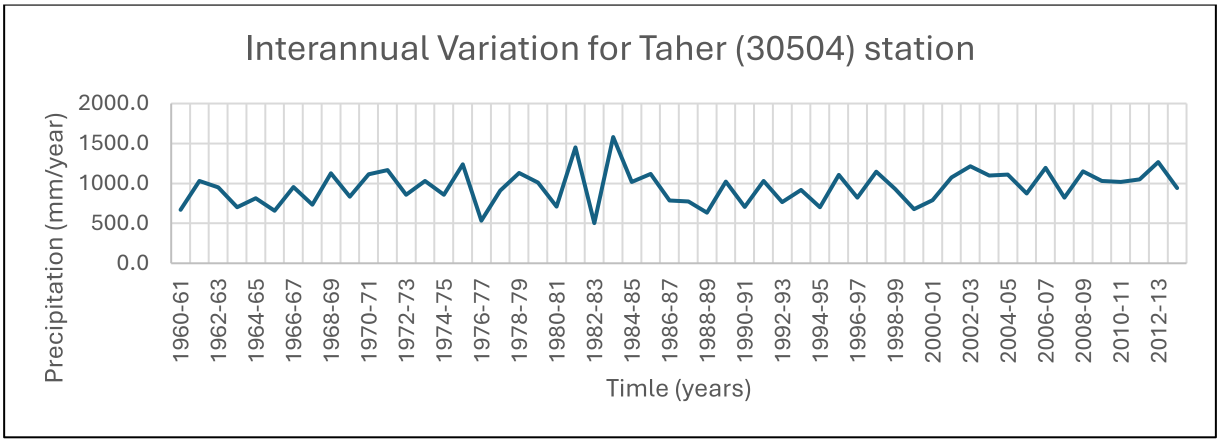

Figure II-8: Annual precipitation for Taher (30504) station

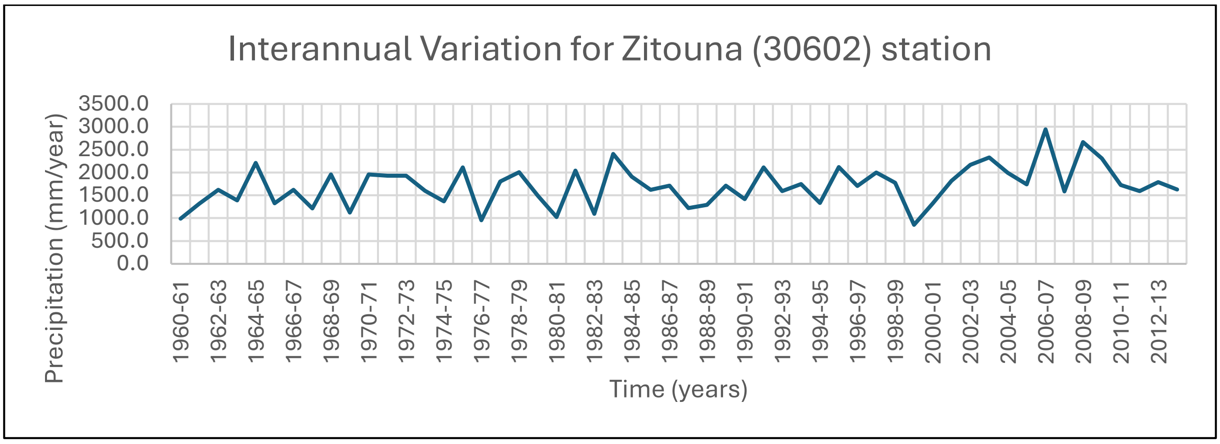

Figure II-9: Annual precipitation for Zitouna (30602) station

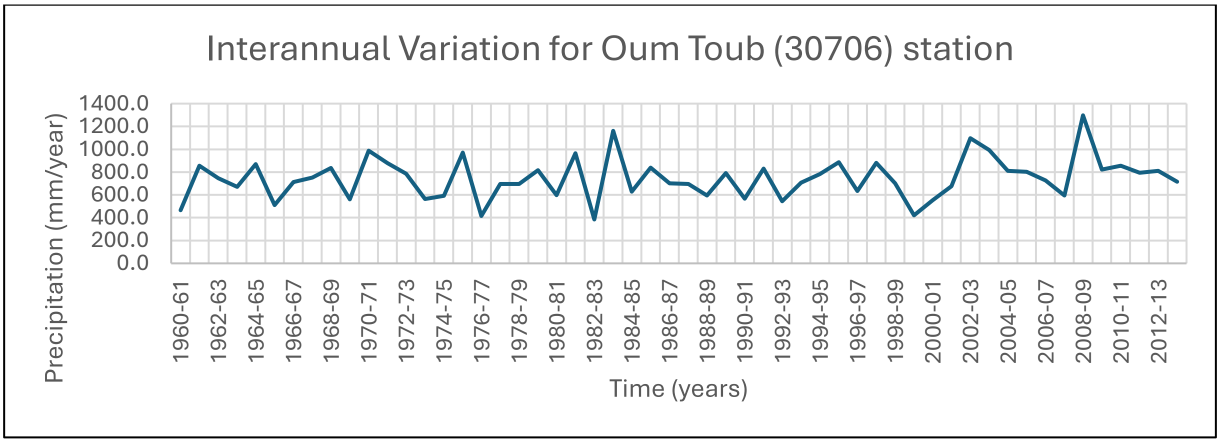

Figure II-10: Annual precipitation for Oum Toub (30706) station

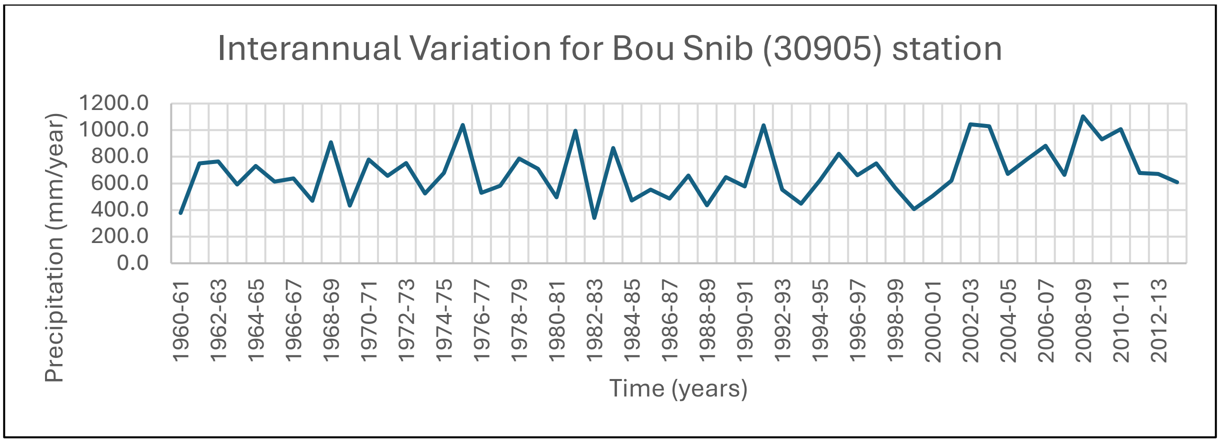

Figure II-11: Annual precipitation for Bou Snib (30905) station

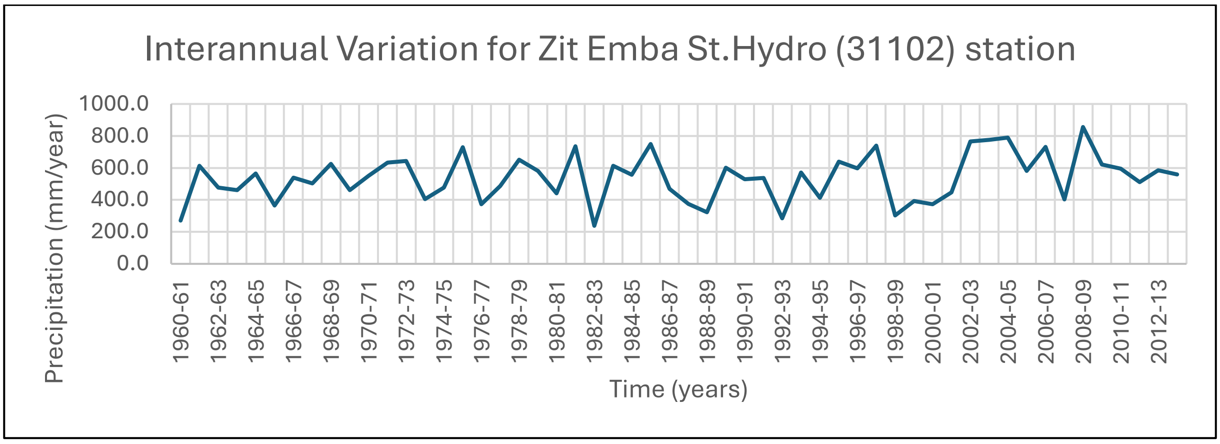

Figure II-12: Annual precipitation for Zit Emba St.Hydro (31102) station

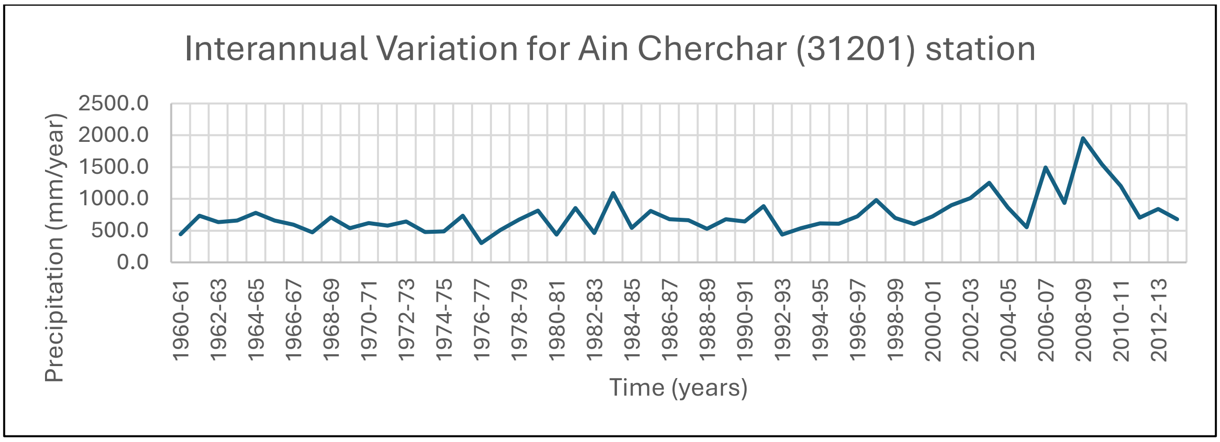

Figure II-13: Annual precipitation for Ain Cherchar (31201) station

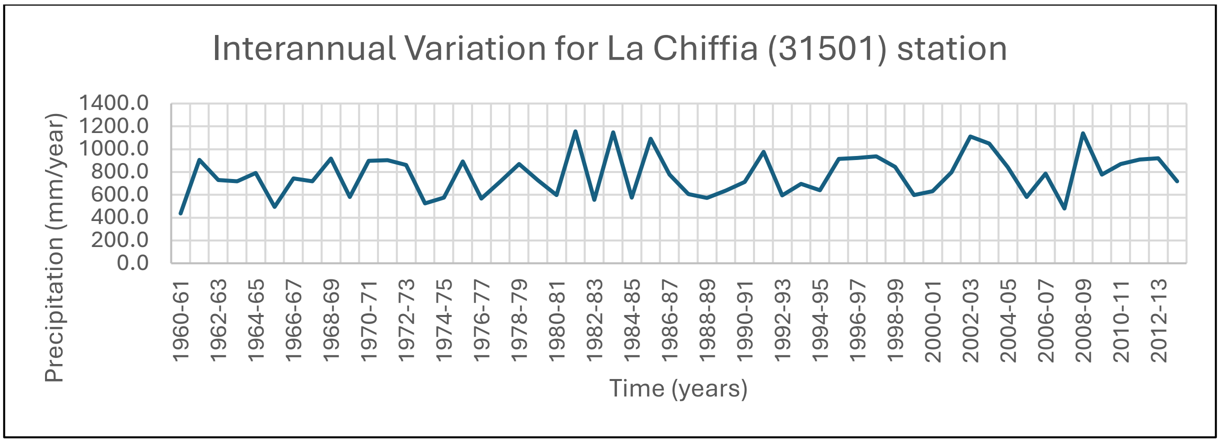

Figure II-14: Annual precipitation for La Chiffia (31501) station

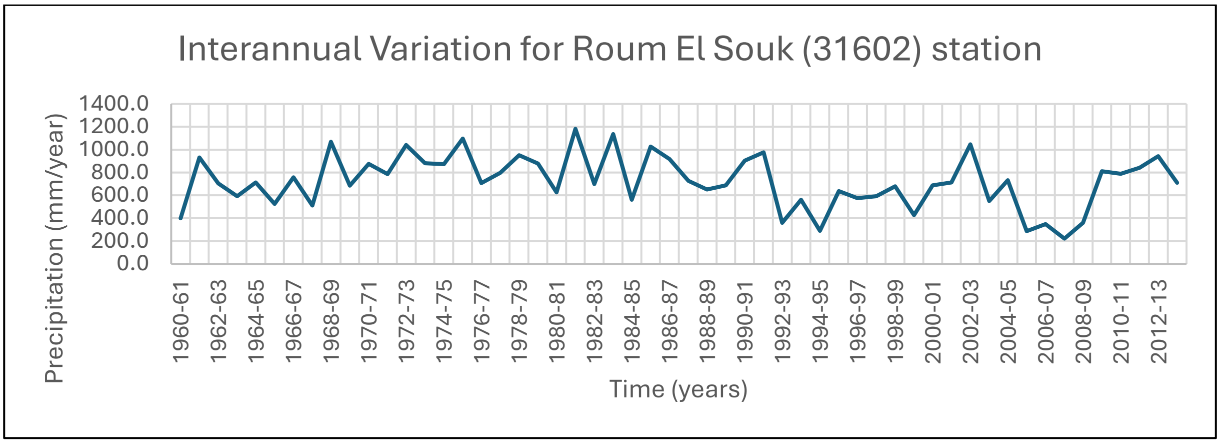

Figure II-15: Annual precipitation for Roum El Souk (31602) station

The stations can be systematically categorized into distinct precipitation regimes based on their magnitude and variability characteristics. The high-precipitation stations, including Zitouna (30602), Col De Fedoules (30403), and Ain Cherchar (31201), consistently demonstrate the highest annual totals ranging between 600-2000mm and exhibit the most dramatic interannual variability. The moderate-high precipitation stations, encompassing Bou Khelifa (30101), Texenna (30302), and Taher (30504), maintain more consistent patterns with annual precipitation typically ranging between 500-1700mm. The moderate precipitation group, including Amoucha (30204), Oum Toub (30706), La Chiffia (31501), Roum El Souk (31602), and Bou Snib (30905), exhibits annual totals generally between 400-1200mm with relatively stable interannual patterns. the low precipitation station, include Zit Emba St.Hydro (31102) which displays annual totals generally between 300-800mm.

Different precipitation patterns over the decades are revealed by the regional climate variability seen across several locations. a number of sites experienced coordinated wet episodes in the early 1970s and early 1980s. On the other hand, Widespread dryness in the mid-1980s is notable, especially at sites like Roum El Souk (31602) and Amoucha (30204), when rainfall fell to record lows (400-700mm). Rainfall generally decreased in many places in the late 1990s, and in the 2000s, there were a variety of precipitation patterns, with some stations maintaining or even surpassing historical averages like Ain Cherchar (31201) while others witnessed consistently low readings.

Significant spatial disparities are revealed by long-term trend analysis across the station network. Particularly since 2000, Amoucha (30204) and Roum El Souk (31602) have shown distinct downward trends in precipitation, which may be indicators of climate change, extended drought cycles, or changes in local weather patterns. The regional variability of climatic impacts is highlighted by stations such as Bou Khelifa (30101), Texenna (30302), Taher (30504), and Bou Snib (30905), which show comparatively stable trends without any significant directional changes. In the meanwhile, it is challenging to distinguish the effects of climate change from natural variability at high-variability mountain sites like Zitouna (30602) and Col De Fedoules (30403) because of their significant annual swings, which mask any long-term patterns.

The observed regional variations in climate underscore the need for specialized adaptation plans that prioritize climate-resilient farming methods, regional water management, and proactive monitoring to tackle a range of issues. Effective irrigation and rainwater collection are necessary in places with variable rainfall, and strong drainage and early warning systems are necessary in areas that could flood. In order to alleviate shortage, water management should prioritize demand-based allocation, community-led conservation. Continuous monitoring with high-resolution data can identify vulnerable locations, allowing for the implementation of targeted measures like incentives for smallholder farmers or infrastructure upgrades in high-risk areas. By putting region-specific policies into place, stakeholders can lessen vulnerability, increase resilience, and shield livelihoods from the unfair consequences of climate change.

According to these figures, the average annual precipitation in the coastal Constantine basin ranges from 550 mm/year to 1100 mm/year, with the exception of Zitouna (30602), which receives an average of 1707 mm/year.

This table represents the highest and lowest data recorded, and the average precipitation of each station for the last half century:

Table II-3: Empirical characteristics of the stations

Name	Code	Max (mm/year)	Min (mm/year)	Average (mm/year)	Standard deviation (mm/year)
Bou Khelifa	30101	1701.4	388.3	980.3	677.9
Amoucha	30204	1209.8	334.2	597.7	498.3
Texenna	30302	1775.4	604.8	1112.1	901.0
Col De Fedoules	30403	2471.4	349.4	963.4	732.5
Taher	30504	1580.3	502.7	951.1	722.3
Zitouna	30602	2944.3	854.4	1707.0	1288.0
Oum Toub	30706	1297.5	384.6	745.2	567.2
Bou Snib	30905	1103.8	340.6	683.5	532.6
Zit Emba St.Hydro	31102	855.9	237.9	539.1	383.0
Ain Cherchar	31201	1953.7	304.0	744.3	602.7
La Chiffia	31501	1156.2	436.6	773.2	621.3
Roum El Souk	31602	1182.1	220.9	722.6	451.9

II-08-Application of the drought indices

Drought indices are the most common tool for estimating future dry conditions or drought forecasting, as they depend on hydrometeorological variables such as precipitation, temperature, evapotranspiration, and runoff. Some researchers base their analysis on the concept that drought is a deficit in precipitation and can be defined and estimated with rainfall as the sole variable [22] .

Precipitation-only indices such as the Standardized Precipitation Index (SPI), is popular because it requires fewer input data and is more flexible and easier to calculate. on which this study will concentrate on, with the intention of providing a detailed examination of drought occurrences in the Coastal Constantine Basin during a 54-year period utilizing the SPI across five-time scales (1, 3, 6, 9, and 12 months). In order for the SPI to accurately depict the basin's drought's temporal and spatial variability, it will do this by identifying localized patterns of drought sensitivity (which station experienced the most impact and which the least), pinpoint times of increased drought activity (regional drought periods), and provide important information on the region's climatic trends over the previous 50 years.

II-9-Conclusion

The Coastal Constantine Basin in northeastern Algeria is a crucial region with diverse topography that plays a vital role in water management, ecological stability, and socioeconomic development. However, it faces challenges from climate variability, rapid urbanization, and unsustainable water exploitation, necessitating integrated management strategies for long-term sustainability. Proactive measures are needed to prevent irreversible water deficits caused by climate change, a strong basis for drought study is provided by long-term rainfall data from 12 sites (54 years). The standardized precipitation index (SPI) is ideally suited to collecting spatial disparities and temporal drought characteristics, which are crucial for determining regional climatic vulnerabilities and assisting with drought mitigation plans.

CHAPTER III: Results and discussion

III-Results and discussion

III-01-Introduction

An effective way to comprehend how climate conditions have changed over time in various places within the study area is to use SPI for drought analysis. It aids in identifying drought patterns, which can be crucial for resource management and regional planning.

The purpose of this study is to examine climate variability at 12 stations within our study region during a 54-year period, from 1960 to 2013. by calculating the drought frequencies across one, three, six, nine, and twelve-month periods and comparing them. The goal is to evaluate the relative vulnerability of the various climatic situations and to comprehend and highlight their frequency and intensity throughout the period of study.

III-02-Standardized Precipitation Index for 1 month (SPI 1)

The 1-month standardized precipitation index (SPI) was used at 12 rainfall stations in the Coastal Constantine watershed to analyze the behavior and spatial variability of drought from the year 1960 to the year 2013.

Providing us with 648 values for each station which will be summarized in the form of a SPI plot as shown in the figures below:

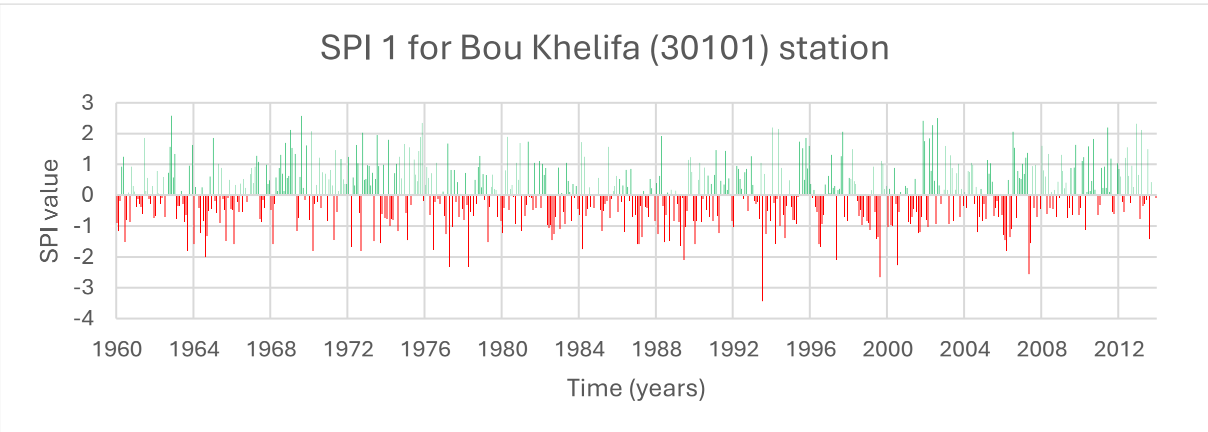

Figure III-1: SPI 1 for Bou Khelifa (30101) station

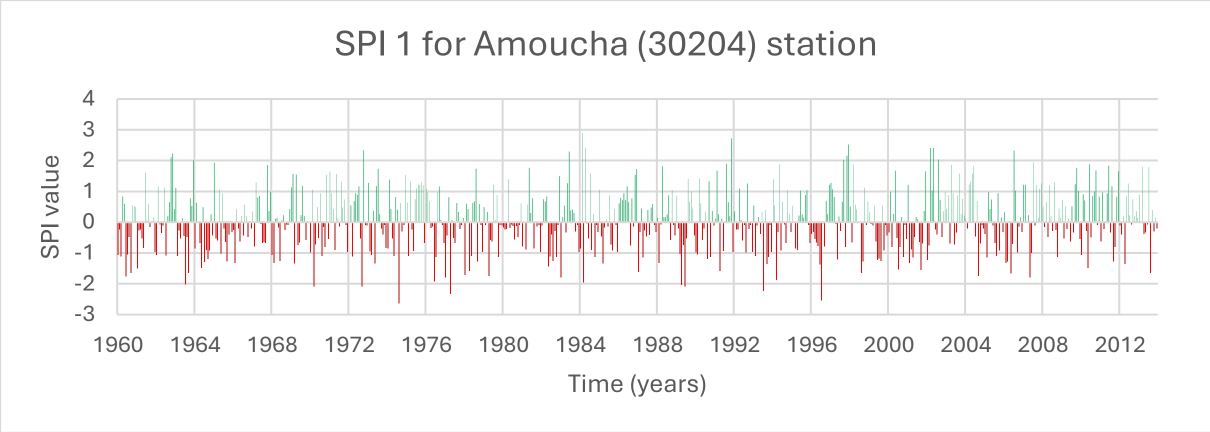

Figure III-2: SPI 1 for Amoucha (30204) station

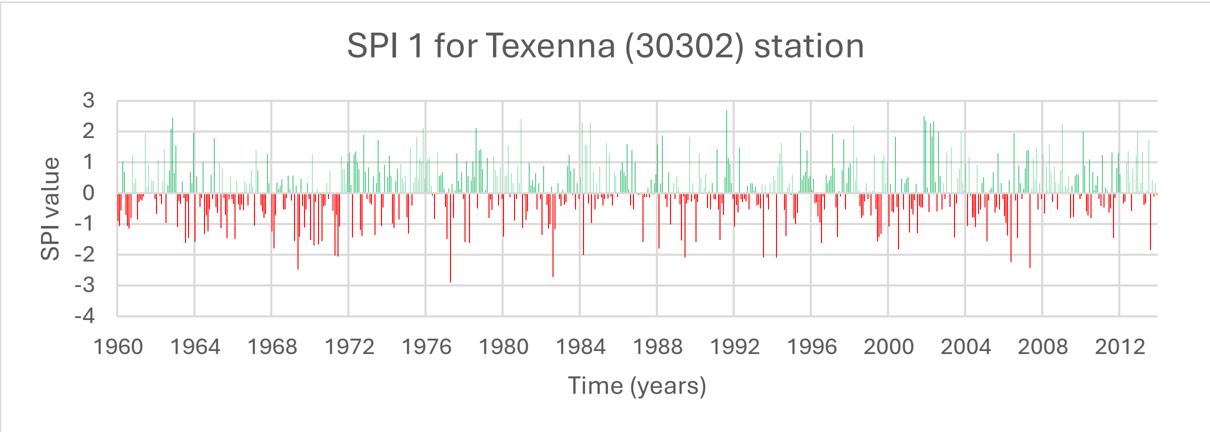

Figure III-3: SPI 1 for Texenna (30302) station

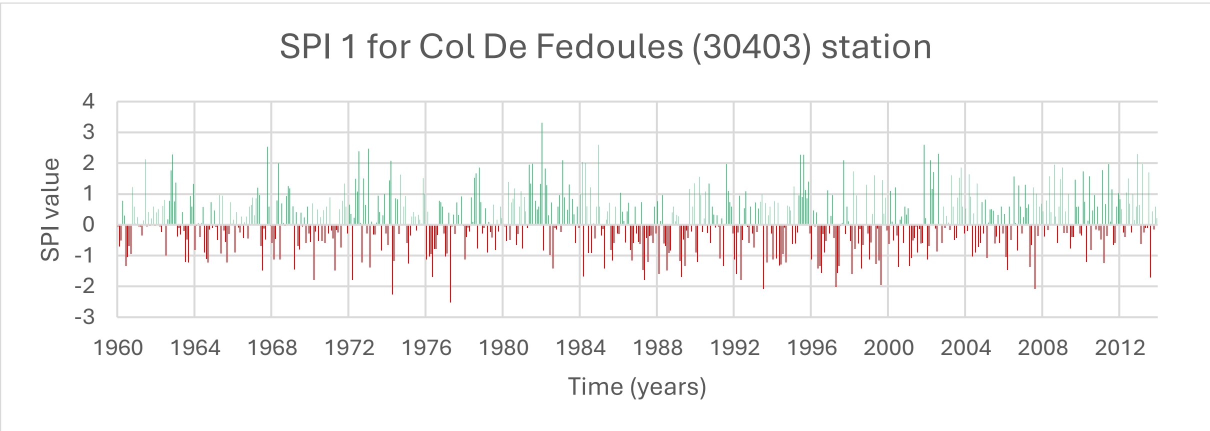

Figure III-4: SPI 1 for Col De Fedoules (30403) station

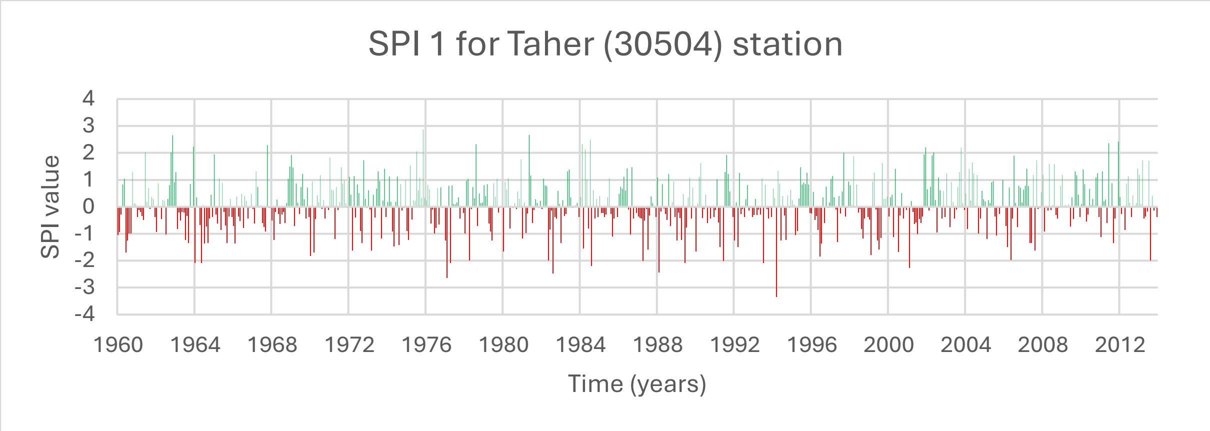

Figure III-5: SPI 1 for Taher (30504) station

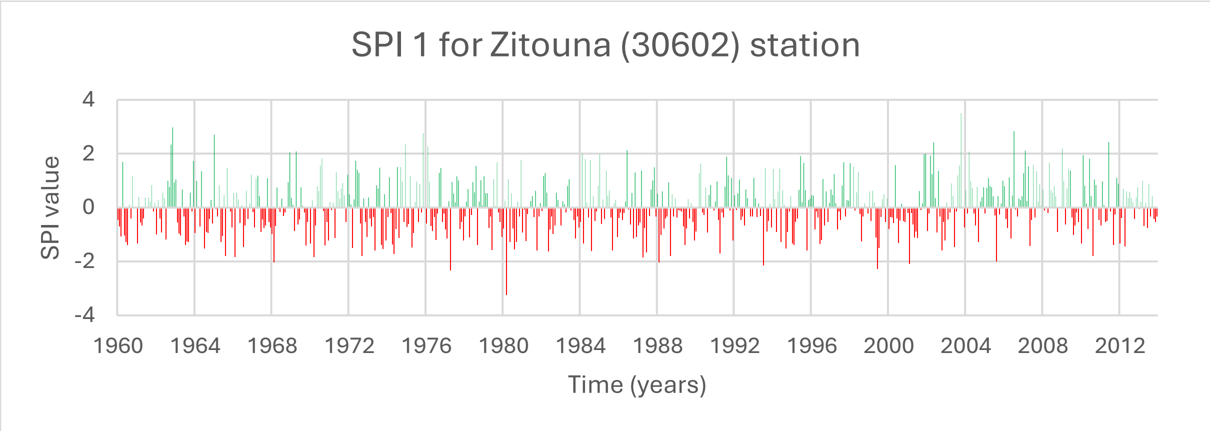

Figure III-6: SPI 1 for Zitouna (30602) station

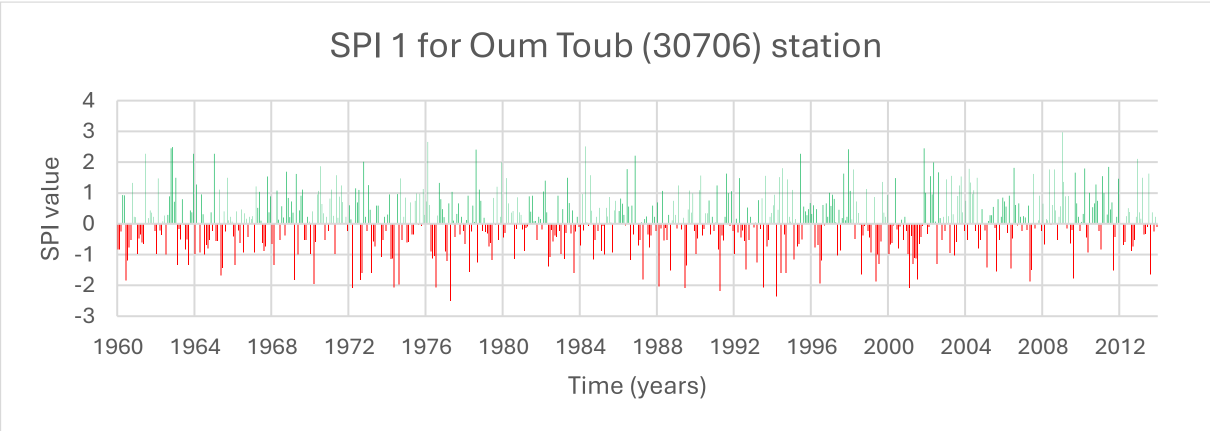

Figure III-7: SPI 1 for Oum Toub (30706) station

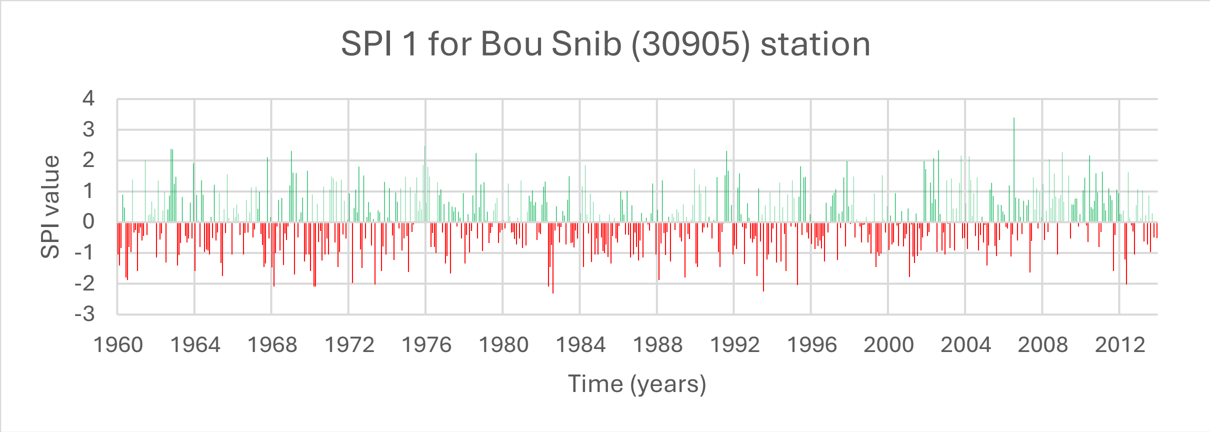

Figure III-8: SPI 1 for Bou Snib (30905) station

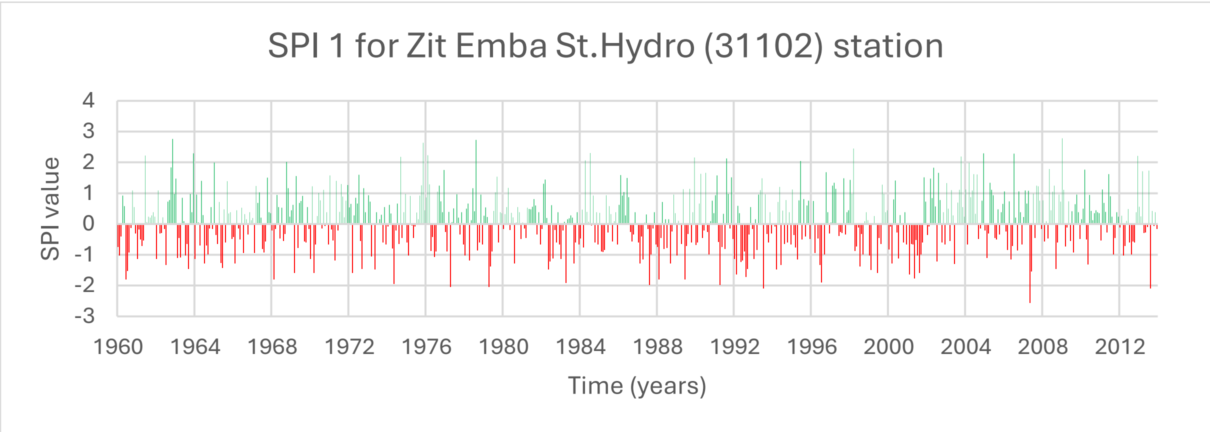

Figure III-9: SPI 1 for Zit Emba St.Hydro (31102) station

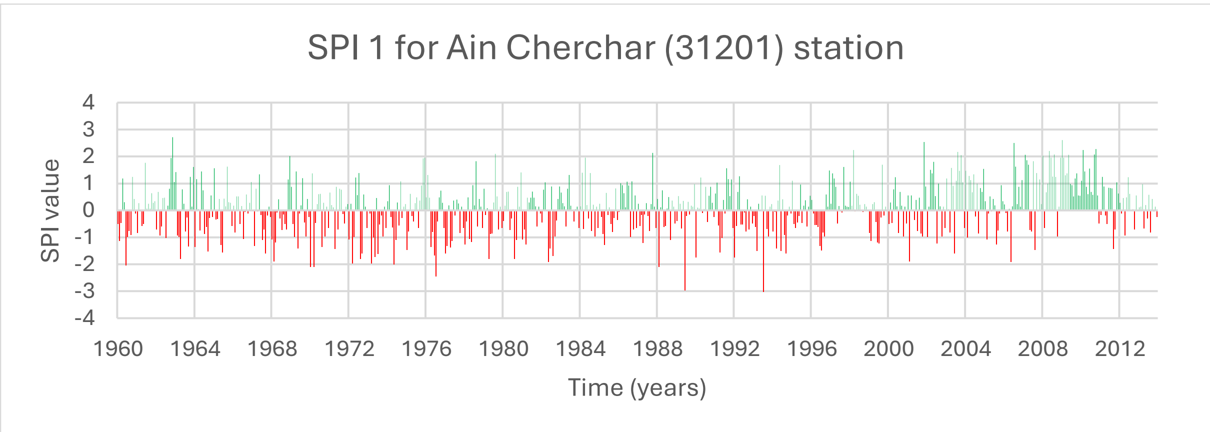

Figure III-10: SPI 1 for Ain Cherchar (31201) station

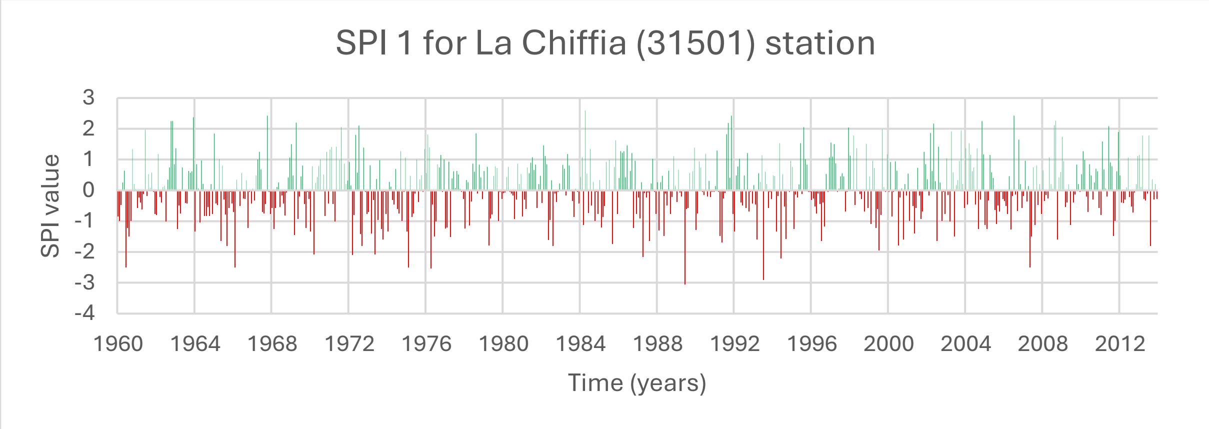

Figure III-11: SPI 1 for La Chiffia (31501) station

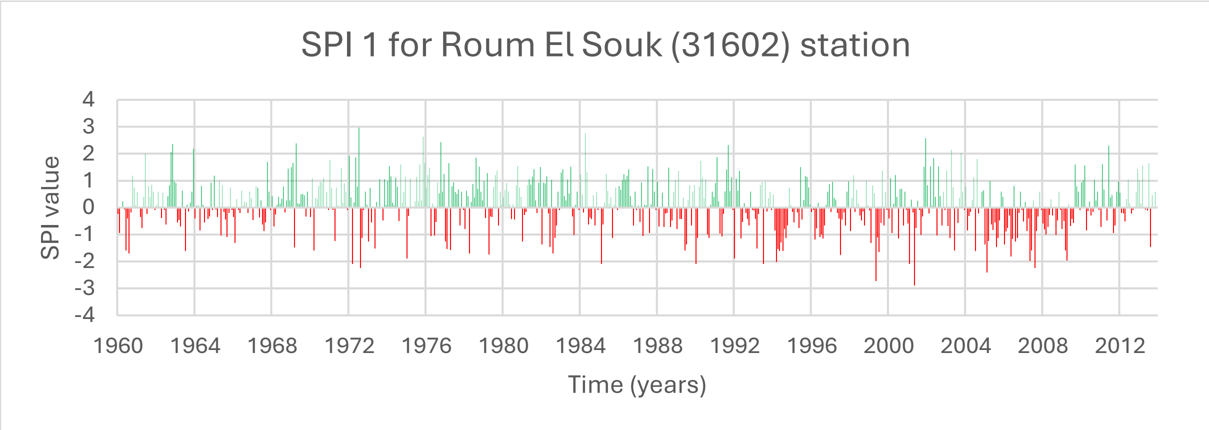

Figure III-12: SPI 1 for Roum El Souk (31602) station

A 54-year study of SPI 1 data from 12 meteorological sites in the study area reveals multiple notable drought periods, with the worst ones taking place in 1981 and 1983, Extreme drought was indicated by SPI values falling below -1.5 at almost all stations and below -3 in the most severely afflicted areas, highlighting the unusual intensity, duration, and geographic scope of this protracted drought. There was a second, less severe drought in 1987–1988 that had moderate to severe conditions.

Zitouna (30602) is the study's most drought-affected meteorological station, especially during the devastating regional drought of 1981–1983, when it reported SPI values below -3, a sign of exceedingly uncommon and severe conditions. Due to its location in a zone that is between the Mediterranean and continental climates, Zitouna (30602) is extremely vulnerable to changes in atmospheric patterns, which exposes it to the instability of both regions without the benefits of either climate. Zitouna (30602) is a vital location for tracking regional drought stress and early warning signs because of the combination of these characteristics that provide significant climate variability and prolonged drought susceptibility.

The study's most drought-resilient station is Bou Khelifa (30101), which exhibits negligible effects even during extreme regional droughts because of its strategic northern coastal location and the Mediterranean Sea's moderating effect. Because the station is protected from severe drought intensities by sea-breeze circulations, and steady atmospheric moisture, this marine location improves precipitation reliability. Only mild to moderate dryness was observed in Bou Khelifa (30101) during periods such as the 1981–1983 drought, with shorter and less severe drought bouts that were followed by faster recoveries. Its location within the steady northern precipitation regime promotes regular wet-dry movement and lower variability, creating a balanced environment that avoids prolonged water shortages.

III-02-1-Drought events for SPI 1

The events distribution of the various wet and dry classes over 12 stations (extremely wet, severely wet, moderately wet, normal, moderately dry, severely dry, and extremely dry) is displayed for 1 month in the table below. Each category, which goes from "extremely wet" to "extremely drought," represents the level of drought and wetness that was recorded in these areas within a specific time frame.

Table III-1: Drought events for SPI 1

Classes and Stations	Extremely wet	Severely wet	Moderately wet	Normal	Moderately dry	Severely dry	Extremely dry
Bou Khelifa (30101)	16	33	53	474	41	22	9
Amoucha (30204)	15	34	57	451	61	21	9
Texenna (30302)	14	28	56	474	45	20	11
Col De Fedoules (30403)	17	32	44	478	58	14	5
Taher (30504)	17	20	65	471	44	18	13
Zitouna (30602)	18	27	55	453	65	23	7
Oum Toub (30706)	15	30	51	480	38	24	10
Bou Snib (30905)	16	24	68	444	69	18	9
Zit Emba St.Hydro (31102)	19	25	57	467	55	20	5
Ain Cherchar (31201)	18	24	60	468	46	24	8
La Chiffia (31501)	18	23	59	468	48	20	12
Roum El Souk (31602)	13	29	61	465	43	26	11

Graphical representations of this data are also available:

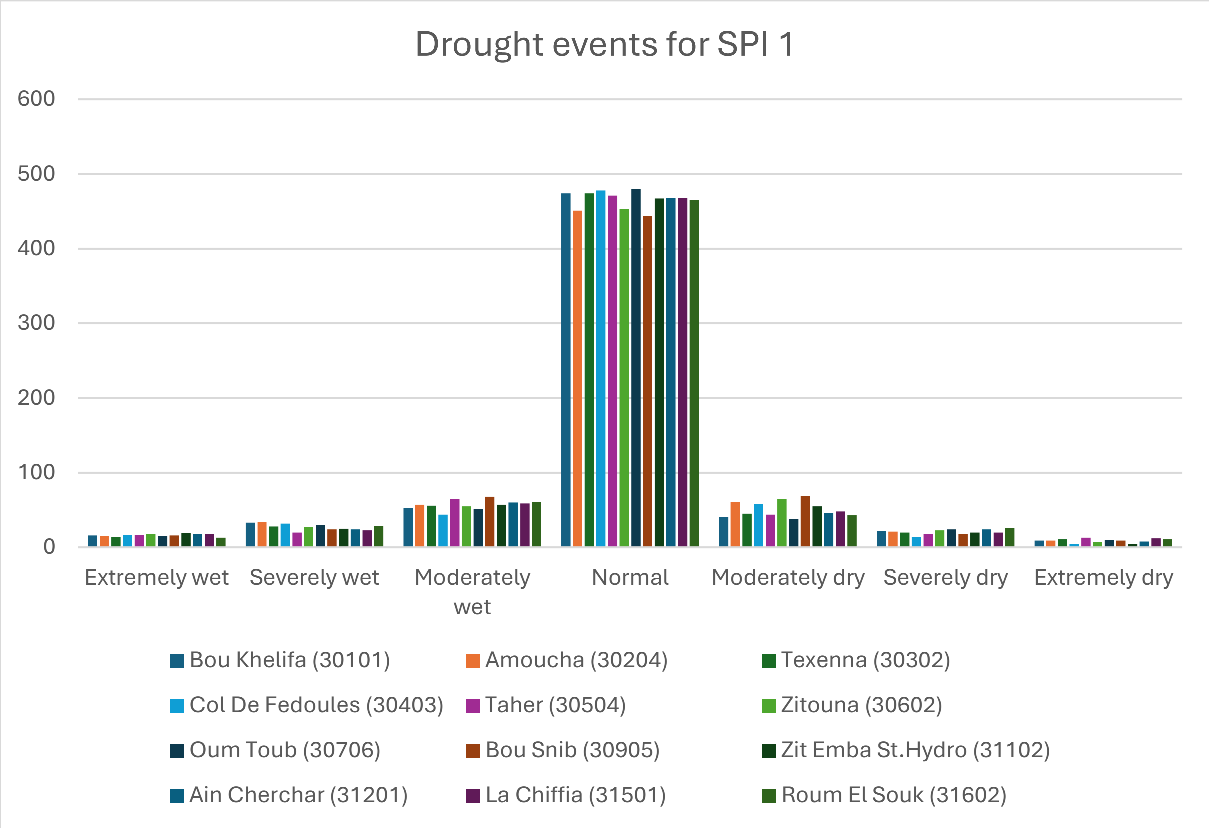

Figure III-13: Drought events for SPI 1

A detailed analysis of SPI 1 data from twelve stations indicates that the climate regime is predominantly characterized by normal conditions with 444 to 480 normal events recorded (68.5%–74%). The highest number of normal events was observed at Oum Toub (30706), with 480 occurrences while Bou Snib (30905) had the least with 444 occurrences (68.5%). Wet events range from 93 to 108 occurrences (14.3%–16.6%), while dry events range from 72 to 96 occurrences (11%–14.8%). Bou Snib (30905) experienced the highest number of drought events with 96 occurrences (14.8%), whereas Bou Khlifa (30101) and Oum Toub (30706) were the least affected, each with 72 occurrences (11%). In terms of wet events, Bou Snib also recorded the most 108 occurrences (16.6%), while Col De Fedoules (30403) experienced the fewest, with 93 occurrences (14.3%).

III-03-Standardized Precipitation Index for 3 month (SPI 3)

Using the 3-month Standardized Precipitation Index on the same 12 stations provided us with 646 values for each station which the following figures below will illustrate in the form of a SPI plot:

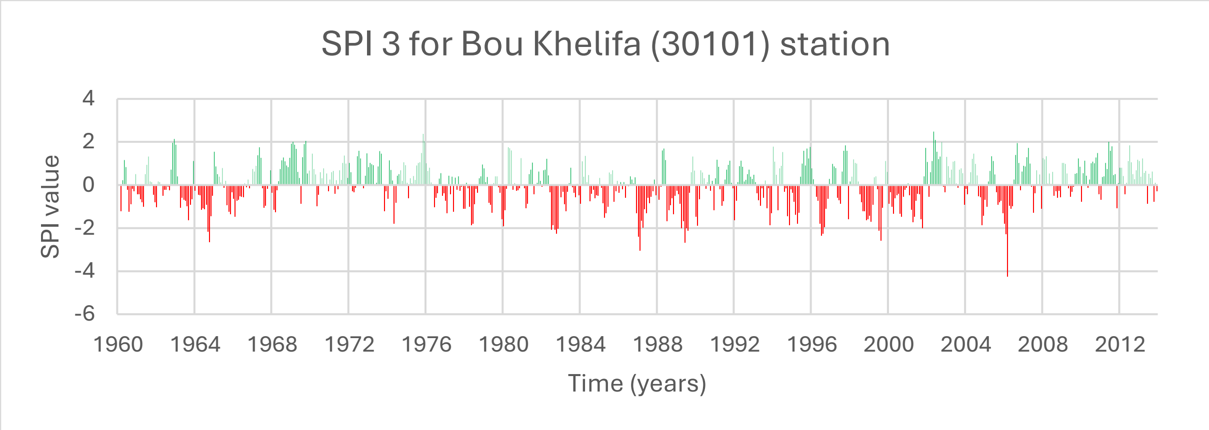

Figure III-14: SPI 3 for Bou Khelifa (30101) station

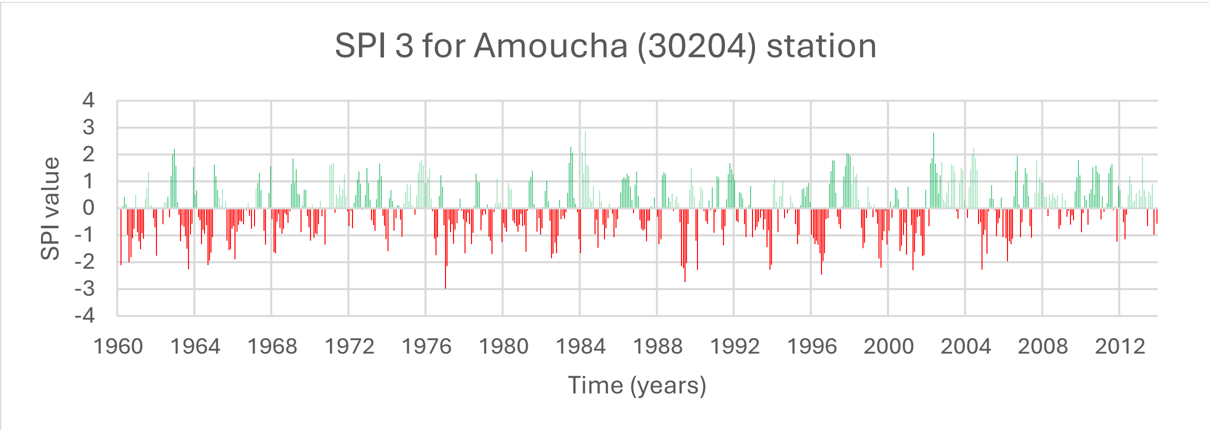

Figure III-15: SPI 3 for Amoucha (30204) station

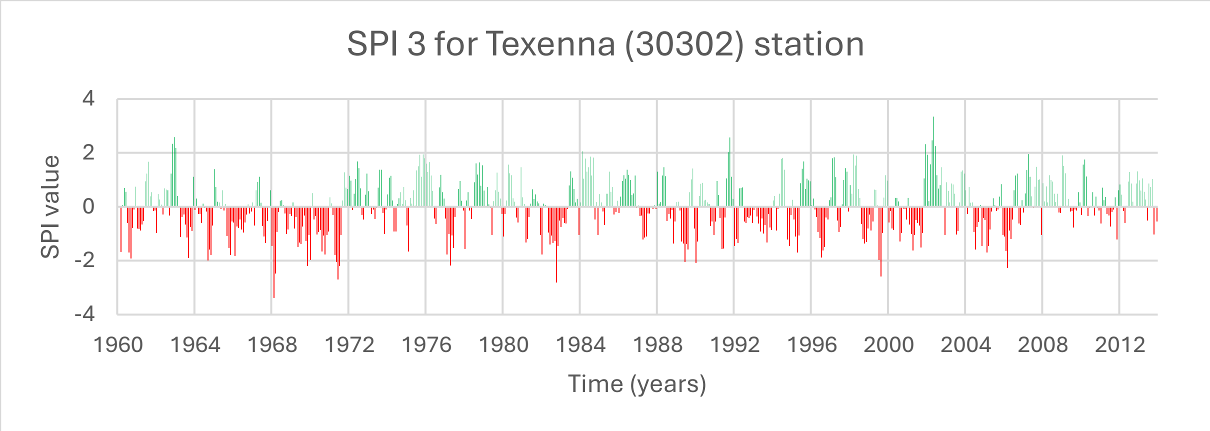

Figure III-16: SPI 3 for Texenna (30302) station

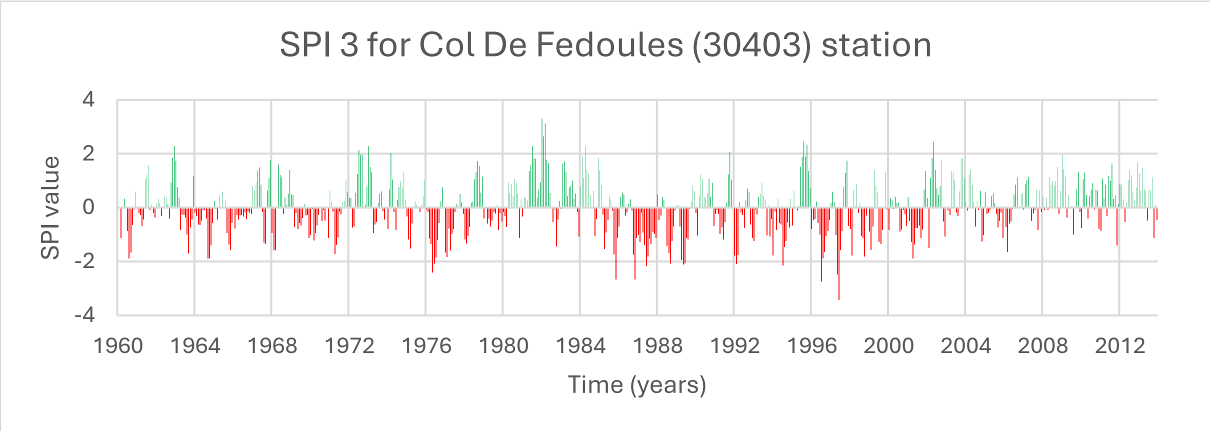

Figure III-17: SPI 3 for Col De Fedoules (30403) station

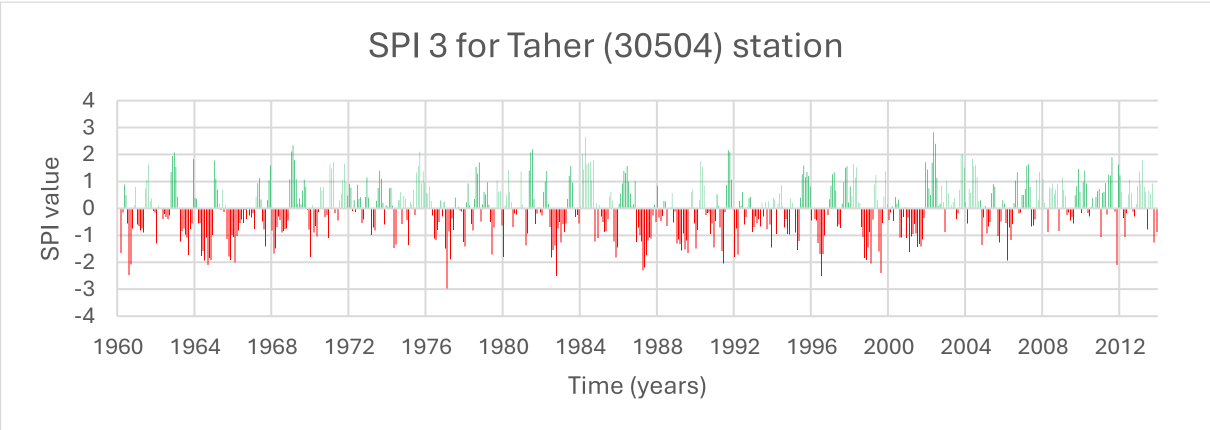

Figure III-18: SPI 3 for Taher (30504) station

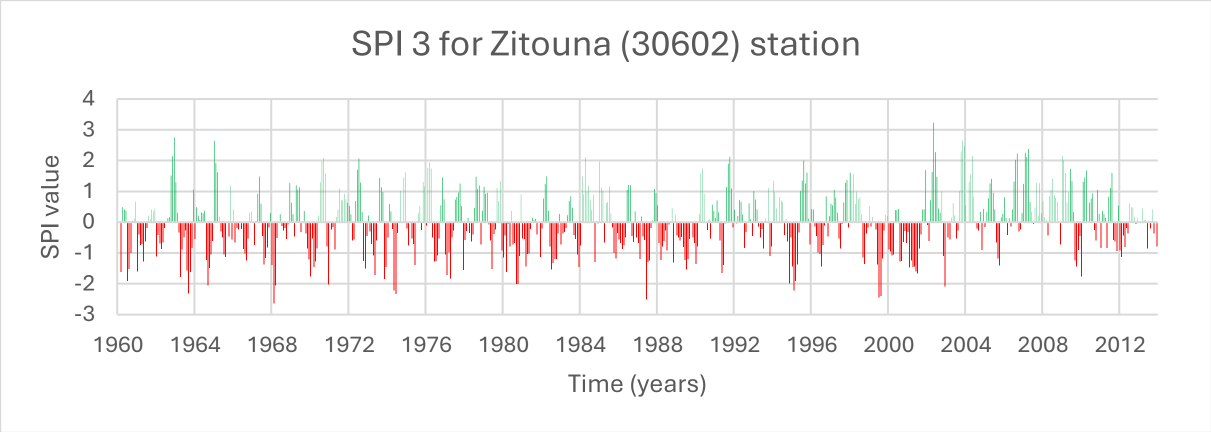

Figure III-19: SPI 3 for Zitouna (30602) station

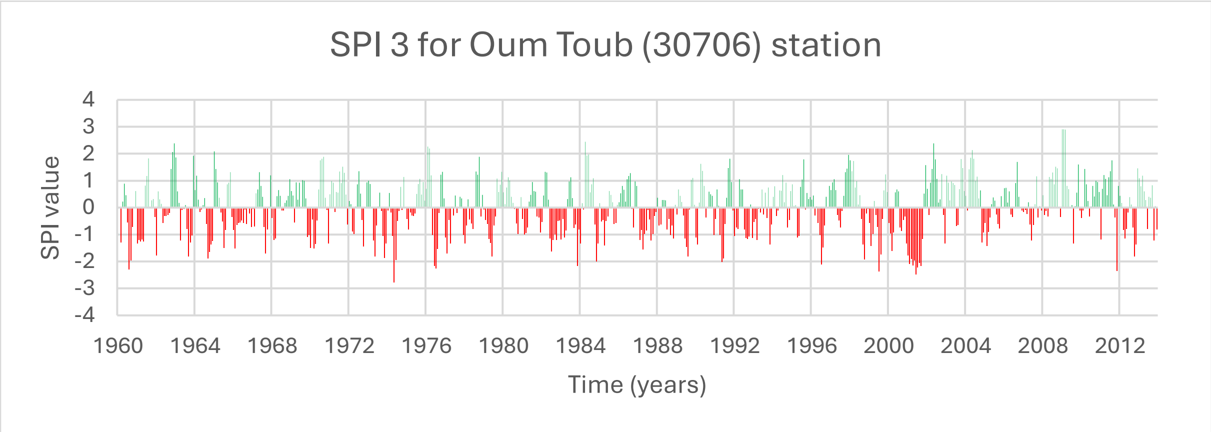

Figure III-20: SPI 3 for Oum Toub (30706) station

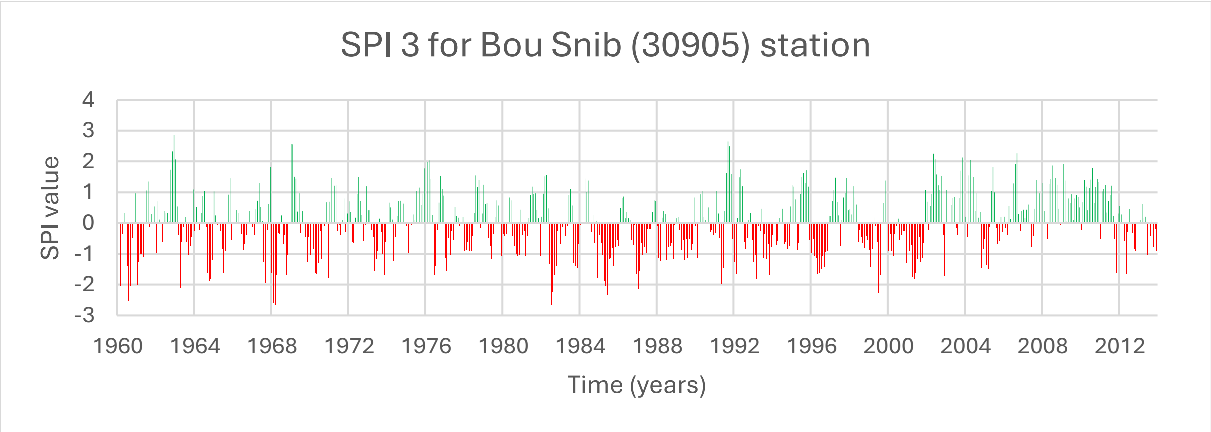

Figure III-21: SPI 3 for Bou Snib (30905) station

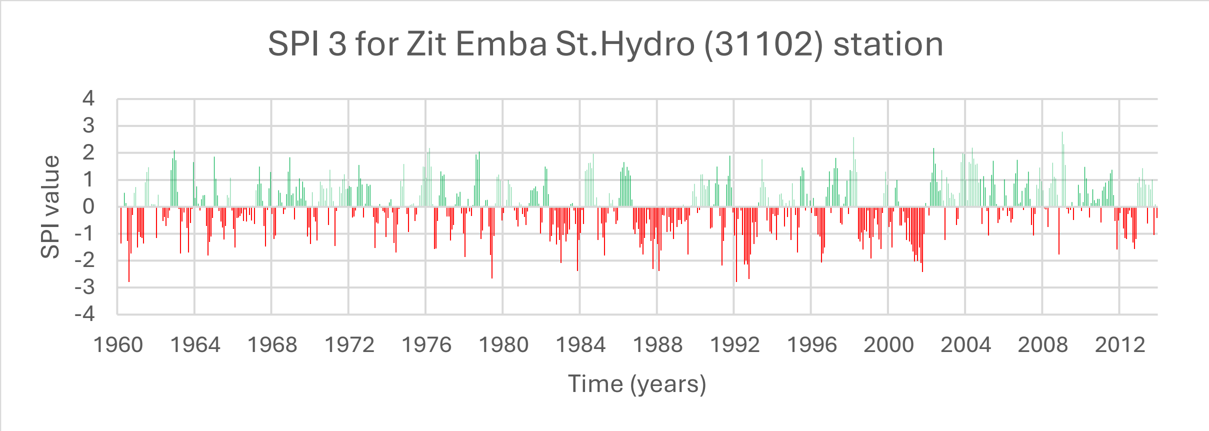

Figure III-22: SPI 3 for Zit Emba St.Hydro (31102) station

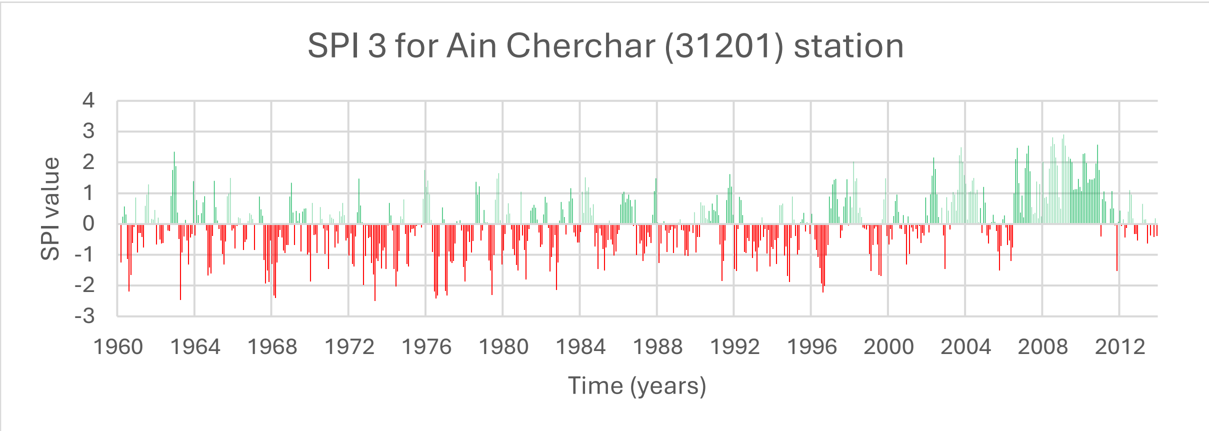

Figure III-23: SPI 3 for Ain Cherchar (31201) station

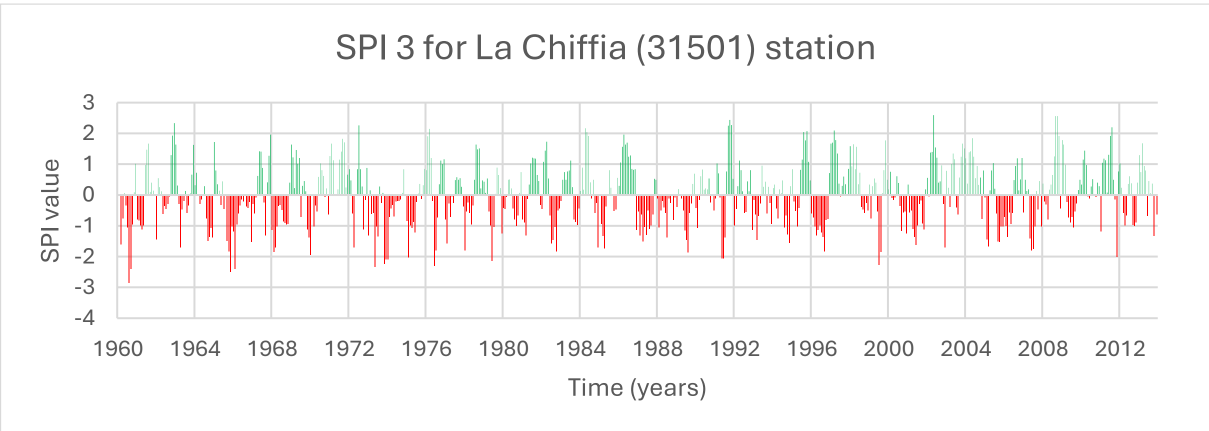

Figure III-24: SPI 3 for La Chiffia (31501) station

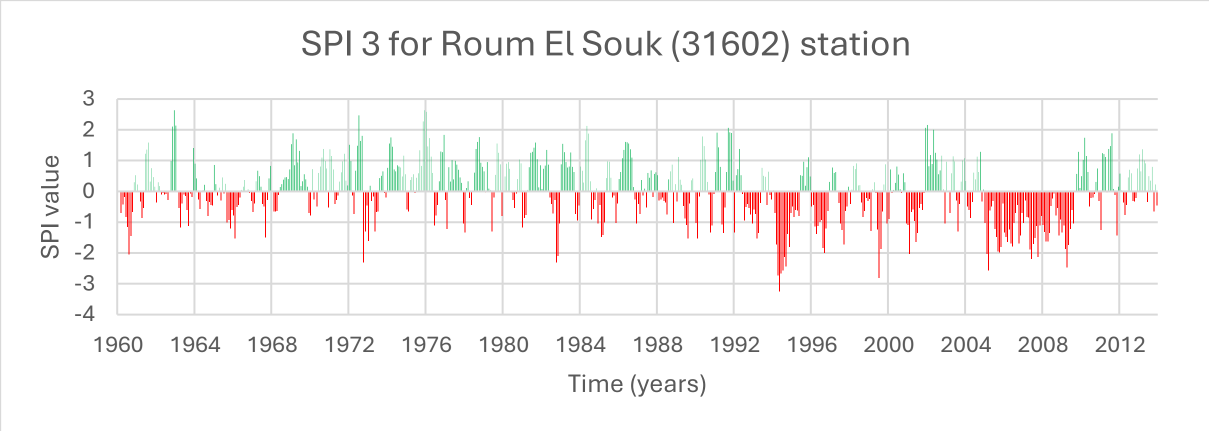

Figure III-25: SPI 3 for Roum El Souk (31602) station

The most widespread and severe region-wide drought episodes, with sustained SPI values below -2 indicating extreme drought conditions across almost all stations, were 1982–1984, the most significant of which was reported across all stations. Another significant drought that occurred from 1999 to 2002 was characterized by long-lasting and severe SPI decreases. A shorter but more severe drought in 2007–2008 caused numerous stations to experience SPI levels below -2.

The most severely impacted station by drought occurrences is Oum Toub (30706), which often shows the most frequent and severe negative SPI excursions—many of which drop below -2, indicating exceptionally severe drought. Notably, it recovered poorly from the regional drought of 1982–1984, frequently staying in drought while neighboring stations got better. This increased susceptibility is probably brought on by Oum Toub's (30706) geographic and climatic location, which may place it in a rain shadow or in an area that is extremely vulnerable to changes in air circulation, making it dependent on unstable seasonal precipitation patterns.

Throughout the time period, Ain Cherchar (31201) continuously exhibits higher resilience to drought conditions. For example, Ain Cherchar (31201) maintained moderate SPI values around -1 to -2 during the big droughts of 1982–1984 and 1999–2002. In contrast to other stations, it experiences fewer and less severe negative SPI spikes, with drought events that are generally shorter and less intense. Ain Cherchar (31201) may be more resilient to extended or severe dry spells because of its favorable geographic location, which may expose it to more stable air circulation patterns and mountainous rains from neighboring altitudes.

III-03-1-Drought events for SPI 3

The events distribution of the various wet and dry classes for SPI 3 is displayed by the table below:

Table III-2: Drought events for SPI 3

Classes and Stations	Extremely wet	Severely wet	Moderately wet	Normal	Moderately dry	Severely dry	Extremely dry
Bou Khelifa (30101)	7	32	72	430	59	27	19
Amoucha (30204)	9	40	58	435	57	30	17
Texenna (30302)	10	30	70	427	66	31	12
Col De Fedoules (30403)	13	29	62	438	60	31	13
Taher (30504)	13	37	55	438	58	32	13
Zitouna (30602)	20	25	65	428	70	24	14
Oum Toub (30706)	11	25	62	433	72	27	16
Bou Snib (30905)	15	26	67	430	61	34	13
Zit Emba St.Hydro (31102)	9	30	67	428	64	32	16
Ain Cherchar (31201)	24	17	54	456	53	27	15
La Chiffia (31501)	15	36	56	430	67	27	15
Roum El Souk (31602)	11	28	57	439	68	25	18

Additionally, this data can be represented graphically:

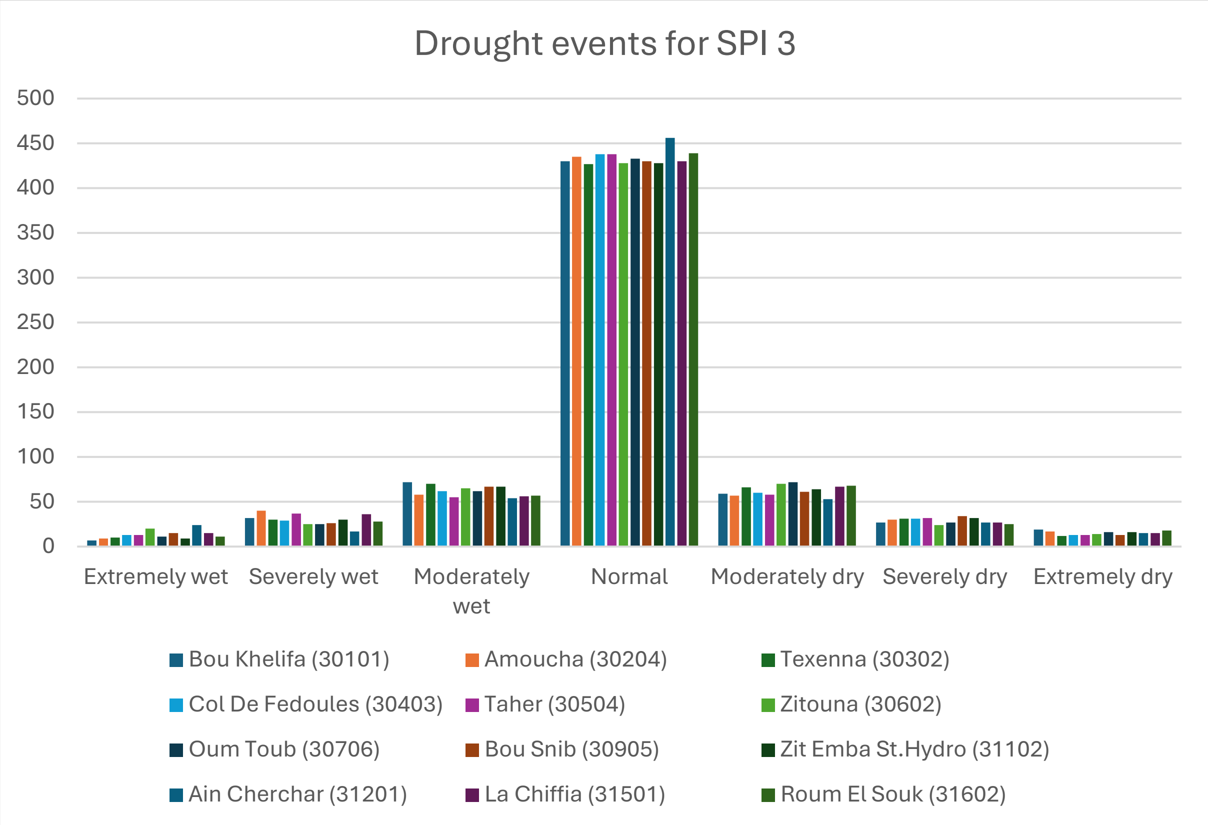

Figure III-26: Drought events for SPI 3

According to a thorough examination of SPI 3 data from twelve stations, 427 to 456 normal events (66.1%–70.5%) were recorded, indicating that the climate regime is primarily defined by normal conditions, 456 normal events (70.1%) were recorded at Ain Cherchar (31201), the most of any location and least of any location was Texenna (30302) with 427 events (66.1%). Dry events occur between 95 and 115 times (14.7%–17.8%), and wet events occur between 95 and 111 times (14.7%–17.1%). With 115 occurrences (17.8%), Oum Toub (30706) had the most drought events, while Ain Cherchar (31201) had the fewest, with 95 occurrences (14.7%). With 111 occurrences (17.1%), Bou Khelifa (30101) likewise had the most wet events, whilst Ain Cherchar (31201) had the fewest 95 occurrences (14.7%).

III-04-Standardized Precipitation Index for 6 month (SPI 6)

Using the 6-month Standardized Precipitation Index on the same 12 stations provided us with 643 values for each station which the following figures below will illustrate in the form of a SPI plot:

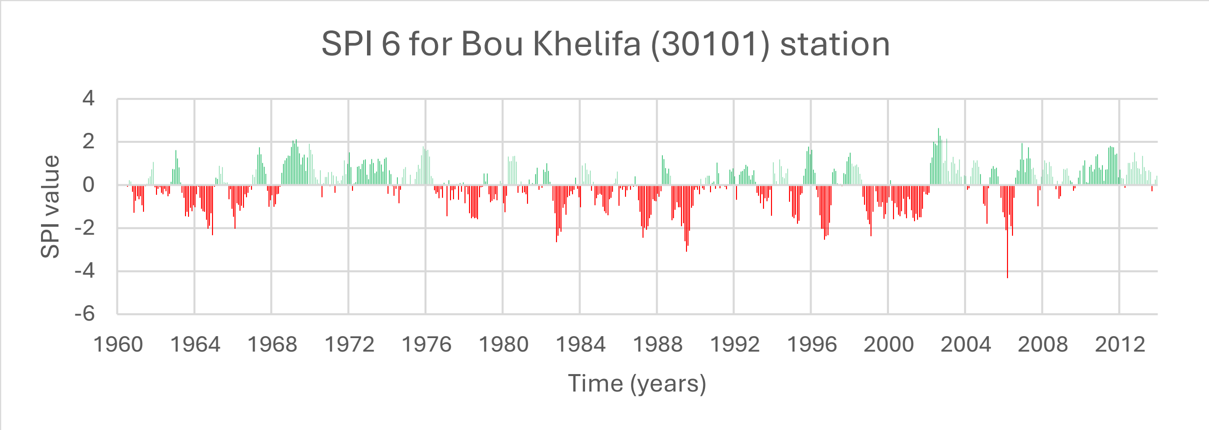

Figure III-27: SPI 6 for Bou Khelifa (30101) station

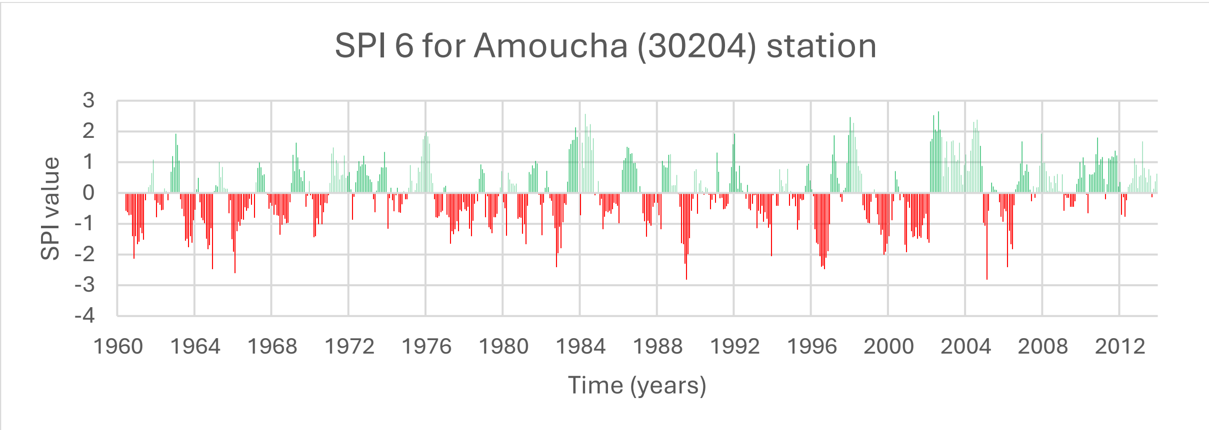

Figure III-28: SPI 6 for Amoucha (30204) station

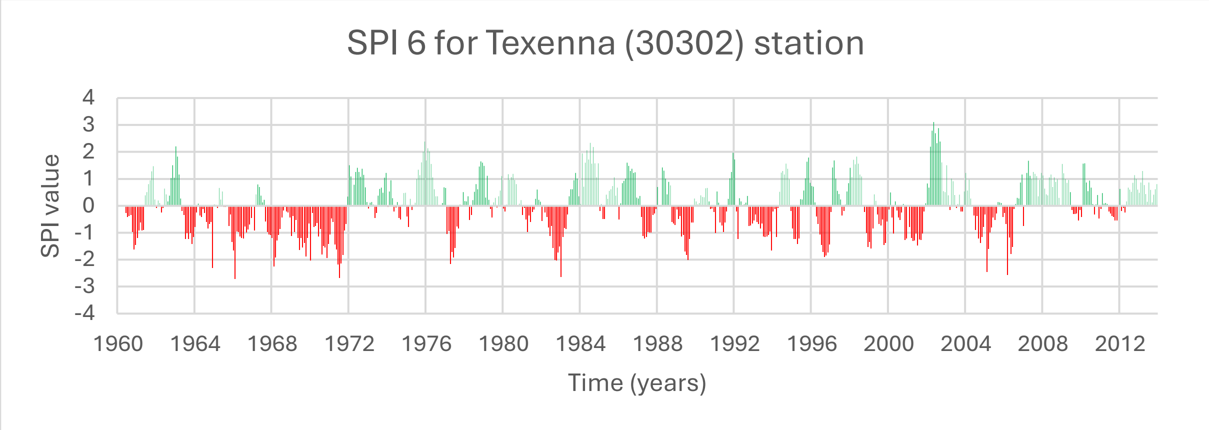

Figure III-29: SPI 6 for Texenna (30302) station

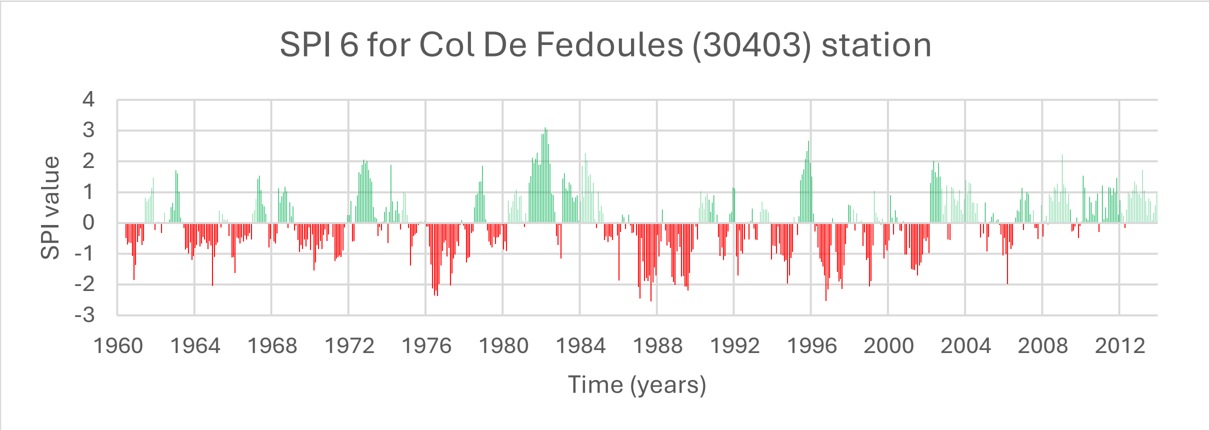

Figure III-30: SPI 6 for Col De Fedoules (30403) station

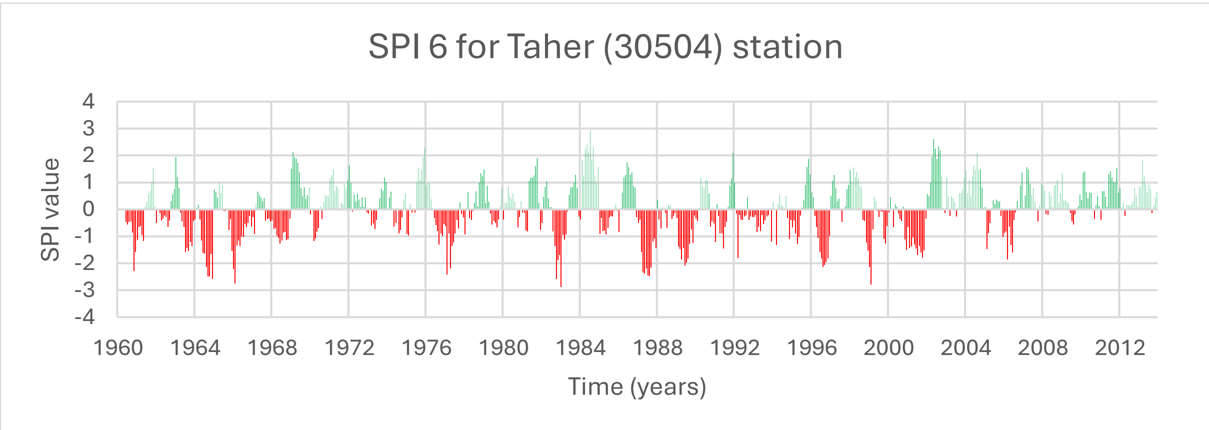

Figure III-31: SPI 6 for Taher (30504) station

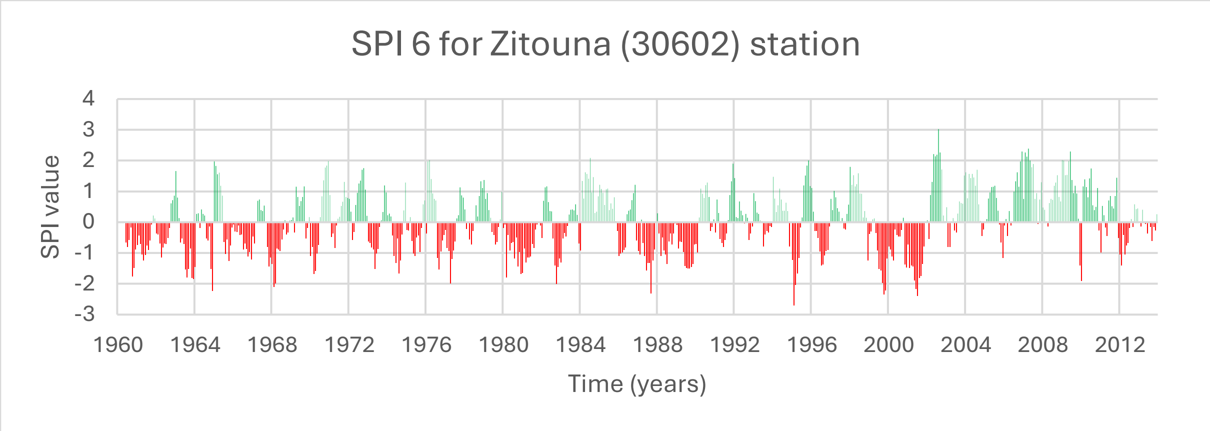

Figure III-32: SPI 6 for Zitouna (30602) station

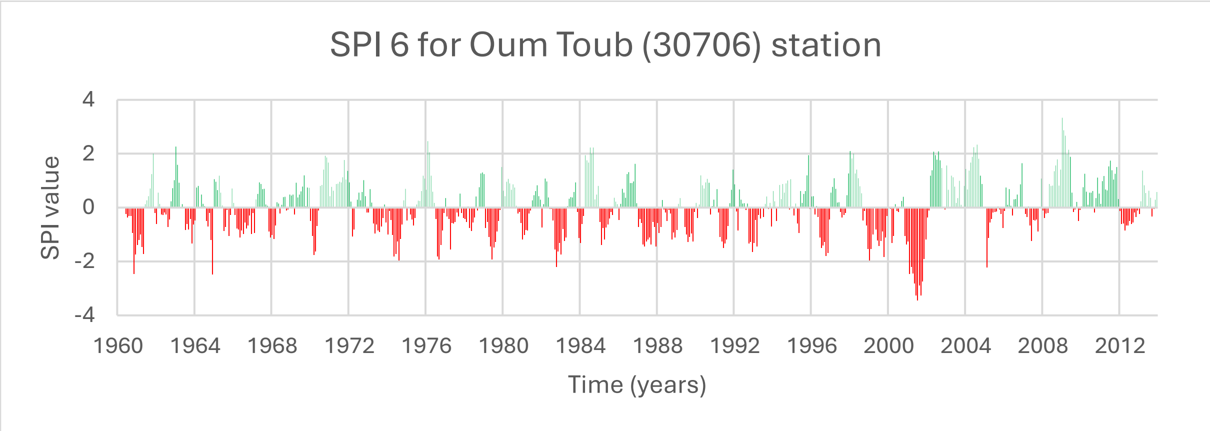

Figure III-33: SPI 6 for Oum Toub (30706) station

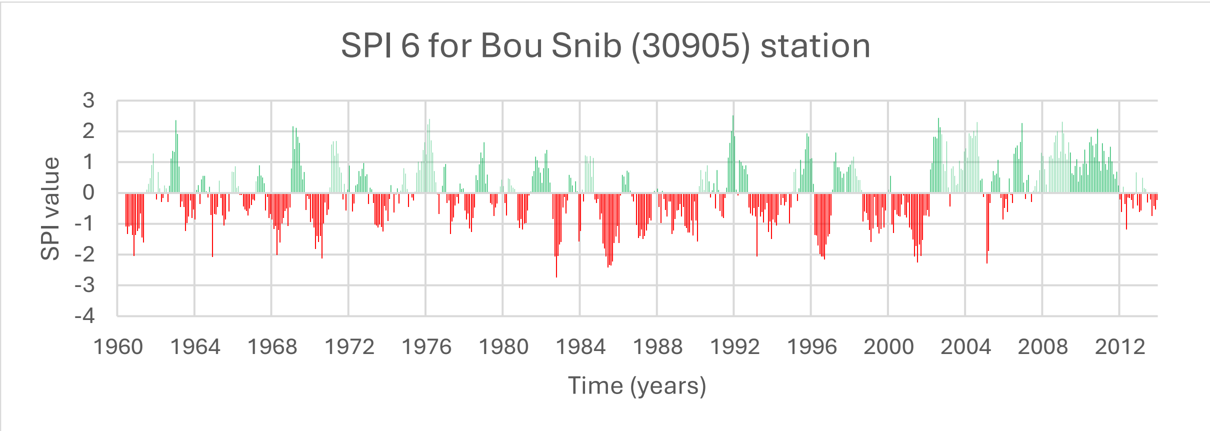

Figure III-34: SPI 6 for Bou Snib (30905) station

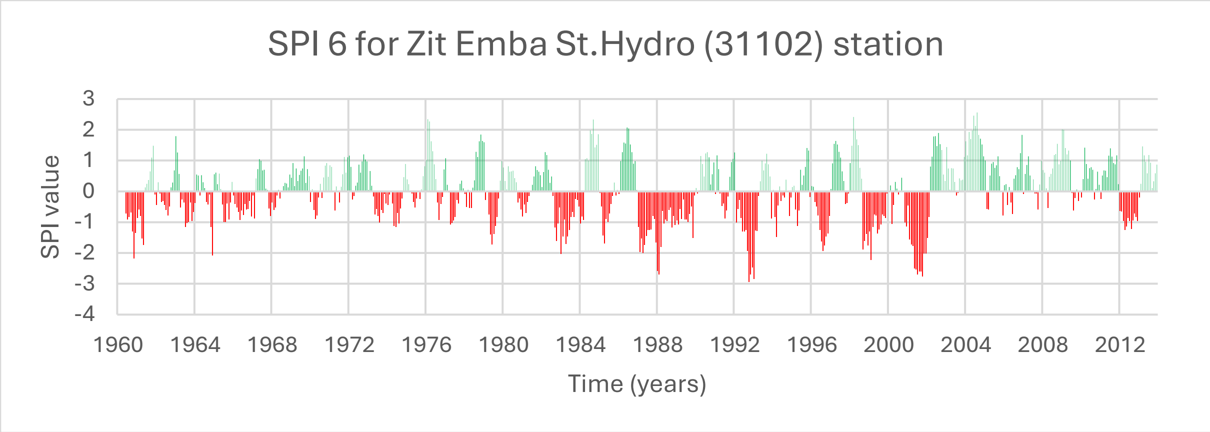

Figure III-35: SPI 6 for Zit Emba St.Hydro (31102) station

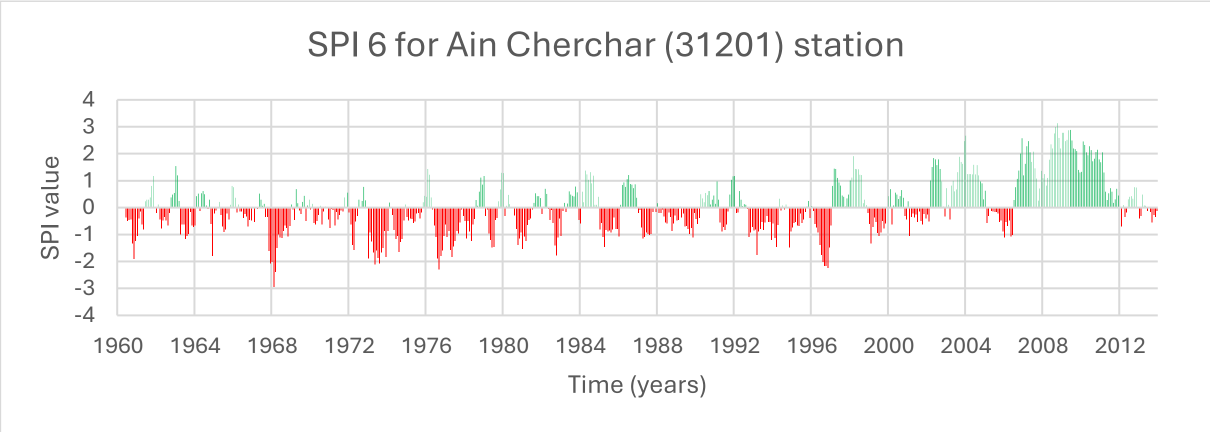

Figure III-36: SPI 6 for Ain Cherchar (31201) station

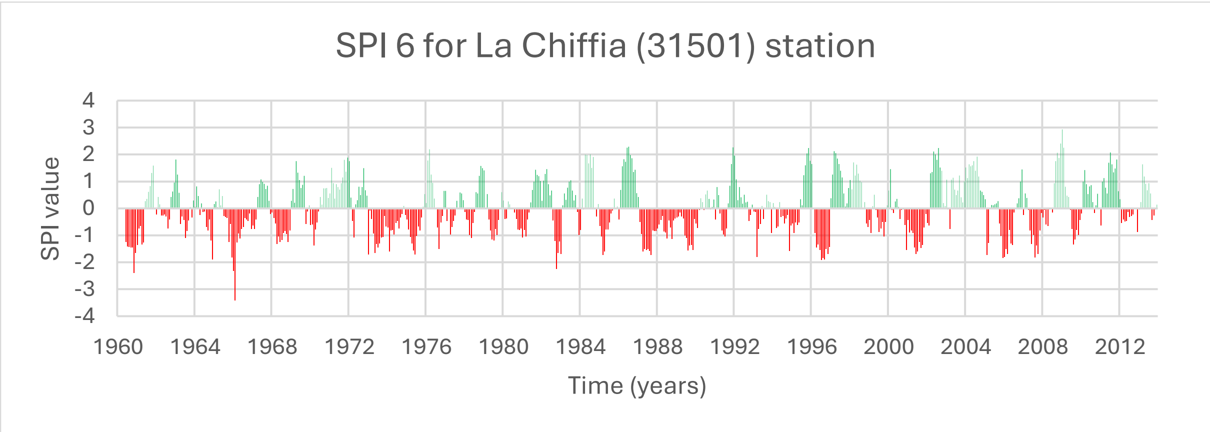

Figure III-37: SPI 6 for La Chiffia (31501) station

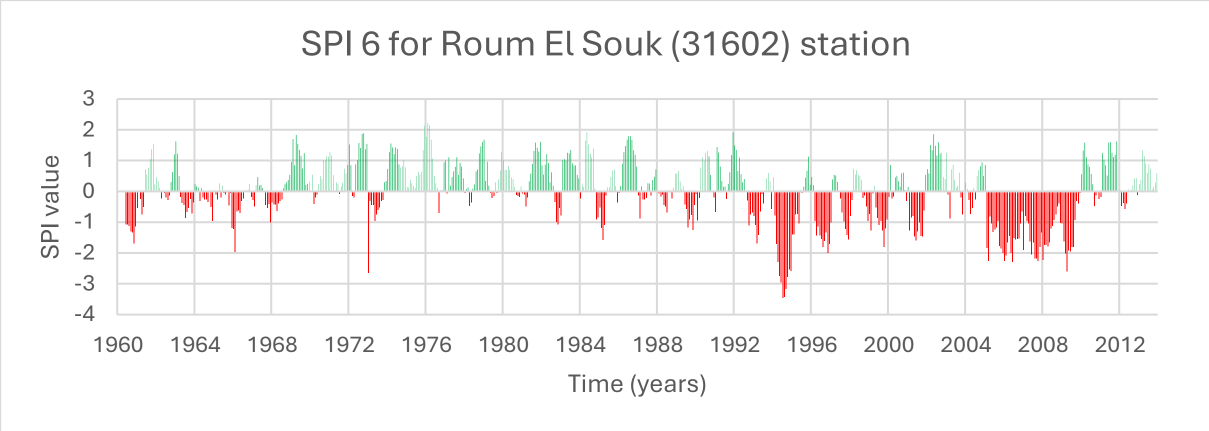

Figure III-38: SPI 6 for Roum El Souk (31602) station

The region has experienced severe to extreme drought on a number of occasions. With almost all stations registering SPI values below -2.0, indicative of extreme drought, the 1982–1984 drought stands out as one of the most severe and pervasive. The same is true for 1988–1989, when all stations encountered harsh circumstances, with SPI values typically falling between -2.0 and -3.0. The drought from 1999 to 2001 lasted for a long time, with the years 2000 to 2001 being especially severe as numerous stations once more experienced exceptional levels. Most recently, all stations reported severe conditions and several indicated extreme drought during the 2007–2008 drought, which impacted the whole region.

During significant droughts, Roum El Souk (31602) is the station most negatively impacted, displaying considerable climate instability. The most severe and extended drought conditions occurred between 1999 and 2001, with SPI values falling below -2 and remaining at these extreme levels, especially between 2000 and 2001, which was the most severe drought of any station that was observed. In a similar vein, Roum El Souk (31602) once more had the worst conditions during the 2007–2008 drought, with SPI levels continuous below -2.0. This extreme sensitivity is probably related to its location and climate, it may be in a rain shadow area or be influenced by continental air masses. In addition, the station's changes between dry and wet periods are particularly sudden and dramatic, highlighting a higher degree of climatic instability than other places.

Ain Cherchar (31201) regularly shows the least severe drought consequences across significant dry episodes due to the combination of favorable environmental and climatic variables, which may expose it to more stable air circulation patterns and mountainous rainfall from nearby heights. Ain Cherchar's (31201) persistent tolerance to harsh drought conditions is highlighted by these benefits, which are shown in its comparatively constant SPI values that rarely drop below -2.0 and the generally shorter duration of drought occurrences when compared to other stations.

III-04-1-Drought events for SPI 6

The events distribution of the various wet and dry classes for SPI 6 is displayed by the table below:

Table III-3: Drought events for SPI 6

Classes and Stations	Extremely wet	Severely wet	Moderately wet	Normal	Moderately dry	Severely dry	Extremely dry
Bou Khelifa (30101)	6	25	69	434	57	30	22
Amoucha (30204)	15	34	46	448	57	28	15
Texenna (30302)	15	31	66	419	69	29	14
Col De Fedoules (30403)	17	29	54	444	52	30	17
Taher (30504)	13	24	62	444	53	25	22
Zitouna (30602)	15	35	59	429	67	28	10
Oum Toub (30706)	17	28	49	448	66	22	13
Bou Snib (30905)	14	34	59	430	65	21	20
Zit Emba St.Hydro (31102)	10	32	59	447	53	24	18
Ain Cherchar (31201)	33	19	51	456	52	21	11
La Chiffia (31501)	15	44	50	432	61	37	4
Roum El Souk (31602)	3	31	72	431	49	36	21

Furthermore, this data can be shown graphically:

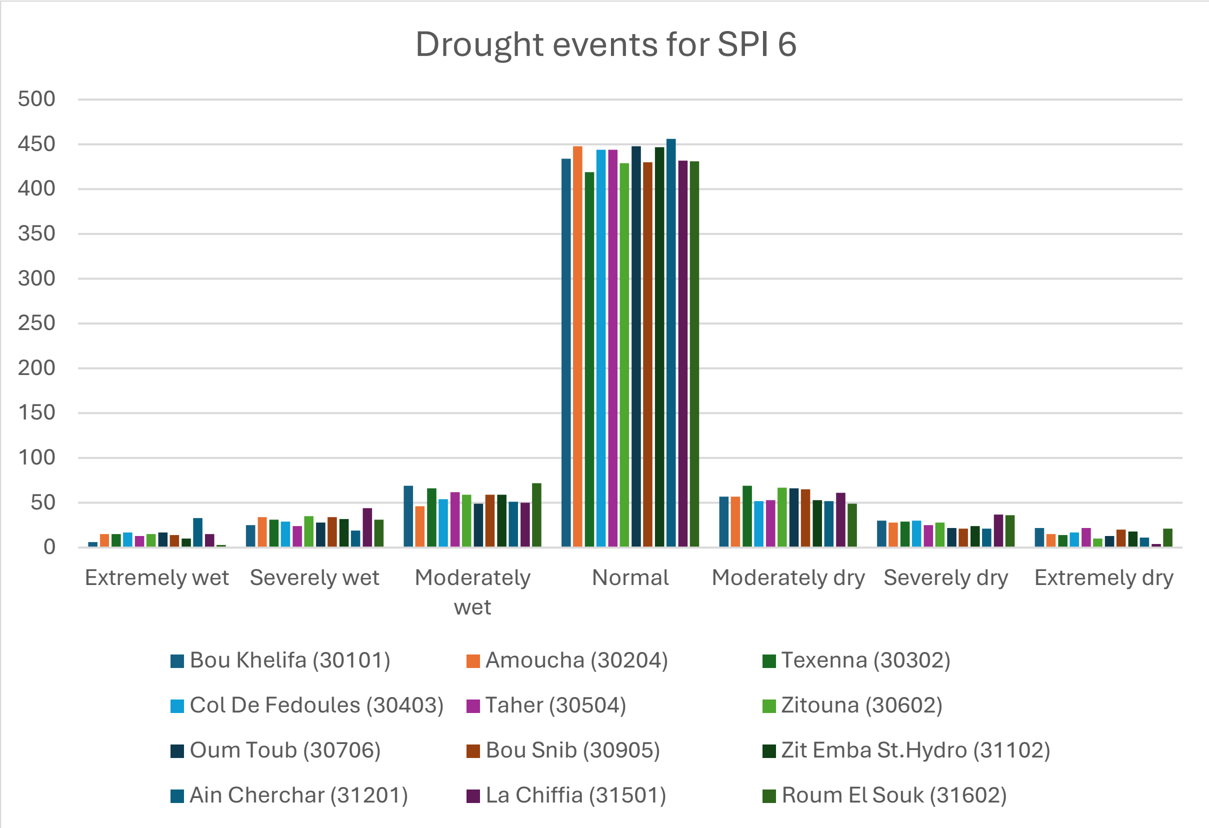

Figure III-39: Drought events for SPI 6

A detailed analysis of SPI 6 data from twelve stations revealed that 419 to 456 normal occurrences (66.1%–70.9%) were recorded, suggesting that normal conditions characterize the climate regime. Of all the locations, Ain Cherchar (31201) had the highest number of normal events, with 456 recorded (70.9%), in contrast Texenna (30302) had the lowest number of normal events with 419 recorded (66.1). Wet events happen 94 to 112 times (14.6%–17.4%), whereas dry occurrences happen 84 to 112 times (13%–17.4%). Texenna (30302) experienced the most drought events, with 112 occurrences (17.4%), while Ain Cherchar (31201) experienced the fewest, with 84 occurrences (13%). Texenna (30302) also had the most wet events with 112 occurrences (17.4%), whereas Oum Toub (30706) had the fewest with 94 occurrences (14.6%).

III-05-Standardized Precipitation Index for 9 month (SPI 9)

Using the 9-month Standardized Precipitation Index on the same 12 stations provided us with 640 values for each station which the following figures below will illustrate in the form of a SPI plot:

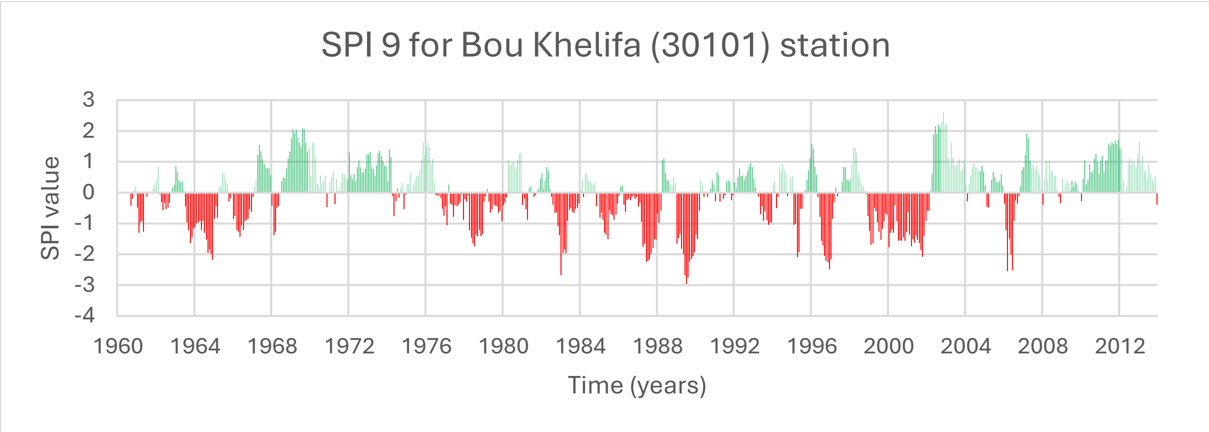

Figure III-40: SPI 9 for Bou Khelifa (30101) station

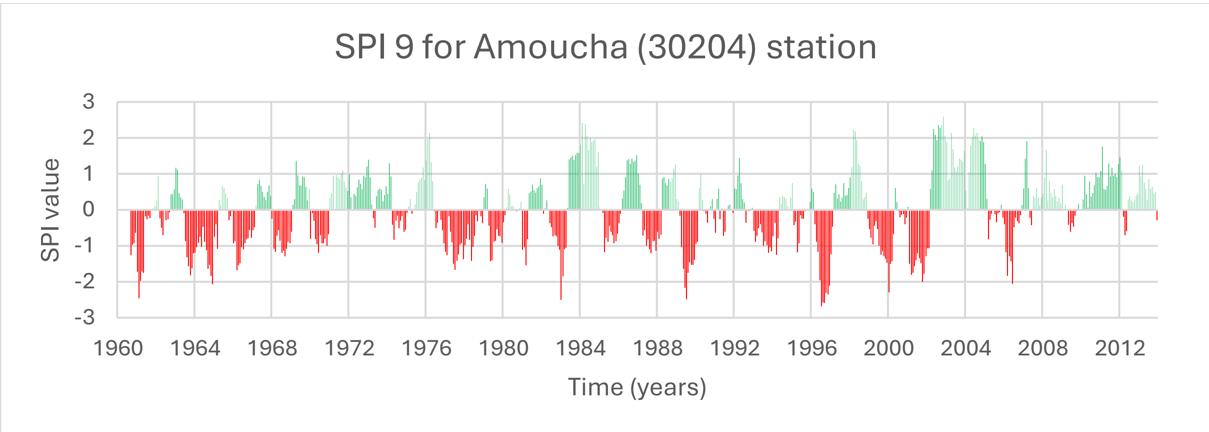

Figure III-41: SPI 9 for Amoucha (30204) station

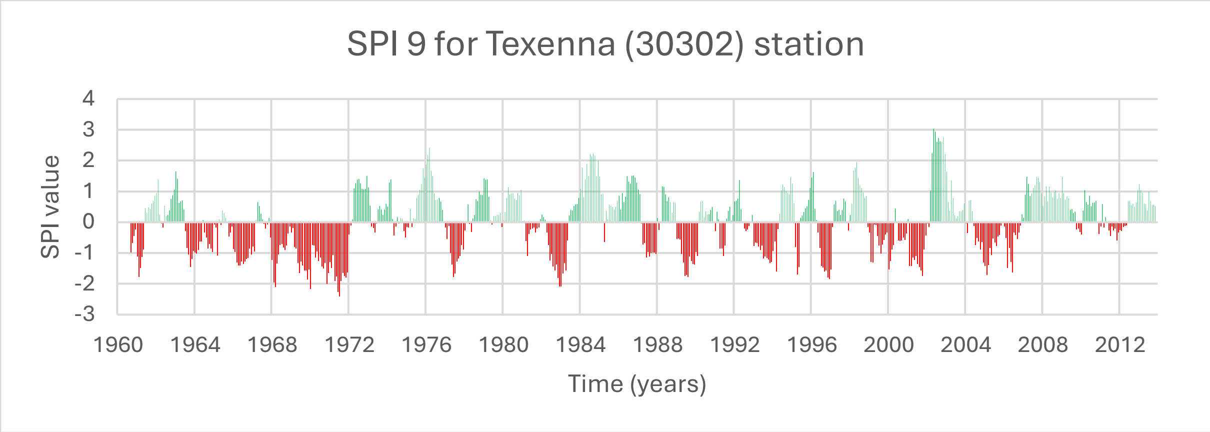

Figure III-42: SPI 9 for Texenna (30302) station

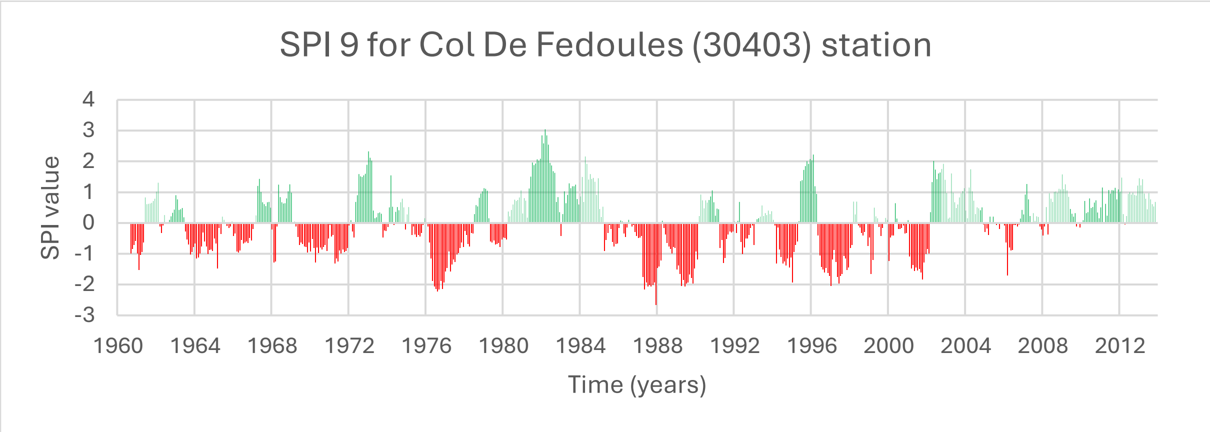

Figure III-43: SPI 9 for Col De Fedoules (30403) station

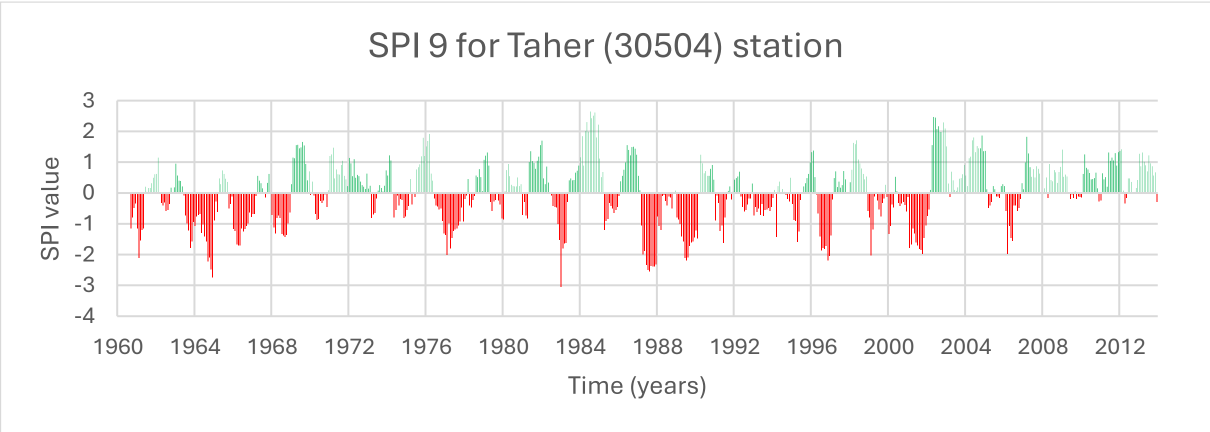

Figure III-44: SPI 9 for Taher (30504) station

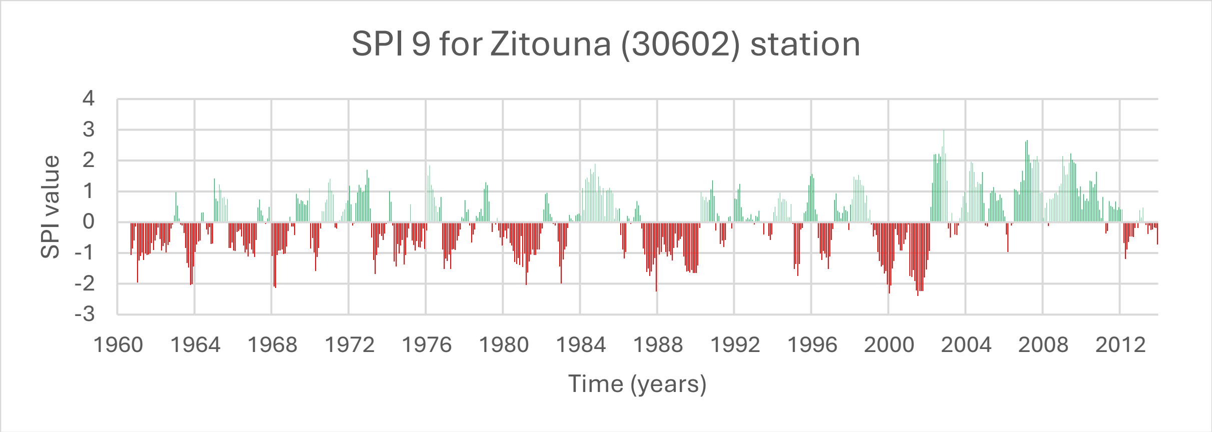

Figure III-45: SPI 9 for Zitouna (30602) station

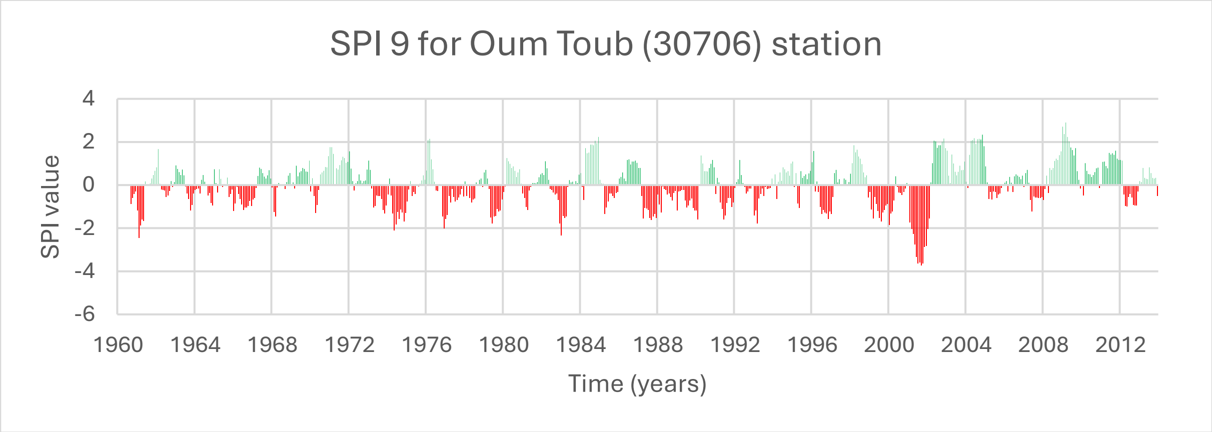

Figure III-46: SPI 9 for Oum Toub (30706) station

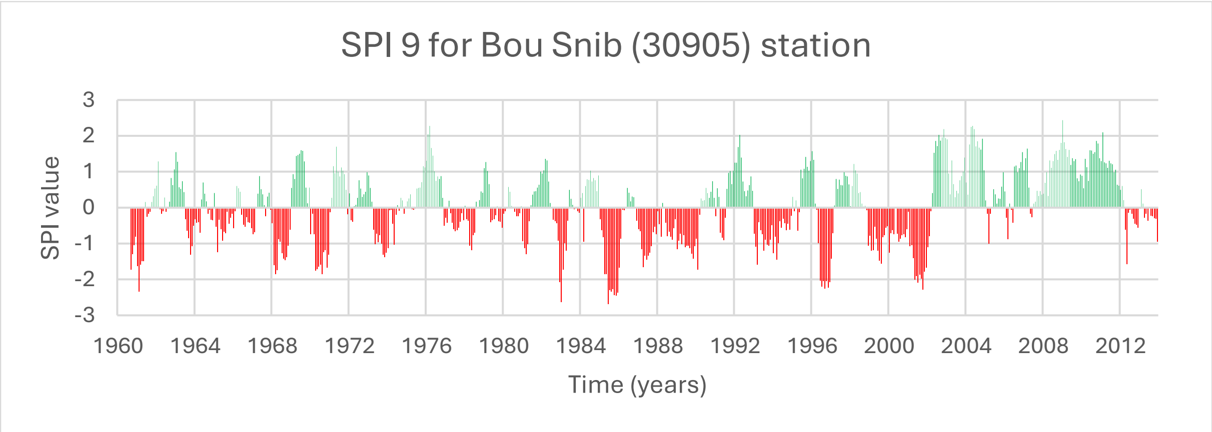

Figure III-47: SPI 9 for Bou Snib (30905) station

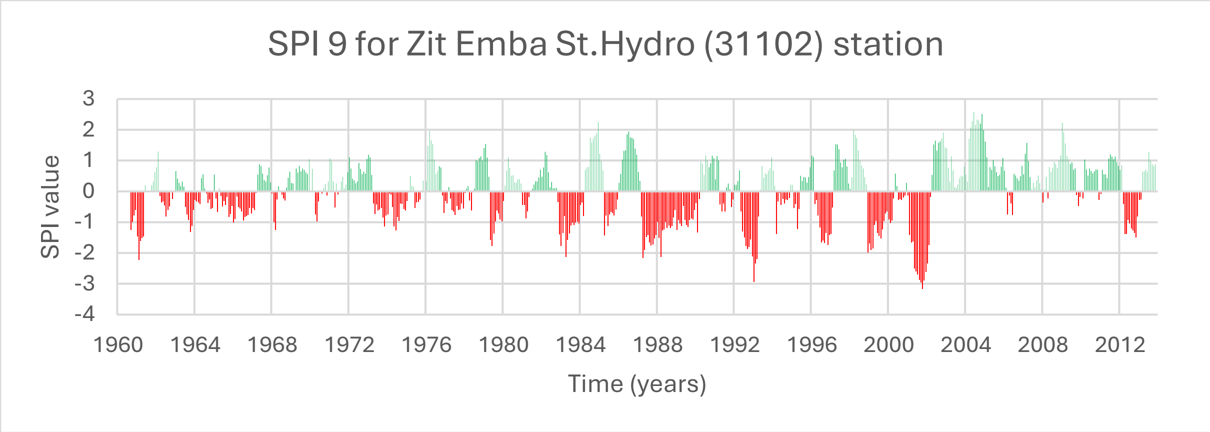

Figure III-48: SPI 9 for Zit Emba St.Hydro (31102) station

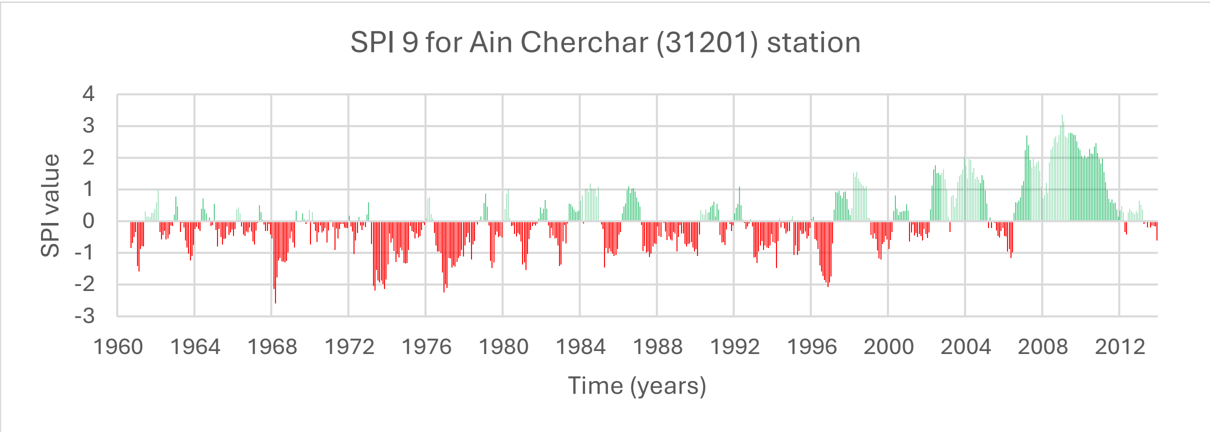

Figure III-49: SPI 9 for Ain Cherchar (31201) station

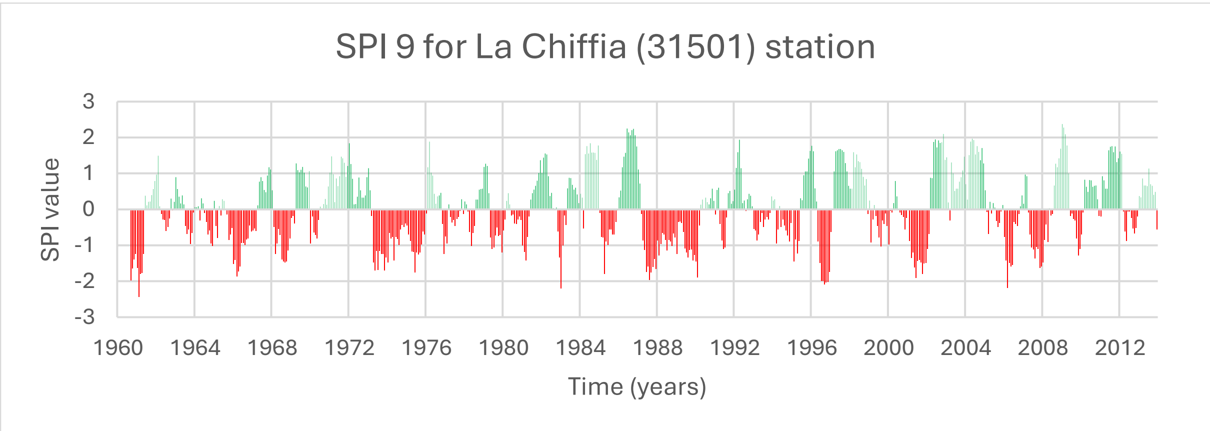

Figure III-50: SPI 9 for La Chiffia (31501) station

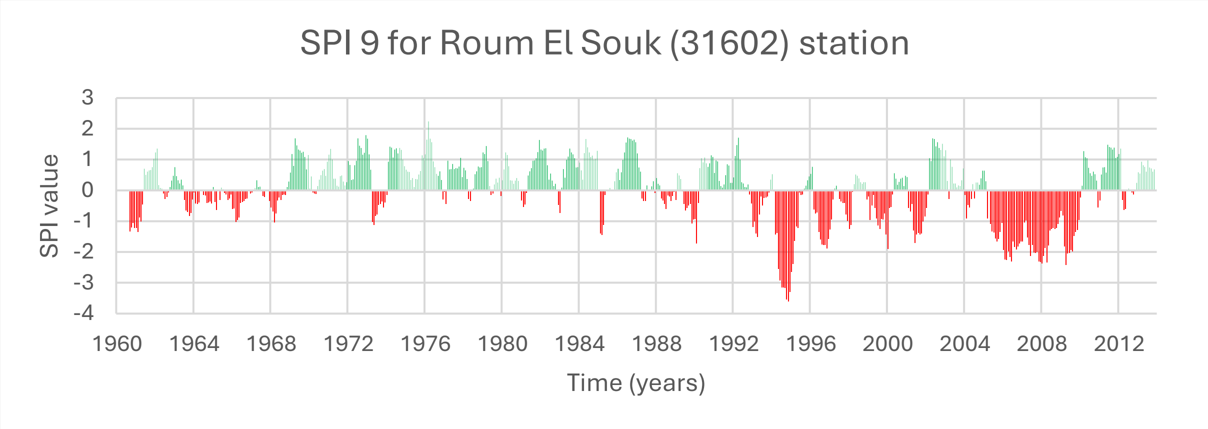

Figure III-51: SPI 9 for Roum El Souk (31602) station

Several significant drought spells occurred in the area with all stations recording extended negative SPI values below -2 and several reaching extreme drought conditions, particularly during 1982–1983, when the whole region was impacted at once, the 1980–1984 drought was the most pervasive and severe. Even though it lasted less time, the 1988–1989 drought was nonetheless rather bad, with SPI values falling below -1.5 at the majority of stations. Spatial variability was evident during the 1993–1995 multi-year drought, as some stations recovered by 1994 while others continued to experience drought until 1995. Lastly, a large portion of the region was damaged by the drought that lasted from 1999 to 2001. While coastal locations were less severely affected, inland stations had very harsh conditions.

The station most affected by drought, Roum El Souk (31602), is particularly vulnerable during the observing period. Significantly, from 1993 to 1995, SPI levels dropped below -3.0, indicating severe drought. Additionally, this station experienced a particularly bad drought from 1999 to 2001, which was characterized by persistently low SPI values and a sluggish recovery. Roum El Souk (31602) exhibits numerous extreme drought occurrences, underscoring its considerable vulnerability in comparison to other dataset stations. This high sensitivity is most likely caused by its climate and location; it could be in a rain shadow area or be affected by continental air masses.

Ain Cherchar (31201) has regularly shown resilience to drought conditions, making it the least afflicted station in the area. Although negative SPI values were recorded during the severe regional drought of 1980–1984, they hardly ever fell below the serious drought threshold of -2.0, suggesting a rather minor impact. Additionally, the station showed higher positive SPI anomalies and faster recovery periods than other sites, indicating a more stable climate response. Notably, Ain Cherchar (31201) only suffered minor effects from the 1999–2001 drought, when many other stations encountered severe drought conditions, highlighting the station's comparatively stable climate, this resilience can be because of its favorable geographic position and climate.

III-05-1-Drought events for SPI 9

The events distribution of the various wet and dry classes for SPI 9 is displayed by the table below:

Table III-4: Drought events for SPI 9

Classes and Stations	Extremely wet	Severely wet	Moderately wet	Normal	Moderately dry	Severely dry	Extremely dry
Bou Khelifa (30101)	11	24	57	442	46	40	20
Amoucha (30204)	20	24	47	443	65	27	14
Texenna (30302)	16	16	63	421	80	37	7
Col De Fedoules (30403)	16	28	58	439	52	33	14
Taher (30504)	13	26	56	439	53	33	20
Zitouna (30602)	16	26	62	427	65	30	14
Oum Toub (30706)	20	26	48	445	62	24	15
Bou Snib (30905)	10	33	67	423	61	26	20
Zit Emba St.Hydro (31102)	10	31	55	442	57	28	17
Ain Cherchar (31201)	32	28	35	465	55	17	8
La Chiffia (31501)	10	50	56	415	71	32	6
Roum El Souk (31602)	1	21	83	428	50	31	26

This data can also be displayed graphically:

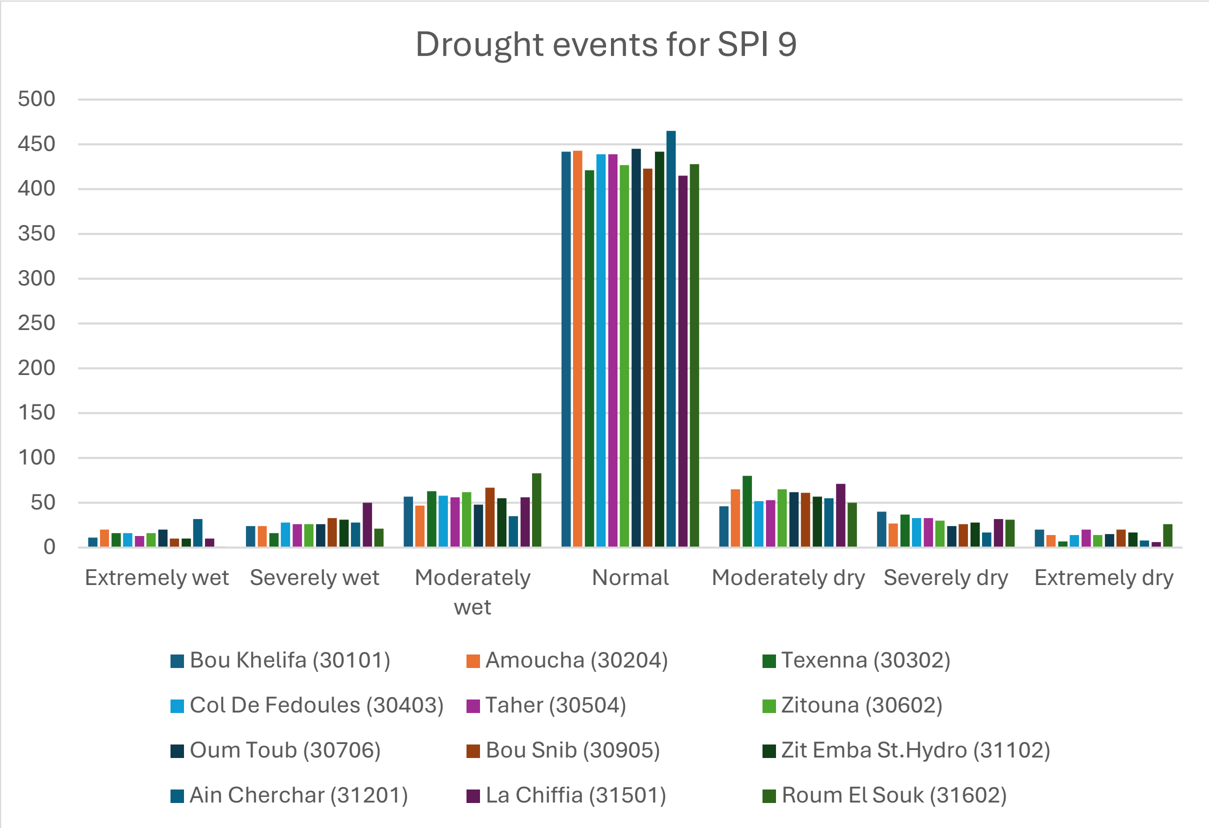

Figure III-52: Drought events for SPI 9

According to a thorough examination of SPI 9 data from twelve sites, 415 to 465 regular occurrences (64.8%–72.6%) were noted, indicating that the climatic regime is characterized by normal conditions. With 465 reported (72.6%) typical events, Ain Cherchar (31201) had the most of any site, whilst with 415 reported (64.8%) La Chiffia (31501) had the lowest of any site. While dry events occur 80 to 124 times (12.5%–19.4%), wet events occur 91 to 110 times (14.2%–17.2%). With 124 occurrences (19.4%), Texenna (30302) had the most drought incidents, whereas Ain Cherchar (31201) had the fewest 80 occurrences (12.5%). With 110 occurrences (17.2%), Bou Snib (30905) had the most wet events, whereas Amoucha (30204) had the fewest 91 occurrences (14.2%).

III-06-Standardized Precipitation Index for 12 month (SPI 12)

Using the 12-month Standardized Precipitation Index on the same 12 stations provided us with 637 values for each station which the following figures below will illustrate in the form of a SPI plot:

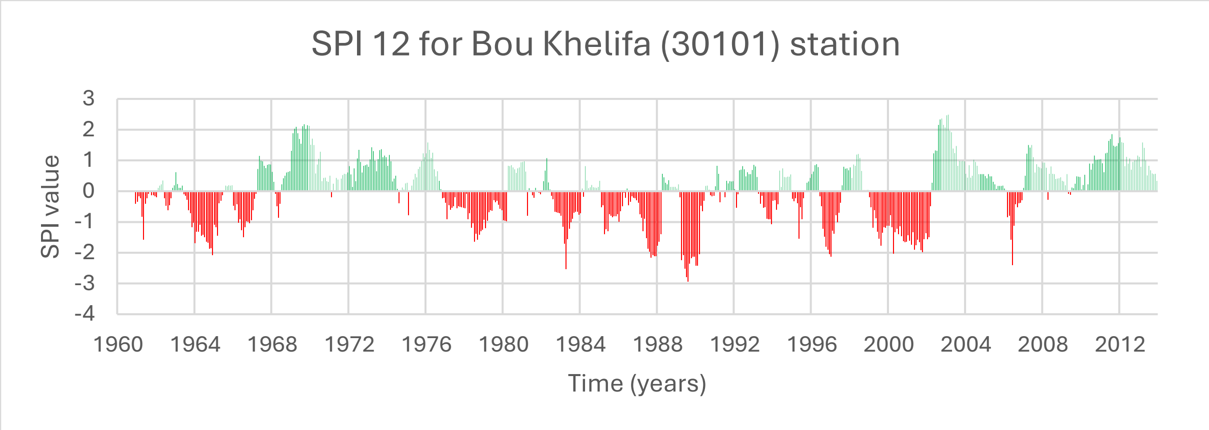

Figure III-53: SPI 12 for Bou Khelifa (30101) station

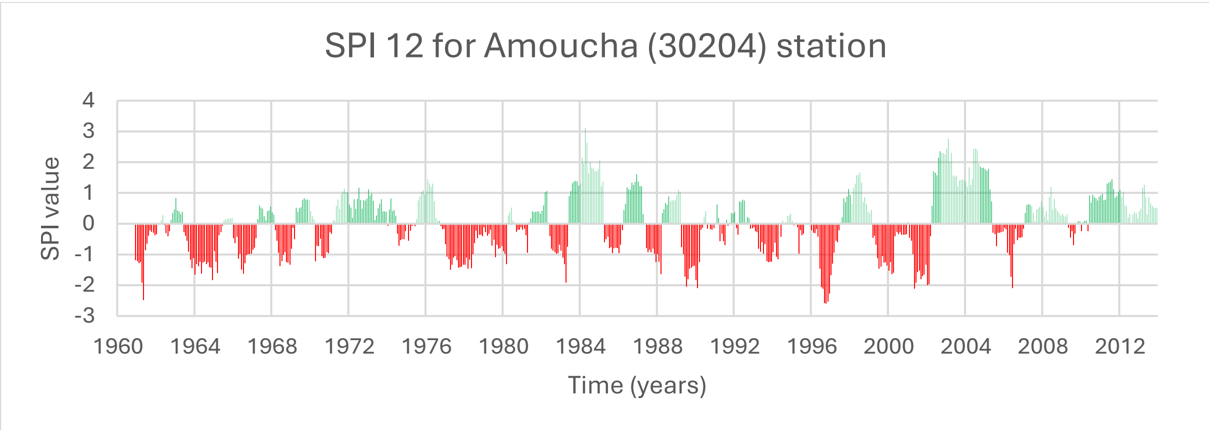

Figure III-54: SPI 12 for Amoucha (30204) station

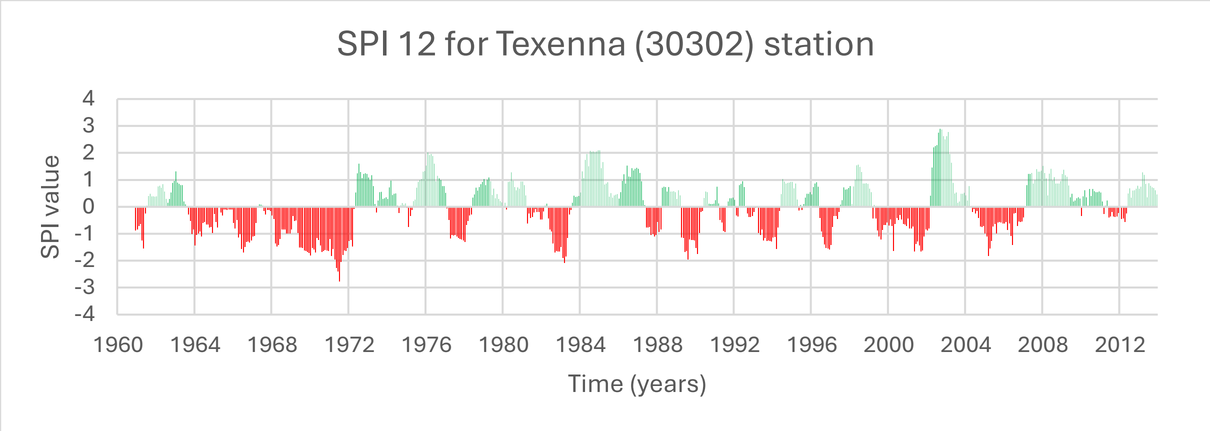

Figure III-55: SPI 12 for Texenna (30302) station

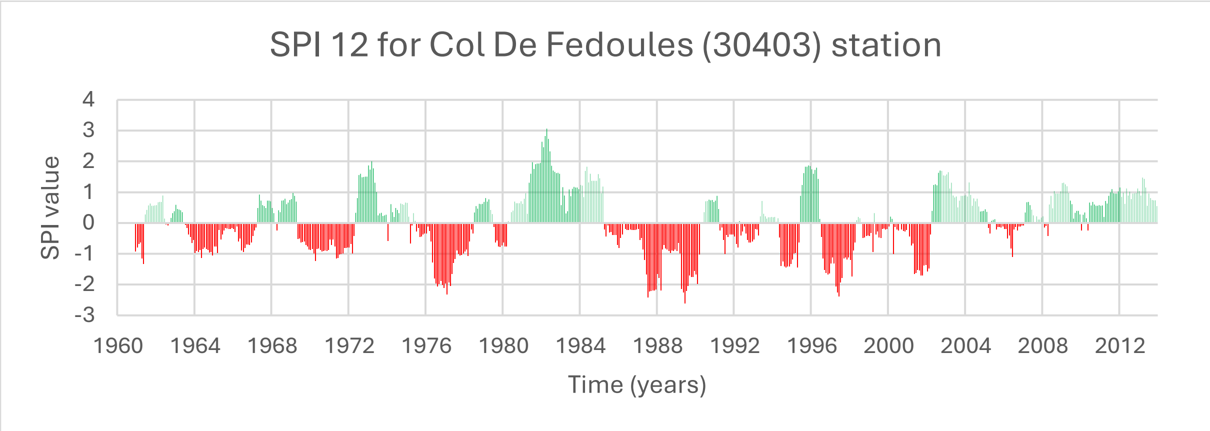

Figure III-56: SPI 12 for Col De Fedoules (30403) station

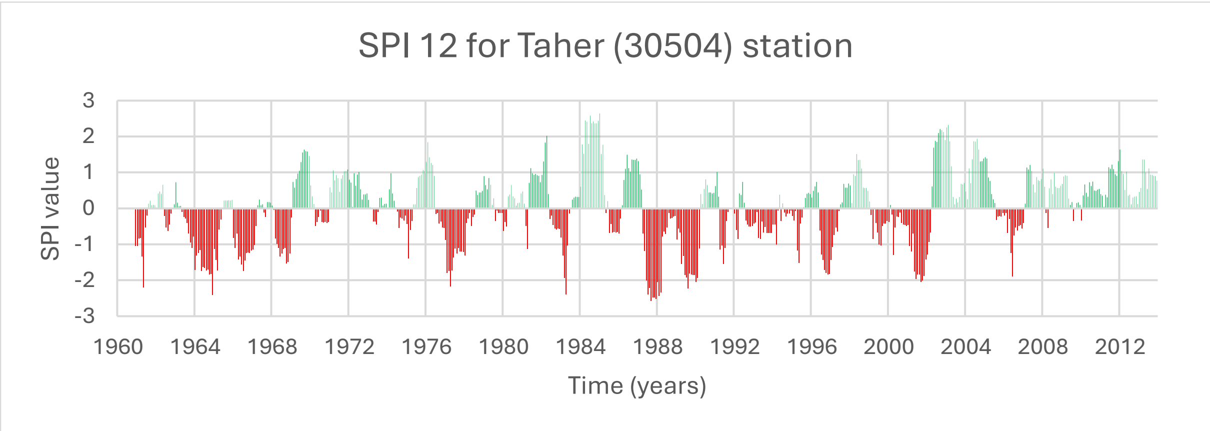

Figure III-57: SPI 12 for Taher (30504) station

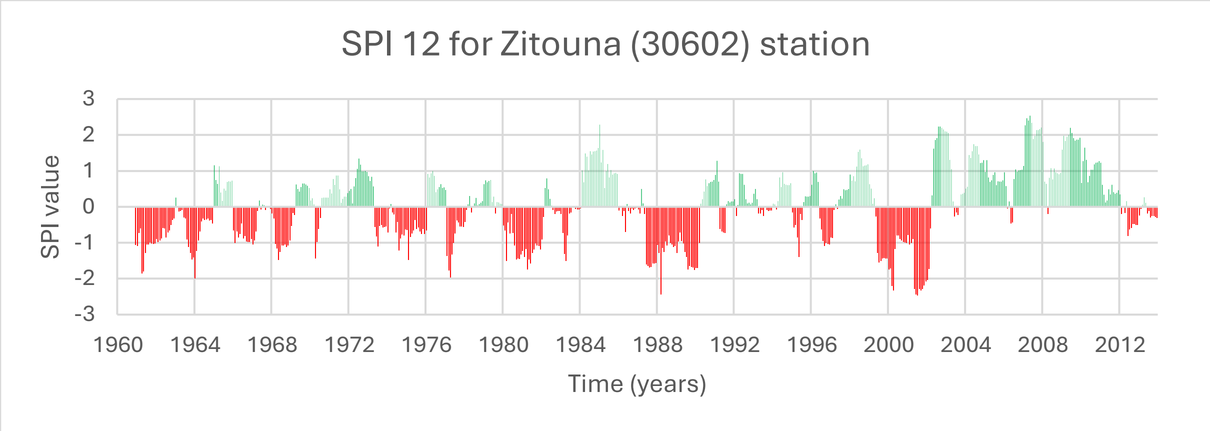

Figure III-58: SPI 12 for Zitouna (30602) station

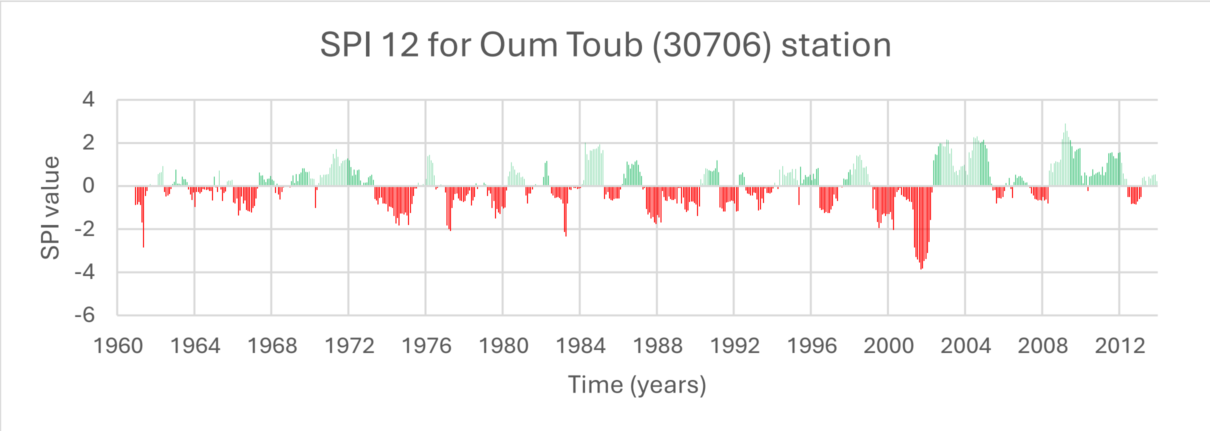

Figure III-59: SPI 12 for Oum Toub (30706) station

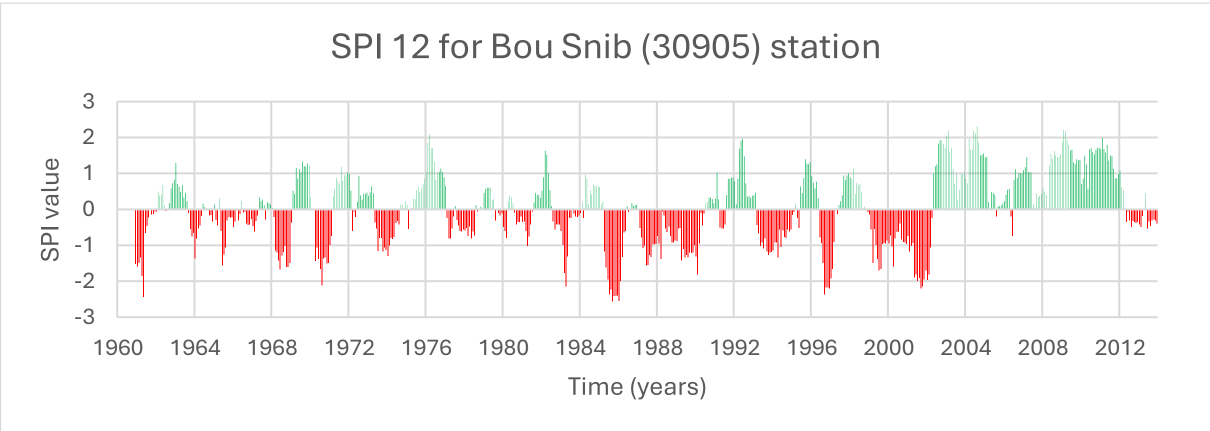

Figure III-60: SPI 12 for Bou Snib (30905) station

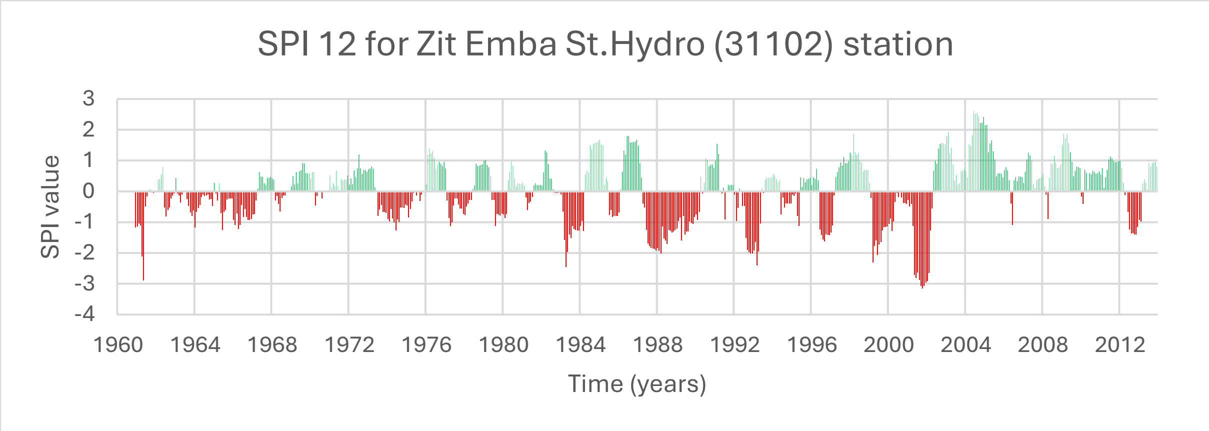

Figure III-61: SPI 12 for Zit Emba St.Hydro (31102) station

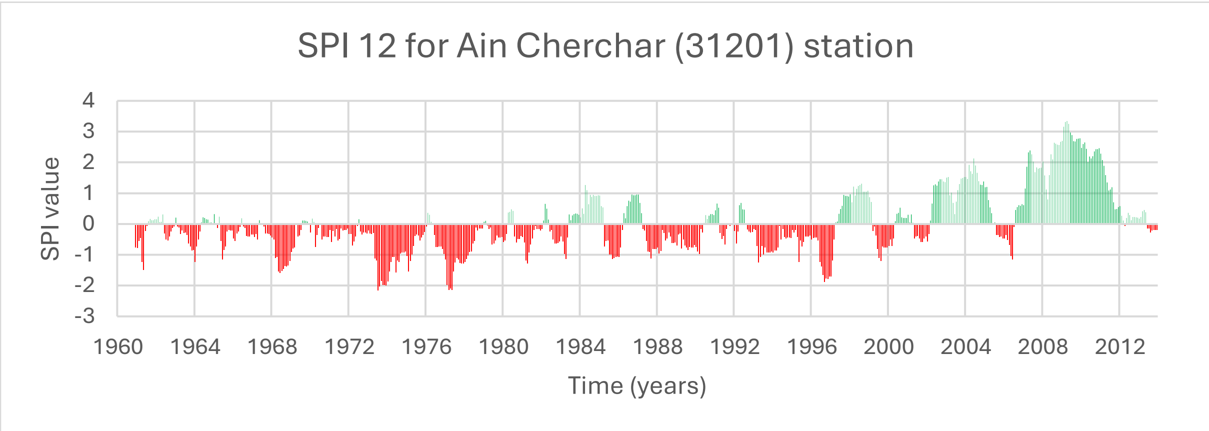

Figure III-62: SPI 12 for Ain Cherchar (31201) station

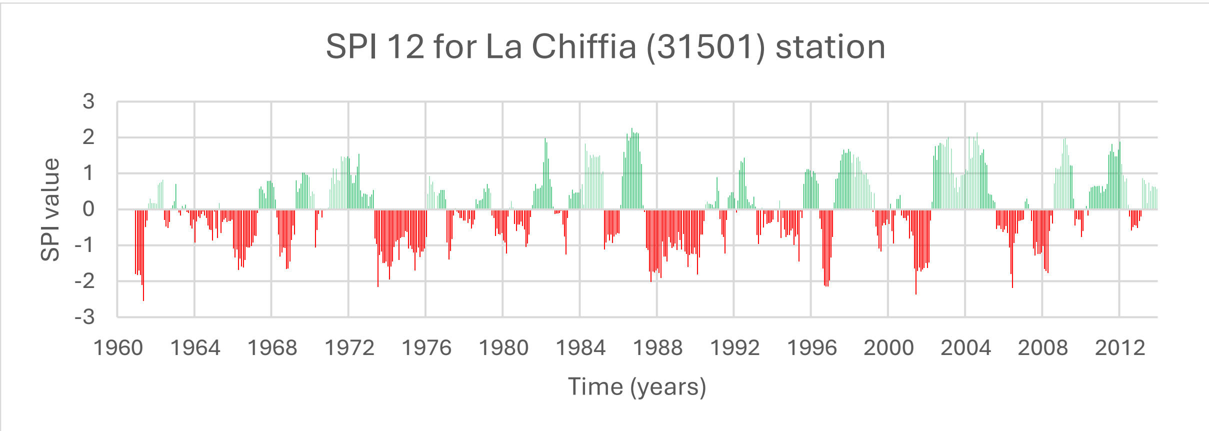

Figure III-63: SPI 12 for La Chiffia (31501) station

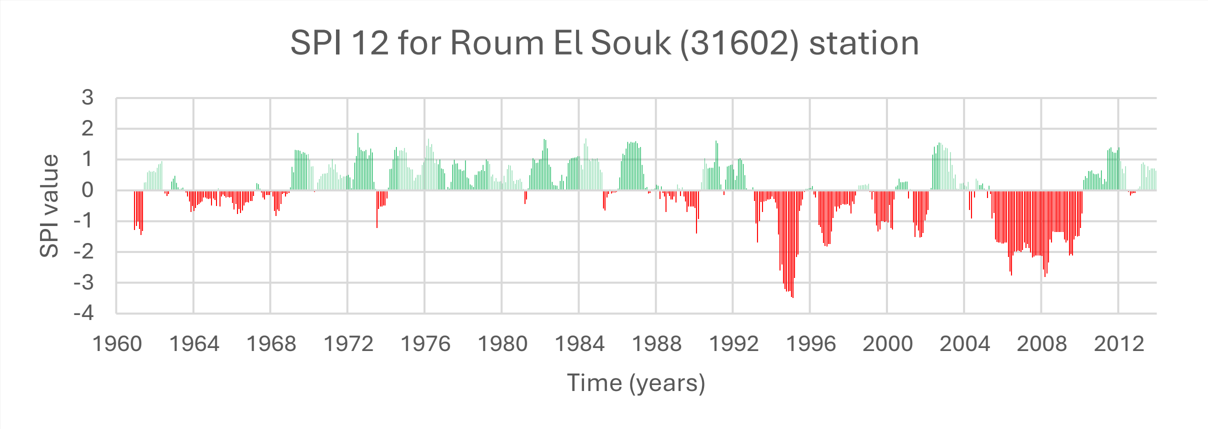

Figure III-64: SPI 12 for Roum El Souk (31602) station

The region was greatly affected by a number of big regional drought spells, varied in intensity. The 1980–1984 drought is the most severe and pervasive; almost all stations had SPI values below -2, signifying extreme drought conditions. Although shorter, the 1987–1989 drought was just as severe, with widespread severe to exceptional drought conditions. Even though it was not as bad, the 1993–1995 incident nonetheless had an impact on the majority of stations. The region's drought conditions varied from 1999 to 2002, with some stations suffering from severe effects and others from more moderate ones. The drought of 2007–2008, however more recent, also showed significant regional severity, with varying degrees of intensity in different places.

Extreme and prolonged drought conditions are evident at Roum El Souk (31602), which is the most consistently and severely impacted station in the time series. SPI values fell below -3 during the unusually severe droughts that occurred there between 1993 and 1995, marking the most extreme drought event ever observed at any location. From 2007 to 2010, the station likewise experienced a prolonged drought, with years of extreme weather and little relief. With few instances of positive SPI readings and short recovery periods, the location's drought impacts were harsh and long-lasting. This could be because of its climate area as the station exhibits a greater degree of climatic instability than other locations, as evidenced by the abrupt and dramatic swings between dry and rainy seasons.

The most resilient station is Texenna (30302), which continuously displays more positive SPI values that indicate improved water availability. Even in years with regional drought, it has shorter and milder drought events, and after these events, it shows robust recovery patterns, suggesting a more stable and beneficial hydrological response than other stations, probably because of its climate and high elevation in the region encouraging mountainous precipitation.

III-06-1-Drought events for SPI 12

The events distribution of the various wet and dry classes for SPI 12 is displayed by the table below:

Table III-5: Drought events for SPI 12

Classes and Stations	Extremely wet	Severely wet	Moderately wet	Normal	Moderately dry	Severely dry	Extremely dry
Bou Khelifa (30101)	14	17	55	440	55	34	22
Amoucha (30204)	17	25	60	424	76	24	11
Texenna (30302)	18	16	53	428	70	47	5
Col De Fedoules (30403)	6	41	45	453	42	30	20
Taher (30504)	16	22	52	435	58	36	18
Zitouna (30602)	19	29	45	429	75	27	13
Oum Toub (30706)	15	31	47	455	59	15	15
Bou Snib (30905)	8	41	57	428	58	29	16
Zit Emba St.Hydro (31102)	9	30	40	453	59	27	19
Ain Cherchar (31201)	39	19	37	469	49	19	5
La Chiffia (31501)	10	42	58	413	70	35	9
Roum El Souk (31602)	0	17	77	442	37	32	32

It is also possible to display this data graphically:

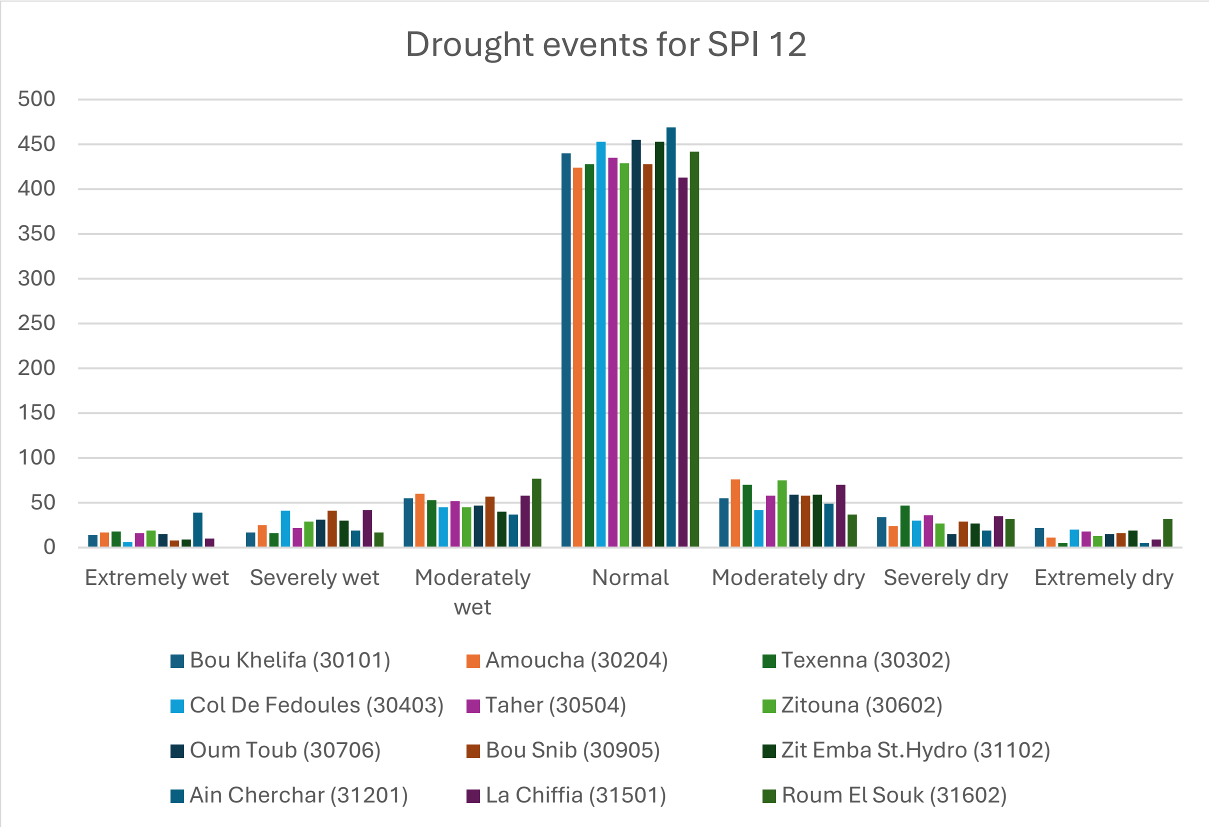

Figure III-65: Drought events for SPI 12

After a detailed analysis of SPI 12 data from twelve sites, 413 to 469 regular occurrences (64.8%–73.6%) were identified, suggesting that the climate regime is defined by normal conditions. La Chiffia (31501) had the fewest normal events of any site, 413 recorded (64.8%), whereas Ain Cherchar (31201) had the most 469 reported (73.6%). In contrast, wet events happen 79 to 110 times (12.4%–17.3%) and dry events 73 to 122 times (11.5%–19.1%). Texenna (30302) had the highest number of drought 122 incidences (19.1%), while Ain Cherchar (31201) had the lowest number 73 incidences (11.5%). The number of wet events was highest in La Chiffia (31501) with 110 occurrences (17.3%) and lowest in Zit Emba St.Hydro (31102) with 79 occurrences (12.4%).

III-07-Conclusion

Findings from analysis on all SPI time periods showed trends of recurrent drought, while short-term droughts occur frequently, longer-term droughts have a greater impact and last longer, especially in the years 1982–1984, 1987–1988, 1999–2002, and 2007–2008. A small number of stations continuously shown resistance, while others showed great vulnerability to recurring drought strikes. For both short-term and long-term drought events the standardized precipitation index (SPI) worked well. The importance of adaptive water management strategies and localized drought evaluations is highlighted by these findings.

General conclusion

General conclusion

Using the standardized precipitation index (SPI) applied to a 54-year precipitation dataset from twelve meteorological stations, this study offers a thorough evaluation of drought in the Coastal Constantine Basin. With distinct regional and temporal fluctuations caused by climatic, topographic, and geographic factors, the study presents a complex landscape of drought occurrences. While short-term droughts are common, they are usually not as severe. On the other hand, medium and long-term droughts, particularly those indicated by 9 and 12 month SPI values, pose serious problems for the sustainability of water resources and agricultural output.

For monitoring the region's drought, the standardized precipitation index (SPI) has shown itself to be a useful, scalable, and resource-efficient instrument. Because of its use, it has been possible to identify areas that are at risk as well as to characterize the severity and length of drought. In areas like the Coastal Constantine Basin that are particularly vulnerable to climatic variability, the study firmly advocates for the inclusion of SPI-based drought indices in regional and national drought early warning systems.

The study suggests creating integrated frameworks for drought management in the future that incorporate socioeconomic and ecological effect assessments together with SPI analysis. Public awareness campaigns, enhanced water infrastructure, and climate-resilient agriculture should be the main focuses of policy initiatives. The protection of the water-energy-food nexus and the advancement of sustainable development in Algeria will depend on proactive drought risk governance in the face of accelerated climate change.

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