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Article

Assessing drought risk conditions through SPI and NDVI indices in Oued Kert watershed

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Abstract: The Oued Kert watershed in Morocco is essential for local biodiversity and agriculture, yet it faces significant challenges due to meteorological drought. This research addresses an urgent issue by aiming to understand the impacts of drought on vegetation, which is crucial for food security and water resource management. Despite previous studies on drought, there are significant gaps, including a lack of specific analyses on the seasonal effects of drought on vegetation in this under-researched region, as well as insufficient use of appropriate analytical tools to evaluate these relationships. We utilized the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI) to analyze the relationship between precipitation and vegetation health. Our results reveal a very strong correlation between SPI and NDVI in spring (98%) and summer (97%), while correlations in winter and autumn are weaker (66% and 55%). These findings can guide policymakers in developing appropriate strategies and contribute to crop planning and land management. Furthermore, this study could serve as a foundation for awareness and education initiatives on the sustainable management of water and land resources, thereby enhancing the resilience of local ecosystems in the face of environmental challenges.

Keywords: meteorological drought; Normalized Difference Vegetation Index (NDVI); Oued Kert watershed; Standardized Precipitation Index (SPI)

1. Introduction

Meteorological drought is characterized by a significant decrease in precipitation compared to the historical average, thus affecting the normal functioning of local ecosystems and the growth of living organisms [1]. This gradual phenomenon develops over an extended period and its impacts are diffuse, slowly spreading through the environment, affecting many countries around the world, particularly those located in arid or semi-arid regions like Morocco.

Oued Kert watershed is notably impacted by this phenomenon due to its vulnerability to climate fluctuations and its socio-economic importance to local populations. This region has experienced significant climate variations over the decades, exacerbated by the effects of climate change. Rising temperatures and changes in precipitation patterns have intensified arid conditions, making water resource management even more critical.

In the 1990s, several studies were conducted to examine the links between water access and development. These studies include those carried out by organizations such as the World Water Council, the Global Water Partnership, the World Panel on Water Infrastructure Financing, and during the Third World Water Forum in Kyoto [2–5].

The conclusions of these studies highlighted a marked sensitivity to changes in hydrological regimes, an increase in water resource scarcity, and emphasized the threats to water availability and management [6].

The primary aim of this study is to evaluate drought risk conditions in the Oued Kert watershed using the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI). We selected these two indicators due to their complementary ability to provide insights into hydrological conditions and vegetation health. In particular, the study of the correlation between precipitation patterns and vegetation dynamics throughout the seasons highlights the influence of climatic variability on vegetation. The SPI allows us to analyze precipitation variations and detect periods of drought, while the NDVI assesses the health and coverage of vegetation. By correlating these two indices, we aim to illustrate how climatic variations affect the response of vegetation in the region. These indices are particularly relevant for several reasons:

(1) Identification of dry and wet episodes: These tools enable the rapid detection of climatic condition variations, which is essential for proactive management of water resources and ecosystems.
(2) Analysis of spatial and temporal variations: The indices provide a dynamic perspective, allowing for the evaluation of how drought and humidity evolve over time and vary across regions, thus offering crucial information for environmental planning.
(3) Interpretation of ecological dynamics: By linking climatic data to vegetation health, these indices facilitate the understanding of the complex interactions between climate, vegetation, and other ecosystem components, which is fundamental for ecological research.
(4) Support for decision-making: The results derived from these indices can guide policies for natural resource management, enabling decision-makers to formulate appropriate strategies to address the impacts of drought.
(5) Awareness-raising tools: By providing visual and quantitative data, these indices help raise awareness among communities and stakeholders about environmental issues, thus fostering a collective approach to resource management.

Furthermore, this study examines the relationships between these indices and their relevance in interpreting landscape dynamics, thereby enhancing our understanding of the impacts of meteorological drought and enabling the development of sustainable solutions.

2. Geographical context of the study

Study area

Oued Kert watershed, located in the northeast of Morocco, west of the Nador province, is characterized by particularly distinct natural boundaries. To the north, it is bordered by the foothills of the Middle Atlas, where the mountainous reliefs of Jbel Tistoutine form a clear natural frontier. Despite this clear delimitation by mountainous formations, the basin, covering an area of 520 km^2, is enclosed, which increases its vulnerability to climatic fluctuations. This enclosed topography directly influences the hydrological regime of the basin, exacerbating the effects of drought and highlighting the importance of careful water resource management for local communities. It also offers protection against climatic influences from the north. To the south, the watershed is bordered by semi-arid plains that extend toward the Sahara (**Figure 1**). These areas present a flatter topography and lower precipitation, contrasting with the northern mountains, which are characterized by diverse vegetation, including dense forests, lush pastures, and grassy plains.

To the east, the basin is bordered by a series of ridges and steep valleys, including the mountain ranges of the eastern Rif, which form a natural barrier separating the region from the surrounding territories. These geographical formations direct rainwater and streams toward the Oued Kert, playing a crucial role in regulating the hydraulic basin. They influence the collection and concentration of surface waters, contributing to the nourishment of Oued Kert and the management of water resources in the region. To the west, the watershed is bordered by other mountainous reliefs, notably the Temsamane massif, which acts as a natural barrier against western influences. This geographical configuration helps preserve the basin ecosystem.

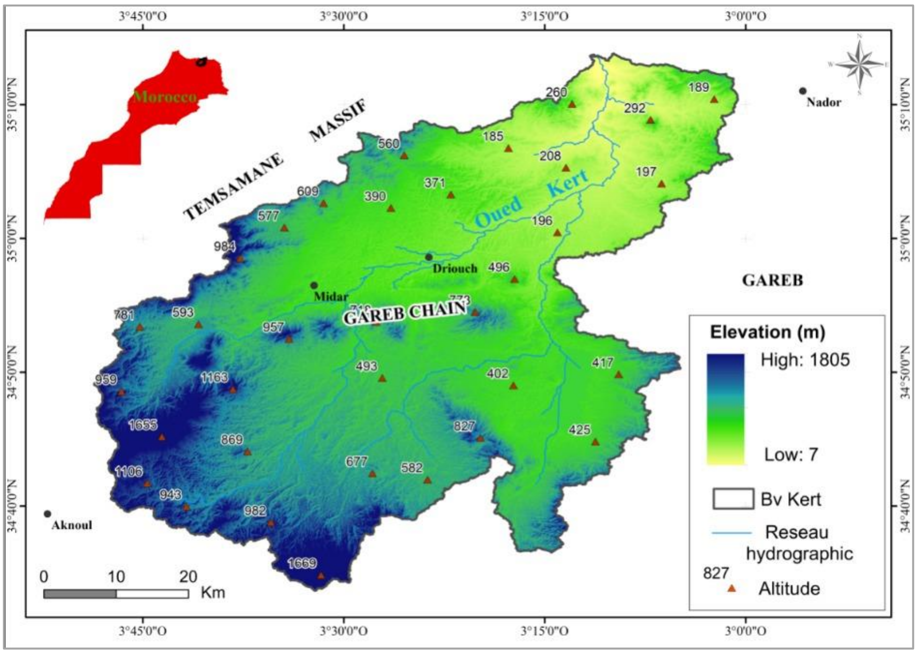

Figure 1. Map of the topography of Oued Kert basin.

3. Climate and hydrological dynamics

3.1. Precipitation patterns and trends

Temporal fluctuations in precipitation are closely linked to the seasonal characteristics of the climate, including parameters such as temperatures and precipitation that vary regularly with the seasons summer, autumn, winter, and spring as well as geographical factors such as altitude, latitude, and land cover [7]. During the twentieth century, the climate observed across Morocco has shown trends toward increasing temperatures and decreasing precipitation [7].

Since the 1970 s, there has been a substantial decrease in precipitation accompanied by a significant rise in temperatures. **Figure 2** illustrates the variation in average precipitation ranging from 216 mm to 450 mm.

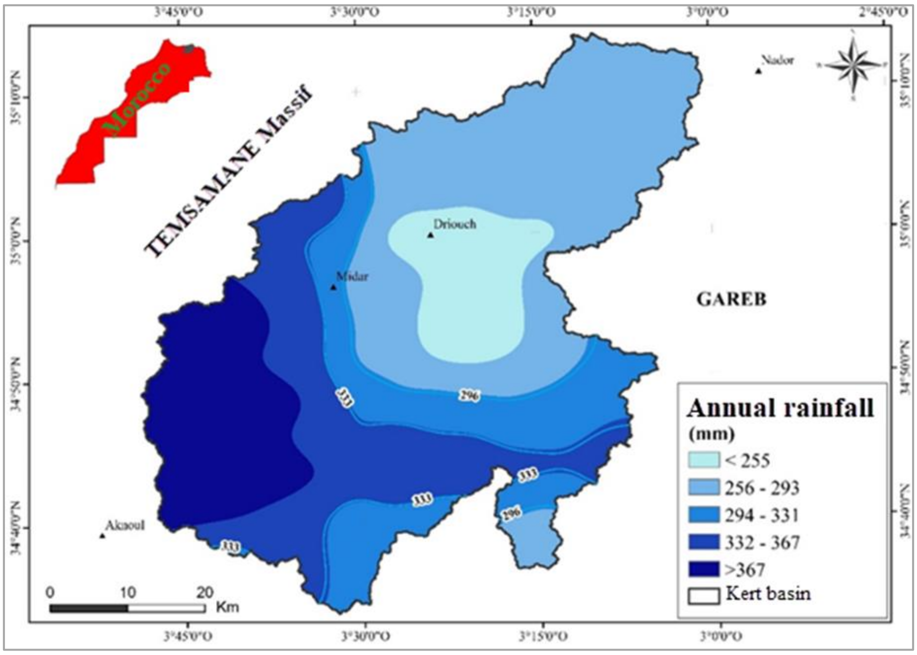

Figure 2. Map of the average annual precipitation using the isohyets method in Oued Kert basin from 1981 to 2022.

3.2. Hydrological processes and water resource management

When examining the issues related to water resources, it is essential to focus on the key unit of hydrological processes: the basin. A basin represents both a topographically delineated area by watershed lines and a zone of precipitation reception [8], with surface flow converging towards an outlet [8]. Indeed, the basin acts as a collector, capturing precipitation and converting it into flow towards an outlet, with water losses influenced by climatic conditions and the physical characteristics of the basin [9].

Temperature and precipitation variations play a crucial role in the hydrological cycle in the Mediterranean, a continuous process of water movement through the atmosphere, on the Earth's surface, and in the subsurface. This cycle includes processes such as evaporation of water from land and water surfaces, cloud formation through condensation, precipitation as rain or snow, and the return of water to the Earth's surface through soil infiltration and runoff into rivers and lakes [7], affecting various aspects such as soil moisture, runoff, streamflow, and lake levels [6,9,10]. Morocco, characterized by an arid to semi-arid climate, faces growing challenges in water resource management due to their limited availability and complex exploitation. These resources are heavily influenced by highly variable precipitation both in time and space [11–13]. The hydrology of Oued Kert basin is of paramount importance due to its crucial role in water resource management, environmental conservation, and support for the region's socio-economic activities. Oued Kert basin includes various water sources such as precipitation, permanent and temporary rivers, springs, wells, and water reservoirs. The availability of these resources varies according to seasons and climatic conditions, directly affecting agricultural, industrial, and domestic practices in the region.

4. Data and methods

Drought events exhibit variations in terms of intensity, duration, and spatial extent. Their assessment is generally based on comparing an index with a predefined critical norm [1]. To understand droughts, researchers adopt various approaches, including:

- Traditional approaches: These use simple statistical tests applied to climatic or hydrological time series.
- Satellite-based approaches: These utilize data collected by satellite sensors and processed using remote sensing tools.
- Combined approaches: These integrate traditional data with satellite data for a more comprehensive and accurate assessment.

4.1. CHIRPS data

Precipitation data play a crucial role in assessing and monitoring drought in Oued Kert basin. Among the widely used data sources is CHIRPS [14], which provides precipitation estimates by combining rain gauge observations with satellite data. This dataset of annual precipitation covers the period from 1981 to 2022. Calibration of CHIRPS data with precipitation measurements from 28 national stations has allowed to use these data for this study area to calculate the Standardized Precipitation Index (SPI) on both a seasonal and annual basis.

4.2. Satellite data

Satellite data play a crucial role in assessing vegetation at the basin scale. Among the satellite tools used is the Moderate-Resolution Imaging Spectroradiometer (MODIS 6.0, Terra and AQUA), which provides detailed information on vegetation. One widely used index for evaluating vegetation health is the Normalized Difference Vegetation Index (NDVI). The MODIS products utilized have a 16-day temporal resolution and a spatial resolution of 500 meters. These data enable the monitoring of changes in vegetation distribution and abundance in Oued Kert basin. The MODIS (Moderate Resolution Imaging Spectroradiometer) satellite scenes, available through the NTCDF (NASA's Distributed Active Archive Center), are essential tools for calculating the Normalized Difference Vegetation Index (NDVI) for the period from 1981 to 2022. These data provide detailed images of the Earth's surface, allowing for the assessment of vegetation health and coverage on a global scale. With their ability to capture information across different wavelengths, MODIS images offer valuable insights into seasonal and interannual variations in ecosystems. Users can access and download these data by visiting the NTCDF website [15]. Analyzing NDVI from these satellite scenes enhances our understanding of climate change impacts and environmental dynamics. While satellite images offer significant advantages, such as broad spatial coverage and the ability to monitor large areas over time, they also have notable limitations. One major issue is the resolution; many satellite images may not capture fine-scale features, making them less effective for localized studies. Additionally, atmospheric interference can affect data quality, resulting in inaccuracies due to clouds, haze, or varying lighting conditions. The temporal resolution is another constraint, as some satellites do not provide frequent updates, which can be problematic for tracking rapidly changing phenomena. Furthermore, satellite data often requires calibration and validation with ground-based measurements to ensure accuracy, and such data may not always be available or reliable. Lastly, certain variables, such as soil moisture or specific vegetation types, may not be directly measurable from space, limiting the applicability of satellite data for specific research questions.

4.3. Methods

This work is based on a methodology suited for evaluating drought in Oued Kert basin, incorporating the use of the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI). This approach allows for the quantification and monitoring of precipitation anomalies relative to a reference period, supported by CHIRPS data. CHIRPS data are used to generate spatial precipitation maps with a spatial resolution of 5 km, as schematically illustrated in **Figure 3**. In our study, we utilized various equipment and software tools to analyze precipitation anomalies and vegetation dynamics. Below are the details of the key components used: OriginPro: Is a powerful data analysis and graphing software widely used in scientific research. It offers advanced statistical analysis capabilities and extensive graphing options, enabling users to create high-quality visual representations of their data. OriginPro facilitates the manipulation of large datasets, supports various file formats, and provides a user-friendly interface for performing complex analyses. In our study, we employed OriginPro for statistical analyses and visualization of the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI). Standardized Precipitation Index (SPI): is a statistical index used to quantify precipitation anomalies relative to a reference period. It helps in identifying drought conditions by assessing precipitation deficits over various time scales. In our study, we used SPI to monitor and analyze precipitation trends using CHIRPS data. Normalized Difference Vegetation Index (NDVI): is a widely used remote sensing index that assesses vegetation health and density. It is calculated using satellite imagery, allowing for the monitoring of vegetation cover over time. In our research, NDVI was calculated using MODIS data to analyze vegetation responses to precipitation variations. CHIRPS (Climate Hazards Group InfraRed Precipitation with Station Data): is a high-resolution precipitation dataset that combines satellite data with ground station observations. It provides spatial precipitation maps with a resolution of 5 km, which were essential for our analysis of precipitation anomalies in conjunction with the SPI. By combining these tools and datasets, we were able to effectively quantify and monitor precipitation anomalies and vegetation dynamics, contributing to a comprehensive understanding of the study area.

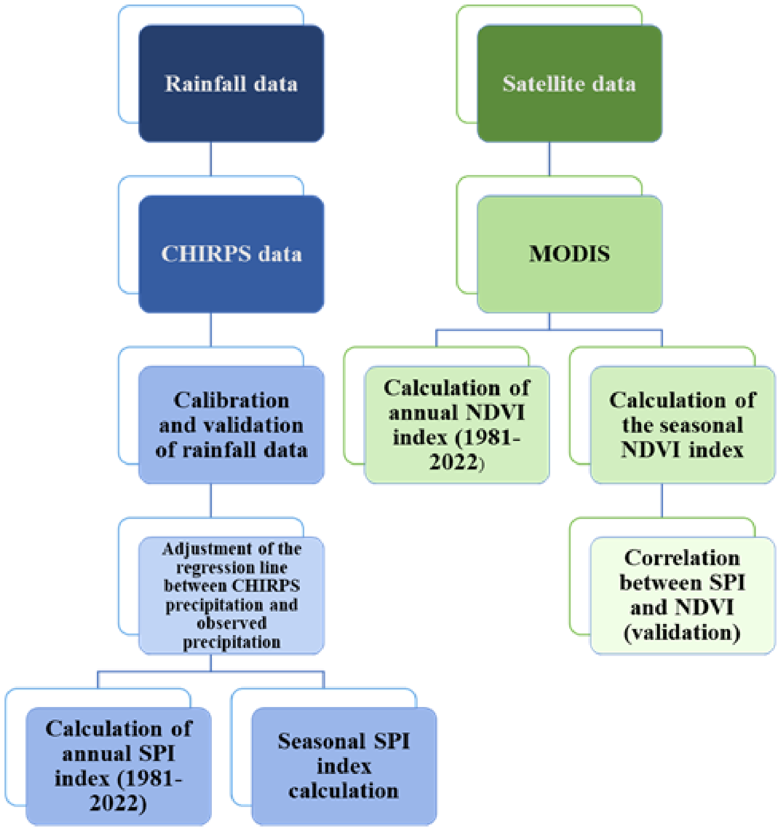

Figure 3. General framework flowchart of the adopted methodology.

4.4. Calculation and mapping methodology for SPI

The Standardized Precipitation Index (SPI) is a statistical indicator based on the probability of precipitation for a given period. It offers advantages in terms of statistical consistency and can describe the impacts of drought both in the short and long term across various time scales [16]. In the short term (1 to 6 months), it provides information on weather conditions and soil moisture, which is useful for agriculture. In the long term (6 to 24 months), it provides insights into groundwater levels, streamflow, and stored water volumes. Additionally, the SPI can provide early warnings of drought and help assess its severity [17]. In our study, we specifically used the SPI on an annual scale. We chose this scale for several reasons. First, the annual SPI allows us to assess precipitation conditions over a sufficiently long period to capture long-term trends and seasonal variations while providing a stable view of climatic anomalies. This approach is particularly relevant for analyzing impacts such as droughts or excess rainfall, which often manifest over extended periods.

Regarding the use of 24- or 48-month scales, we deemed them unnecessary in our context. Longer scales can sometimes mask important fluctuations that may be revealed through annual analysis. By using the annual SPI, we could better focus on the climatic effects relevant to our study.

The SPI at different time scales expresses the variability of precipitation in relation to long-term averages. Specifically, the annual SPI measures precipitation over a full year, providing insights into long-term trends and overall water availability. It smooths out seasonal variations, allowing us to assess how the year compares to historical norms. This is particularly useful for evaluating the impact of precipitation anomalies on water resources, agriculture, and climate trends.

In contrast, the seasonal SPI focuses on specific seasons (e.g., winter, spring, summer, autumn) and captures variations in precipitation during these critical periods. The seasonal SPI helps identify patterns that may affect agriculture, hydrology, and ecosystem health, as certain crops and water systems are more sensitive to precipitation during specific times of the year.

The mathematical formula for SPI, established by McKee et al. in 1993 [18], is as follows:

$$PI = \frac{(\mathrm{Pi} - \mathrm{Pm})}{\sigma} \tag{1}$$

Pi: Precipitation for year iii;

Pm: Average precipitation;

σ: Standard deviation or standard deviation.

Using severity thresholds defined by the standard deviation method, Aghrab [19] developed a new classification of the Standardized Precipitation Index (SPI), known as the corrected SPI (SPIc), specifically for the Sais region [20]. This revised classification (see **Table 1**) appears particularly well-suited to the Moroccan climate, and especially to the Oriental region [21,22].

We utilized monthly precipitation data to calculate the Standardized Precipitation Index (SPI) for both annual and seasonal time scales. By analyzing these monthly precipitation records, we were able to assess the variability and trends in precipitation patterns over time. The SPI, which quantifies the deviation of precipitation from the mean, allows us to classify the severity of wet or dry periods, providing valuable insights into drought conditions and hydrological changes. This method not only enhances our understanding of precipitation dynamics but also aids in water resource management and agricultural planning by highlighting critical periods of moisture availability.

Table 1. Classification of drought severity according to the corrected SPI compared to the classification proposed by Mckee et al. [18].

Class	Classification	Threshold according to SPI	Threshold according to SPIc
Extremely humid	More than 2.0	pi > pm + 2o	More than 2.0
Very humid	1.5 to 1.99	Pm + o < pi < pm +2o	1 to 1.99
Moderately humid	1.0 to 1.49	Ls < pi < pm + o	0.31 to 0.99
Near normal	−0.99 to 0.99	Li < pi < Ls	−0.30 to 0.30
Moderately dry	−1.0 to −1.49	Pm − o < pi < Li	−0.31 to −0.99
Severely dry	−1.5 to −1.99	Pm − 2o < pi < Pm − o	−1 to −1.99
Extremely dry	Less than −2.0	pi < Pm − 2o	Less than −2.0

4.5. Remote sensing approach: The NDVI

Vegetation indicators are essential quantitative measures of vegetation cover status, crucial for monitoring its dynamics and detecting signals of water stress or drought. Various indices such as the Enhanced Vegetation Index (EVI), the Vegetation

Condition Index (VCI), and the Vegetation Health Index (VHI) are available for drought assessment. In the context of this study, the Normalized Difference Vegetation Index (NDVI) has been opted for due to its prominence and recognized effectiveness in analyzing drought conditions. The NDVI is widely acknowledged for providing relevant information in this regard. Utilizing satellite data allows for precise mapping of daily solar irradiance levels, thus facilitating early detection of water stress manifestations within vegetation cover. The NDVI assesses vegetation biomass by considering its phenological phases and offers insights into seasonal and annual fluctuations in vegetation density, influenced by various climatic parameters such as moisture and atmospheric conditions, as highlighted by Franchomme [23]. This study classified vegetation cover into four consecutive categories, adopted from Layelmam and Mimouni et al. [21,24], as illustrated in **Table 2**.

Table 2. Classification of vegetation cover according to the NDVI index [24].

Class	NDVI Value
Degraded	Less than 0.15
Near normal	0.15 to 0.30
Good	0.30 to 0.45
Very good	More than 0.45

5. Results and interpretations

This section presents the results of the meteorological drought monitoring by displaying maps of the Standardized Precipitation Index (SPI), aiming to highlight the influence of precipitation anomalies on vegetation growth.

5.1. Calibration of CHIRPS data

The results of the regression analysis between satellite-derived precipitation data and measurements from 28 national stations revealed a coefficient of determination (R^2) of 0.89, indicating a strong correlation between the two data sets (**Figure 4**). This regression equation was applied to calibrate CHIRPS satellite data at the pixel level over a period of forty-one years, from 1981 to 2022. In other words, this procedure is a method for adjusting satellite precipitation values based on direct observations, allowing for accurate correction of satellite data relative to ground measurements.

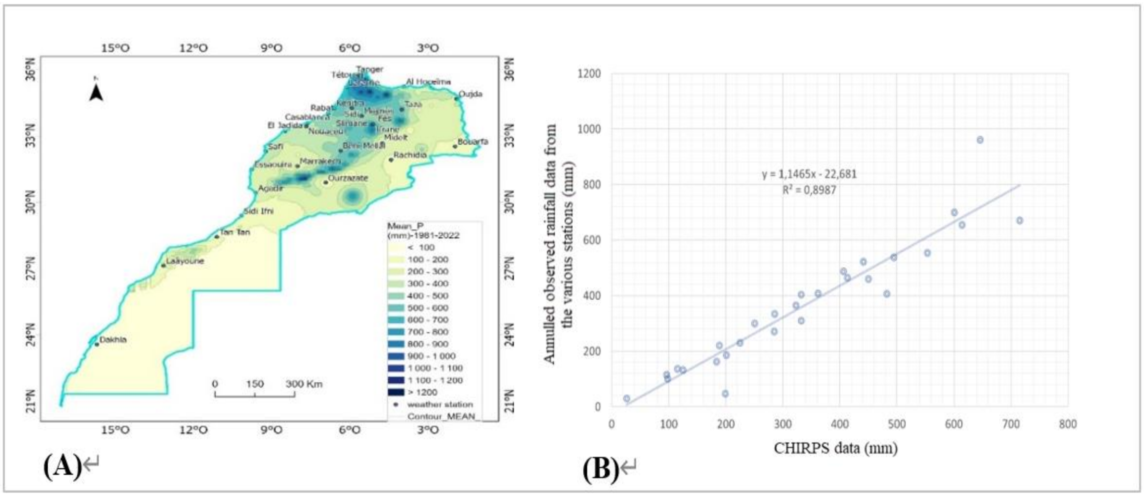

Figure 4. National precipitation map and correlation diagram: **(A)** National average precipitation for the period 1981-2022; **(B)** Correlation between precipitation recorded by national meteorological stations and precipitation estimated from CHIRPS images.

The fundamental value of this method lies in its ability to enhance the accuracy and reliability of satellite-derived precipitation data. This approach is particularly relevant in regions where ground observations are limited or unreliable, as is the case in this study area, because it helps address gaps in meteorological data, thereby improving the quality of information available for planning and decision-making processes.

5.2. Frequency and intensity of droughts in Oued Kert Basin

According to the results obtained, over the study period from 1981 to 2022, the following observations were noted:

(1) Two extremes: in 1983, the driest year (with SPI = −1.5), and in 2010, the year with the most extreme moisture (with SPI = 3.7);

(2) An alternation between dry and wet periods, with the longest non-dry period recorded between 2006 and 2013 (**Figure 5**). Due to its standardization, the SPI has the advantage of allowing comparison of drought conditions over different time periods [24]. Comparative analysis of seasonal SPI indices highlights the seasonal characteristics of precipitation as well as the associated drought conditions.

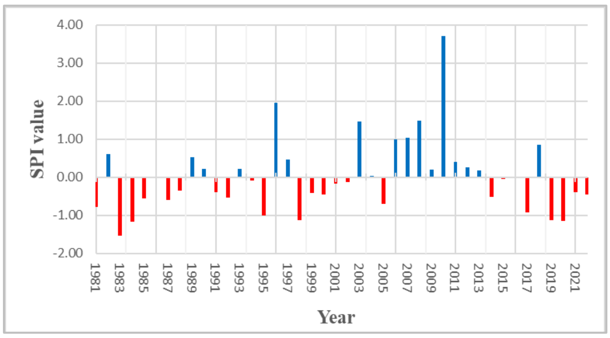

Figure 5. Annual values of the standardized precipitation index (SPI) in Oued Kert Basin (1981–2022).

5.3. SPI maps derived from CHIRPS data

Monitoring meteorological drought relies on a rigorous analysis of various indicators, which are determined from multiple climatic parameters. Due to the inherent complexity in objectively quantifying the characteristics of drought, such as its duration, intensity, and spatial extent, significant efforts have been made to develop techniques for monitoring, characterizing, and analyzing drought. These efforts have led to the creation of several specific indices and indicators designed to better understand this critical climatic phenomenon. CHIRPS precipitation data consist of satellite estimates corrected by integrating ground-based meteorological station observations. They are represented as raster images in time series available from 1981 to the present [14]. These CHIRPS data are presented as spatial precipitation maps with a spatial resolution of 5 km.

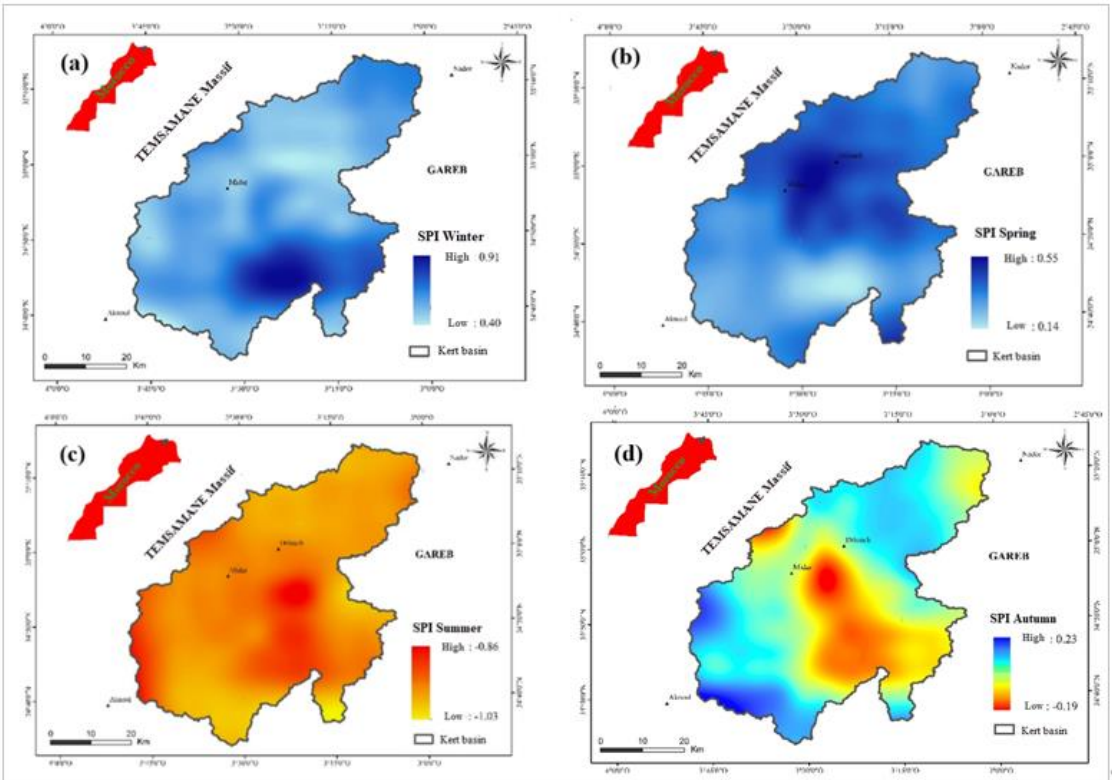

Figure 6. Seasonal SPI maps derived from average seasonal CHIRPS data (1981–2022). **(a)** Winter SPI; **(b)** Spring SPI; **(c)** Summer SPI**; (d)** Autumn SPI.

The expected results of this study, based on the calculation of the seasonal SPI index from seasonal average CHIRPS data (1981–2022) in Oued Kert basin, reveal significant observations. Specifically, the SPI index for the winter period ranges from 0.40 to 0.91 (**Figure 6a**). These values indicate a period characterized by moderate moisture, suggesting relatively favorable precipitation conditions in the studied basin. Spring presents a period of moderate moisture, reflecting spring precipitation amounts that are greater than those received during summer and less than those received during winter (**Figure 6b**). In contrast, in Oued Kert basin, the SPI index for the summer period, representing the dry season, shows values of −0.86 and −1.03 (**Figure 6c**). The summer season in Oued Kert basin is characterized by dry weather conditions due to a significant reduction in precipitation. In the context of Oued Kert basin, the analysis of the autumn SPI index (**Figure 6d**) reveals that the basin experiences conditions close to normal during autumn, which can be explained by precipitation amounts equal to or near the autumnal average.

5.4. Spatial distribution of NDVI in Oued Kert Basin

The results of mapping the Normalized Difference Vegetation Index (NDVI) reveal considerable diversity in the matrices, both temporally and spatially. The fluctuations observed in the studied seasonal series highlight a variety in land cover and land use characteristics. The spatial distribution of the NDVI shows that during the spring season, vegetation conditions were better compared to other seasons (**Figure 7**). During this phase, non-degraded vegetation covered areas characterized by dense and diverse plant cover, supporting a variety of plant species. Non-degraded areas in Oued Kert basin are often associated with specific topographic features, such as fertile soils and adequate water availability. These conditions promote the development and maintenance of natural vegetation, leading to the formation of healthy and resilient ecosystems. Some areas exhibit vegetation degradation throughout all seasons, which may be attributed to construction activities.

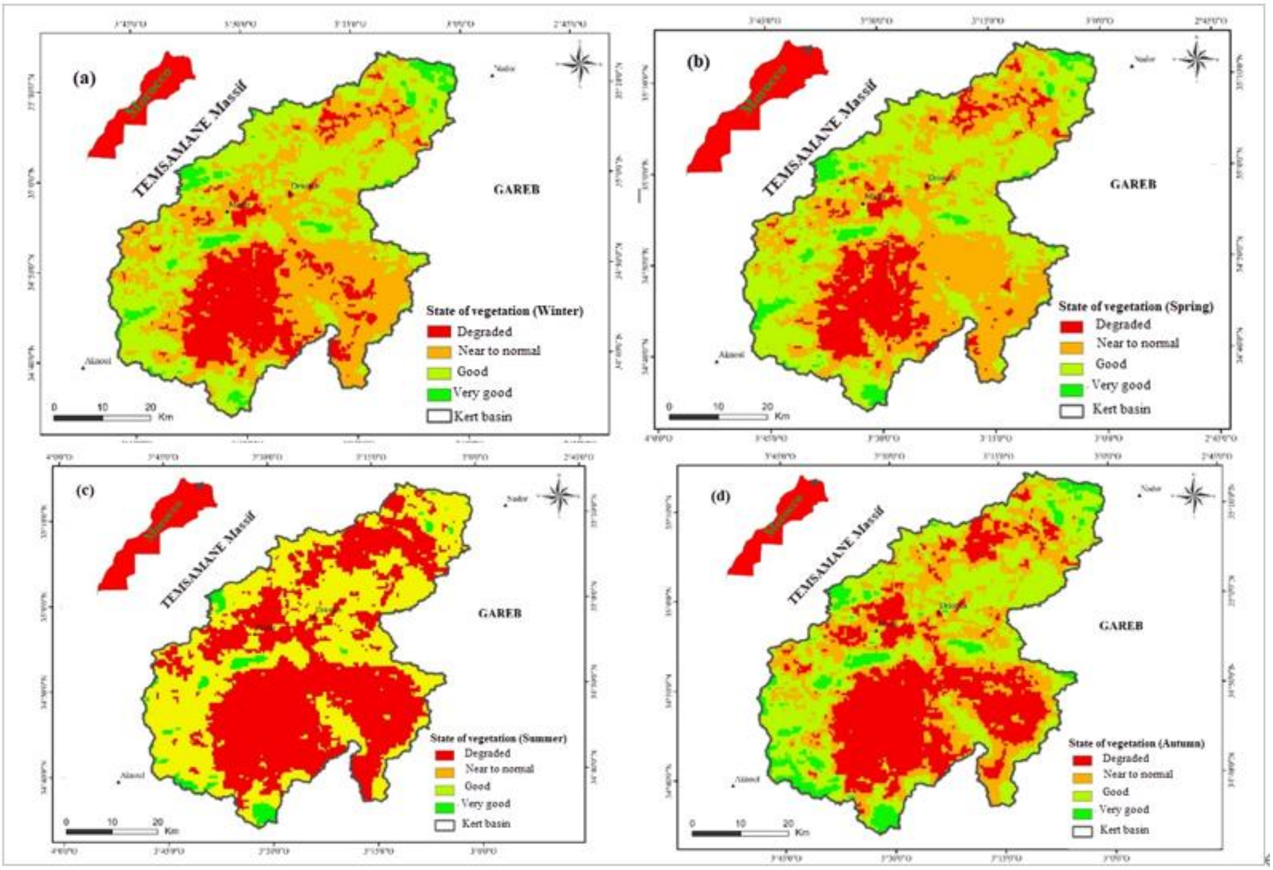

Figure 7. Maps of drought classes according to the seasonal normalized difference vegetation index (NDVI) in Oued Kert Basin **(a)** Vegetation condition (Winter); **(b)** Vegetation condition (Spring); **(c)** Vegetation condition (Summer); **(d)** Vegetation condition (Autumn)).

Spring vegetation cover is greater than that of other seasons. This situation results from the precipitation received during the winter semester and the accelerated physiological activity of plants during the spring season. During wet periods, farmers in Oued Kert basin are encouraged to practice plowing, even beyond the traditional soil preparation phase for major crops, due to increased precipitation. However, this practice exacerbates the vulnerability of the area.

5.5. Correlation between seasonal SPI and NDVI

The study of the correlation between precipitation patterns and vegetation dynamics throughout the seasons highlights the influence of climatic variability on vegetation. An analysis of the relationship between the Normalized Difference Vegetation Index (NDVI) during the winter season and the Standardized Precipitation Index (SPI) for the same period reveals a correlation coefficient (R^2) of 0.66. This result underscores a significant correlation between vegetation vigor and drought conditions during winter (**Figure 8**). These findings emphasize the importance of closely monitoring winter climatic conditions and their impact on pasture availability in grazing areas.

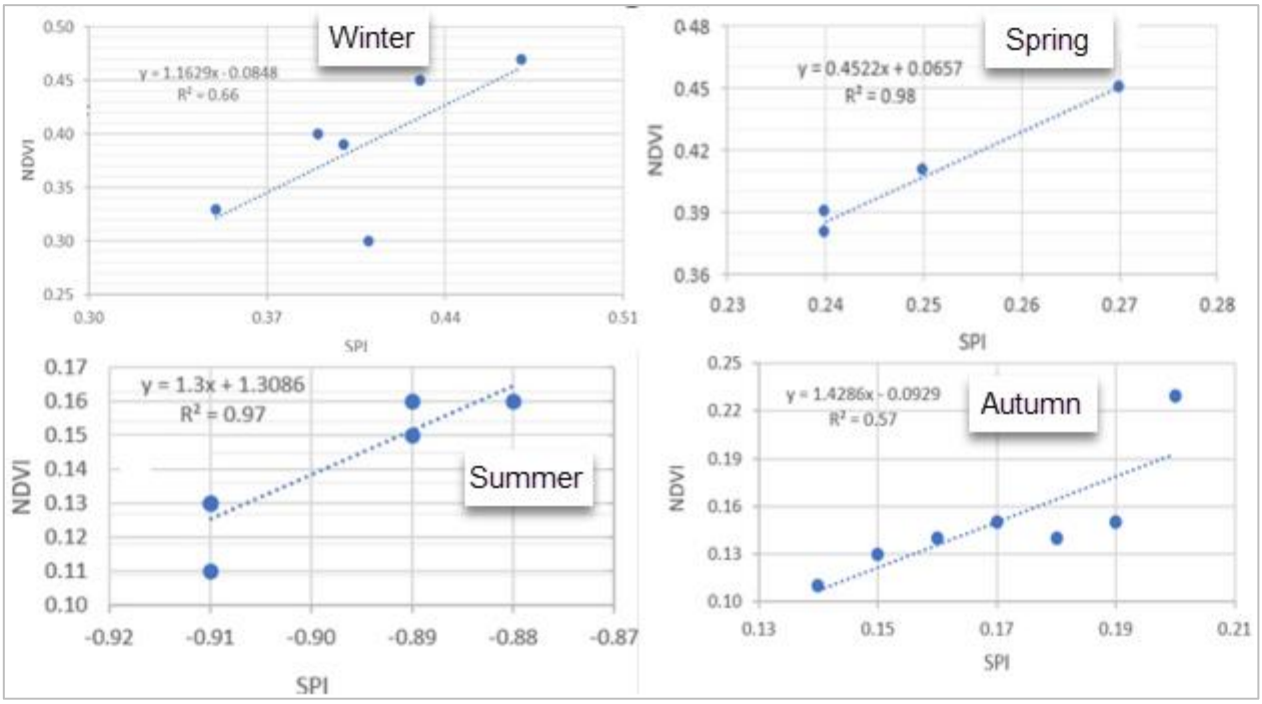

Figure 8. Correlation diagram between seasonal NDVI and SPI in Oued Kert Basin.

During the spring season, precipitation plays a crucial role in vegetation growth and development. Adequate precipitation levels can promote optimal plant growth, while prolonged drought can lead to reduced vegetation biomass. Thus, significant variations in the SPI can translate into similar variations in the NDVI, resulting in a strong correlation between the two.

The NDVI is sensitive to rapid changes in weather conditions, especially during active growing seasons like spring. Vegetation responds quickly to changes in hydrological conditions, which is reflected in the NDVI. Consequently, when precipitation varies considerably, the NDVI may exhibit similar fluctuations, leading to a high correlation of $R^2 = 0.98$ with the SPI.

A high correlation between the NDVI and SPI for the spring season indicates a strong association between precipitation and vegetation vigor during this active growth period, reflecting the vegetation's sensitive response to weather conditions.

During the autumn season, the interactions between vegetation and weather conditions are often more complex due to the transition between active growth and dormancy seasons. Precipitation may impact vegetation vigor, but other factors such as temperature, day length, and soil conditions may also play a role. This complexity can reduce the strength of the correlation between NDVI and SPI. The results show a moderate correlation, R^2 of 0.57, between the Normalized Difference Vegetation Index (NDVI) and the Standardized Precipitation Index (SPI) for the autumn season, which is due to the complexity of environmental interactions, delayed effects of precipitation on vegetation, and local and regional variability in environmental conditions.

6. Discussion

Numerous studies have shown that the Normalized Difference Vegetation Index (NDVI) is frequently correlated with the Standardized Precipitation Index (SPI), reflecting the influence of precipitation on plant health. For example, research indicates that during droughts, NDVI decreases align with negative SPI values, highlighting vegetation's direct response to water availability. This approach has notable advantages, such as utilizing satellite data for large-scale assessments and easily integrating climatic and ecological information. However, it also has drawbacks; factors like temperature, soil conditions, and land management can significantly affect vegetation health beyond just precipitation. Thus, while the NDVI-SPI correlation is valuable for understanding drought impacts, a comprehensive analysis must consider additional variables.

Further explored this relationship in the upper Noteć catchment area in central Poland [25], demonstrating that NDVI effectively indicates variations in vegetation health during droughts. Their findings underscore the importance of remote sensing in climate monitoring and reveal a significant correlation between NDVI values and SPI-identified drought episodes. This research contributes to the growing literature advocating for the combined use of these indices to enhance natural resource management amid climate change challenges.

The approach that analyzes the relationship between the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI) offers several significant advantages. Firstly, it enables large-scale assessments through the use of satellite data, providing an overview of vegetation health and drought conditions. The NDVI, as a sensitive indicator, reacts quickly to variations in plant health, facilitating the monitoring of drought impacts [26]. Additionally, this method promotes the integration of climatic and ecological data, enriching multidisciplinary analyses and allowing for continuous monitoring of environmental conditions over extended periods.

However, this approach also has its drawbacks. Local variability can affect the results, as factors such as soil quality and agricultural practices may nuance data interpretation. Furthermore, vegetation health is influenced by multiple elements, including temperature and soil moisture, which complicates the analysis. The timing of the data presents another challenge, as NDVI measurements may not always align with drought periods, making it difficult to establish clear relationships. Moreover, the accuracy of satellite data can vary due to atmospheric factors like cloud cover. Lastly, it is essential to note that a correlation between NDVI and SPI does not necessarily imply a causal relationship, which can lead to misinterpretations.

In summary, while the association between SPI and NDVI provides valuable insights into understanding drought impacts on vegetation, it is crucial to consider the various advantages and disadvantages to achieve a comprehensive and accurate analysis.

7. Conclusion

The anticipated results of this study have highlighted a statistically significant correlation between the two selected indices on a seasonal scale. This can be attributed to the immediate response of photosynthetic activity to precipitation. The choice of the Standardized Precipitation Index (SPI) for monitoring drought from precipitation data offers several advantages. During this study, the index was calculated for Oued Kert basin over a period extending from 1981 to 2022.

Monitoring vegetation cover changes using satellite-derived indicators provides insights into vegetation response to precipitation fluctuations and facilitates the comparison of its current state on a seasonal level. Additionally, a thorough analysis of these indicators on a seasonal scale allows for the identification of times when anomalies in crop development occur due to climatic variations. This information is crucial for agricultural managers, enabling them to implement appropriate corrective measures to ensure optimal plant growth.

Author contributions: Conceptualization, ZEA, AM and ML; methodology, ZEA, AA and WS; software, ZEA, WS and SE; validation, ZEA, AM and MM; formal analysis, ZEA; writing—original draft preparation, ZEA; writing—review and editing, ZEA, AM and ML; visualization, ZEA, AA, MS, WS, SE and MM; supervision, AM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

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