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Vulnerability of Water Resources to Drought Risk in Southeastern of Morocco: Case Study of Ziz Basin

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Abstract: water resources in Morocco have been severely influenced by climate change (CC) and prolonged drought, particularly, in the pre-Saharan zone. The Tafilalet region faces increasing pressure due to high demographic growth, increased demand for water, excessive groundwater consumption, and investment in agriculture. Using the Water Evaluation and Planning System (WEAP), this study assessed land cover and elevation and created future scenarios using the Standard Precipitation Index (SPI) and Standard Groundwater Level Index (SGI) to monitor hydroclimate drought conditions in the Ziz watershed from 1989 to 2022. Results show decreasing precipitation, particularly from 2010-2020, with the last four years being the most challenging (SPI<-2). SPI and SGI have a high correlation, suggesting precipitation impacts groundwater indicators. Future scenarios predict a high risk of CC, with a 30% decrease in annual precipitation accumulation by 2100 under the optimistic scenario SSP126. Minimum temperature is expected to increase by 1.08°C (SSP126) and 2.61°C (SSP585), and maximum temperature by 1.05°C (SSP126) and 2.93°C (SSP585).

Keywords: climate change; water resources; SPI; SGI; WEAP; Ziz watershed; drought

1. Introduction

The impact of climate change (CC) and catastrophic events have become highly felt at the global level [1]. In 2020, more than 100 million people were affected by extreme weather events such as floods, droughts, storms, and wildfires. Economies, livelihoods, and the environment have been affected by these disasters, especially in vulnerable areas, as in some African countries [1,2] . During the period 2000 to 2019, there were 7,348 recorded major disasters, compared to 4,212 between 1980 and 1999 [3]. Climate-related disasters have increased the most, representing 6,681 events [3]. Over the last twenty years (2002-2021) floods (n=793) and droughts (n=137) represented 55% of natural hazards in Africa (n= 1,693), with 14,053 and 20,821 deaths, respectively [4]. Many studies on CC in Morocco show that rainfall is much more contrasted with high spatiotemporal variability, rising temperatures, and a remarkable frequency of drought in recent decades [5–8].

Meteorological drought is most often expressed in terms of rainfall compared to a given average amount and the duration of a dry period and can be defined as a period with lack of precipitation or with rainfall lower than average, lasting sufficiently to cause hydrological and agricultural hazards [9]. This climate impact is compressed by the negative intervention of the anthropogenic factor. According to the World Bank report, the vulnerability of water resources to CC in the country is dramatic. In terms of unmet demand, Morocco will experience an increase in water shortages from 10 to 20 km3 in 2020-2030 and up to 40 km3 in 2040-2050 [10]. This has a negative impact on agriculture, which remains one of the most impacted sectors according to estimates for the next three decades [11]. The decline in agricultural productivity is expected to reach 50% in many countries if resilience to crises and shocks is not considered emergency and comprehensive [12]. This issue is particularly serious in arid and semi-arid areas [13] such as the Moroccan pre-Sahara. Tafilalet oasis, one of the largest palm groves of this zone, however, still faces the same challenges as the rest of the country regarding the water problem and is experiencing significant CC. The arid climate of this region causes more long periods of drought throughout the year and from one year to the next, so water resources are becoming increasingly scarce, considering the over-exploitation of surface and deep water.

To assess land cover, elevation, future scenarios, monitor and track hydroclimate drought conditions in the Ziz watershed from 1989 to 2022, three tools were used namely the Water Evaluation and Planning System (WEAP), the Standard Precipitation Index (SPI), and Standard Groundwater Level Index (SGI).

Reviewing the literature, the tools used to simulate the hydrologic processes and evaluate water resources are various including the Dynamic Water Resources Assessment Tool (DWAT), The Hydrologic Modeling System (HEC-HMS), the Soil & Water Assessment Tool (SWAT), and Water Evaluation and Planning System (WEAP). This later was used in the current study in the context of Ziz Basin. This tool was applied in many areas at the Moroccan scale, by Ben Salem et al., [14] in Tafilalet, by Rochdane et al., [15] in Rheraya, and by Karmaoui et al., [16] in the context of Draa Valley.

For the assessment of water resources and the analysis of integrated water resources management, WEAP is applied, and geographical information systems are used for the management, exploitation, and representation of data in the form of thematic maps. In this study, we tried to explore whether the water resources in this semi-arid region will withstand massive agricultural projects and overexploitation. We aimed also to characterize temporal and spatial drought incidences as a function of frequency, magnitude, intensity, and severity status using the SPI and SGI models in Ziz catchment. We also studied the relationship between these two drought indices and future predictions of temperature and precipitation according to the greenhouse gas emissions scenarios.

2. Materials and Methods

2.1. Study Area

Ziz unit is located in the southeast of Morocco (Figure 1). it corresponds to the basins of the oued Ziz, delimited by Moulouya watershed in the North, by Guir in the East and by Rheris watershed in the west. This area covers approximately 13,185 km² [17].

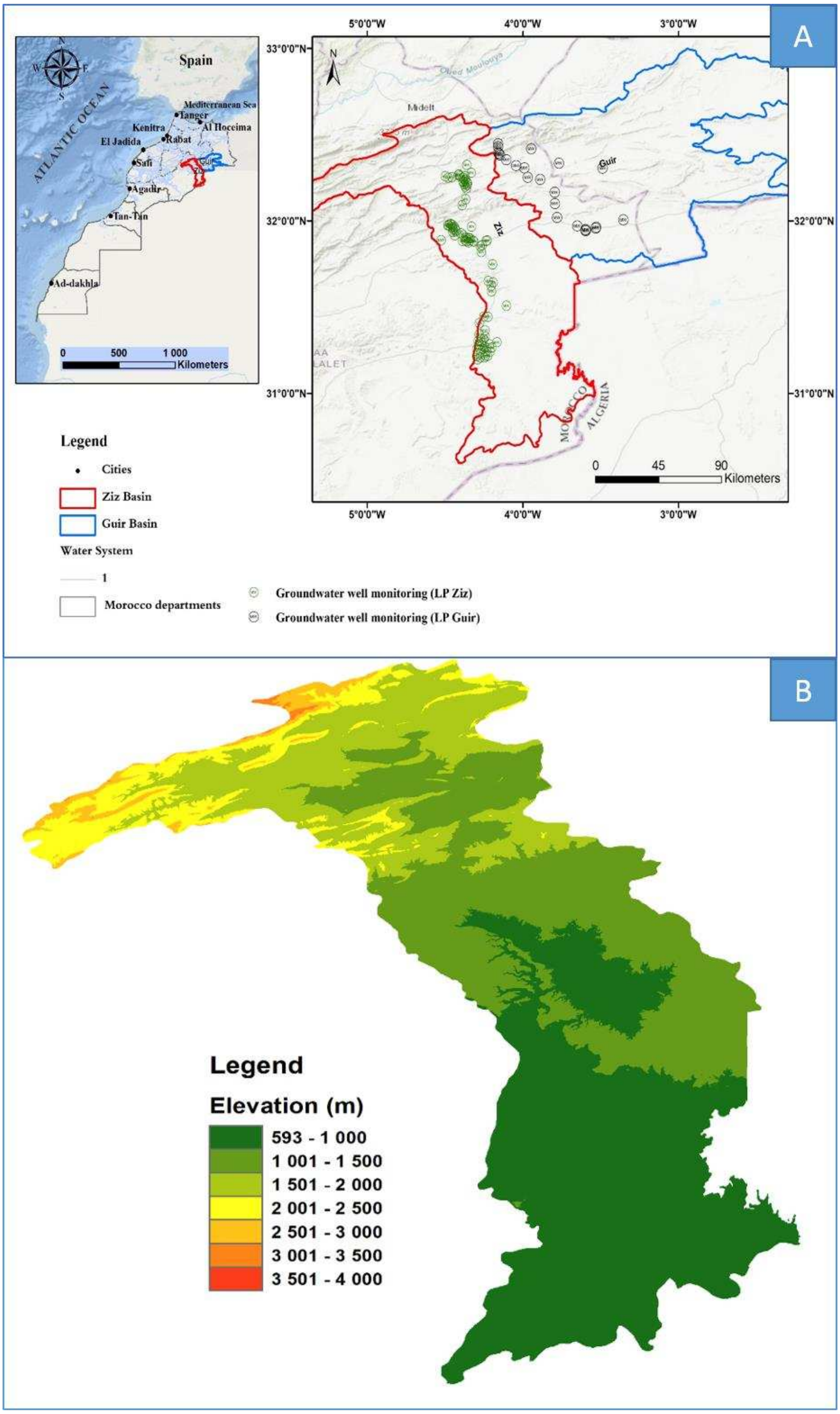

Figure 1. The study area. A, Localization of Ziz Catchment including cities, basins, and groundwater wells in Ziz and Guir catchments; B, Elevation in meters above sea level.

The climate of the area is semi-desert with strong continental influence. Average annual precipitation is very low, about 60 mm in the south and 265 mm in the north. The annual rain regime

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is characterized by the existence of two rainy seasons: autumn and spring, separated by two dry periods, a rapid winter season to low relative minimum and by a long season summer very marked by drought [18]. Temperatures vary widely from north to south of the area. While it snows in Imilchil during winter, the temperature can reach 50°C in Rissani during the summer. The annual average potential evaporation measured using an evaporating tank is 2500 mm. The prevailing winds are northeast and the Chergui (hot and dry wind from the Southeast) blows mainly in spring and autumn [19,20].

Water resources in our study area have been significantly reduced due to the concentration of water withdrawals (especially in the alluvial aquifer) and the persistence of drought. Surface water supplies have been deficient compared with withdrawals for several years. The palm groves could not be irrigated by the traditional systems (Seguia and Khattaras) and the hydrodynamic imbalance of the aquifers was aggravated by intensive pumping without being able to make up the water deficit of the palm groves [20].

2.2. Methodology

2.2.1. The Use of Water Evaluation and Planning System

Distribution and Resources

The WEAP software has a feature that enables automatic delineation of watersheds and rivers using numerical altitude data [21]. It can also calculate land area by elevation and land cover class. Additionally, the software can download historical climate data for each watershed and prepare a climate map, which greatly simplifies the hydrological modeling process for watersheds [22].

Ziz Basin

The Ziz Basin is one of the first watersheds in the southeast of Morocco to have undergone significant hydraulic development [23]. It is a hydro-agricultural area where an arid atmosphere reigns, but in the heart of the drought, the oasis celebrates the ephemeral triumph of the plant [24]. This basin encompasses many units and structures including Ziz river and Hassan Addakhil Dam (HAD).

Ziz River

In each watershed, there is a river that flows through it and into which it flows. Based on the path through the watershed having the greatest accumulation of flow, WEAP automatically creates a river object [25]. In our case study, we will focus on the Ziz River, which is a major river in Southeast Morocco.

The average inflows to the first node on a river represent the head flow. The latter can be determined either with values calculated by the simplified coefficient or soil moisture methods as coming from a watershed, or with values entered directly with the Water Year Method, the method of reading from the file, or an expression [26].

Hassan Addakhil Dam

Initial storage, as opposed to storage capacity, refers to the volume of water that was initially kept in a tank at the beginning of the first month of use of the current account year. WEAP provides a mass balance of monthly inflows and outflows, which allows for tracking monthly storage volume [26].

The HAD is a vital unit in the Tafilalet area, located in the southern foothills of the High Atlas Mountains and fed by the Ziz River. It is an embankment dike with a height of 85 meters on a foundation and a length of 785 meters on a ridge. Its holding capacity is 347 million cubic meters, which makes it possible to control flooding and guarantee a regulated volume of 100 million cubic meters per year and a random volume of 35 million cubic meters depending on the irregular hydrology of the Oued Ziz, illustrated by annual inputs ranging from 8 to 500 million cubic meters with an average of 135 million cubic meters [23].

Biefs

Surface water and groundwater are often interconnected hydraulically in many watersheds. The "losing" stream is a stream that contributes to groundwater recharge, while the "gaining" stream is a

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stream that gains water from the aquifer based on the level of groundwater in the aquifer. WEAP can model these flows between groundwater and surface water in two ways: either by determining the flow rate from surface water to groundwater (Groundwater Outflow) and from groundwater to surface water (Groundwater Inflow), or by modeling these flows based on the level of the groundwater table and the reach length in WEAP [26].

Flow measurements

In WEAP, the streamflow gauge object is used to facilitate comparing simulated and observed streamflows, both in terms of quantity and quality [26].

Data from four hydro-climate measurement stations were analyzed to identify the water runoff in the Ziz Basin (Figure A1). Two stations are located in the High Ziz River, while the other two stations are located in the River Bitch:

- Foum Tillicht station controls upstream of the Ziz River watershed;
- Foum Zaabel station controls upstream of the HAD;
- The HAD hydrometric station controls downstream of the HAD;
- The Erfoud station controls downstream of the Ziz Basin.

2.2.2. The Use of Standard Precipitation Index

Drought indices are essential to characterize several drought features such as the onset and cease time of drought, drought duration, areal extent, severity and frequency at global, regional and local level [27]. In 2009, World Meteorological Organization recommended SPI as the main meteorological drought index that countries should use to monitor and follow drought conditions [28]. This indicator is developed by [29,30], and by identifying it as an index for broad use, WMO provided direction for countries trying to establish a level of drought early warning. The SPI is relatively new application, gaining worldwide acceptance and widely used at present because of its powerfulness, effectiveness, flexibility, versatile and standardized nature [31–34]. SPI has an intensity scale in which positive and negative values are calculated, which is directly associated with wet and dry events [35]. In order to analyze the impact of rainfall deficiency on drought development in this study area, SPI has been used to quantify the precipitation deficit in the periods since 1989 up to 2019 for 15 climate stations in the study area.

Rainfall data (X) for each station were arranged in columns format, that data is incorporated into the MDM software, using these data. This index meets the following equation:

$$\mathbf{SPI} = (\mathbf{X}\boldsymbol{i} - \overline{\boldsymbol{X}}) \,/\, \boldsymbol{\sigma}$$

where $\mathbf{X}\boldsymbol{i}$ is the cumulative rainfall for year **i**, $\overline{\boldsymbol{X}}$ is the average annual rainfalls observed for a long data series and $\boldsymbol{\sigma}$ is the Standard deviation.

Data used, SPI and drought classes:

Input data to this study consists of monthly rainfall values, for the period 1989 to September 2022 (Figure A1), for 7 rainfall sites in Ziz from NASA's GMAO MERRA- 2 (https://gmao.gsfc.nasa.gov/merra/) assimilation model and GEOS 5.12.4 FP-IT (https://gmao.gsfc.nasa.gov/news/geos_system_news/2016/FP-IT_NRT_G5.12.4.php). The World Meteorological Organization [33] has adopted a classification of seven different drought classes according to SPI, ranging from extremely dry to extremely wet (Table 1).

Table 1. SPI classification according to McKee et al., [29].

2.0 +	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

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2.2.3. The Use of the Standardized Groundwater Index

Understanding and evaluating groundwater resources and their vulnerability to CC are challenging tasks that require programs capable of describing the subsurface and conceptualizing the aquifer system as well as withdrawal and recharge rates. Numerous studies have been conducted to investigate the relationship between groundwater levels and climatic variables such as precipitation and temperature, based on standardized hydrometeorological indicators [36]. The SGI is an indicator used to calculate the degree of groundwater drought, whose calculation method is similar to that of standardized indicators [37,38]. It requires monthly mean groundwater level records in observation wells as input data. SGI may vary between -3 and 3, where negative values indicate drought conditions and positive values indicate moisture conditions. A SGI value of zero indicates an average condition. SGI is a useful tool for monitoring long-term hydrological conditions and can be used for groundwater resource management.

3. Results and Discussion

3.1. Land Use and Land Cover

The data was extracted from the delineation mode of the WEAP software, which includes a digital elevation model (DEM) of the Ziz Basin. This Basin is a geographic region with an area of 1400890 hectares and an elevation range from 615 to 3675 meters, with a mean elevation of 1210 meters (Figure 2). The basin is characterized by a diverse range of elevations, with the majority of the catchment area falling between 500 to 1500 meters. The results showed that 42.42% of the catchment area falls between 500 to 1000 meters, while 32.26% falls between 1000 to 1500 meters (Table 2). The elevation range of 1500 to 2000 meters makes up 16.31% of the area, while the remaining elevation ranges of 2000 to 4000 meters contribute to less than 10% of the total catchment.

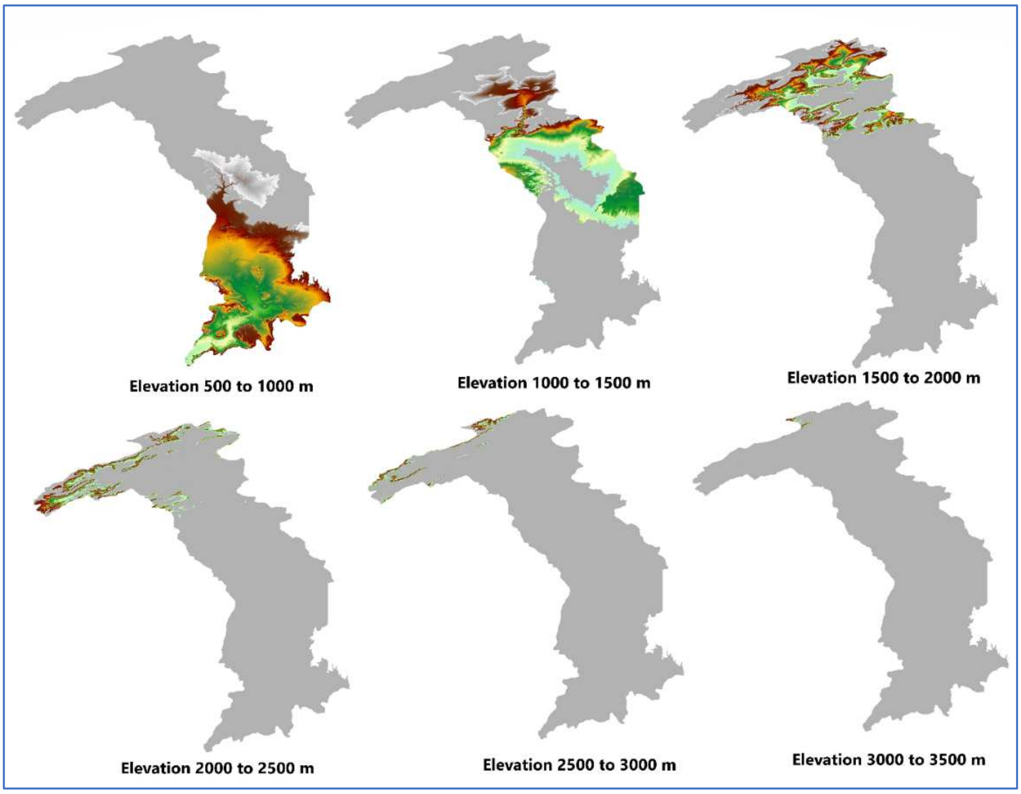

Figure 2. Distribution of elevation ranges within the Ziz watershed.

Table 2. Ziz Catchment informations concerning the elevation.

Elevation (m)	Area (ha)	%
500 – 1000	594256	42,42
1000 – 1500	451912	32,26
1500 – 2000	228535	16,31
2000 – 2500	95871	6,84
2500 – 3000	26487	1,89
3000 – 3500	3733	0,27
3500 – 4000	97	0,01
TOTAL	1400890	100

These statistics suggest that the Basin Ziz is a region with a predominantly low to mid-elevation range, with a smaller portion of the catchment area characterized by higher elevations. The distribution of elevation ranges within the catchment area is important to consider when assessing the region's ecological and hydrological processes, as different elevations may be associated with distinct vegetation types, precipitation patterns, and runoff characteristics. In regards to land cover distributions in the study area, the data pertain to land cover in the Ziz watershed in Errachidia Province (Table 3). The land cover information is presented in terms of the different land cover types and their area in hectares and percentages of the total catchment area.

Table 3. Land Cover of the study area using ESA-CCI-LC classification.

Land Cover	Area (ha)	%
Agriculture	38510	2,75
Forest	419	0,03
Grassland	164	0,01
Urban	7834	0,56
Shrubland	1247	0,09
Barren or Sparse Vegetation	1146163	81,82
Open Water	555	0,04
TOTAL	1400890	100

The findings showed that the majority of the catchment area is covered by barren or sparse vegetation, accounting for 81.82% of the total area (Table 3). Agriculture is the next largest land cover type, covering 2.75% of the catchment area, followed by urban areas, shrubland, forest, grassland, and open water, which have much smaller coverage percentages.

The dominance of the sparse vegetation is likely due to the arid and semi-arid climate, which limits the growth of vegetation. The presence of agriculture is likely associated with irrigation practices, which are necessary for sustaining crop growth. The small coverage percentages of forest, grassland, urban, shrubland, and open water suggest that these land cover types are relatively rare in the catchment area. The presence of forest and grassland may be associated with areas with higher elevation or more favorable conditions for vegetation growth. The presence of urban areas may be associated with population centers or economic activity, while the presence of open water may be associated primarily with reservoirs. The land cover information can be useful for understanding the spatial distribution of different land cover types in the study area and their potential impact on hydrological processes. For example, areas with barren or sparse vegetation may have higher rates of runoff and erosion than areas with vegetation cover. Urban areas may have higher rates of impervious surfaces, leading to increased surface runoff and decreased infiltration.

3.1.1. Agricultural Land

The results showed the evolution of agricultural land for each altitude class in the Ziz basin, in the Tafilalet region, during the study period from 1992 to 2020 (Figure 3A).

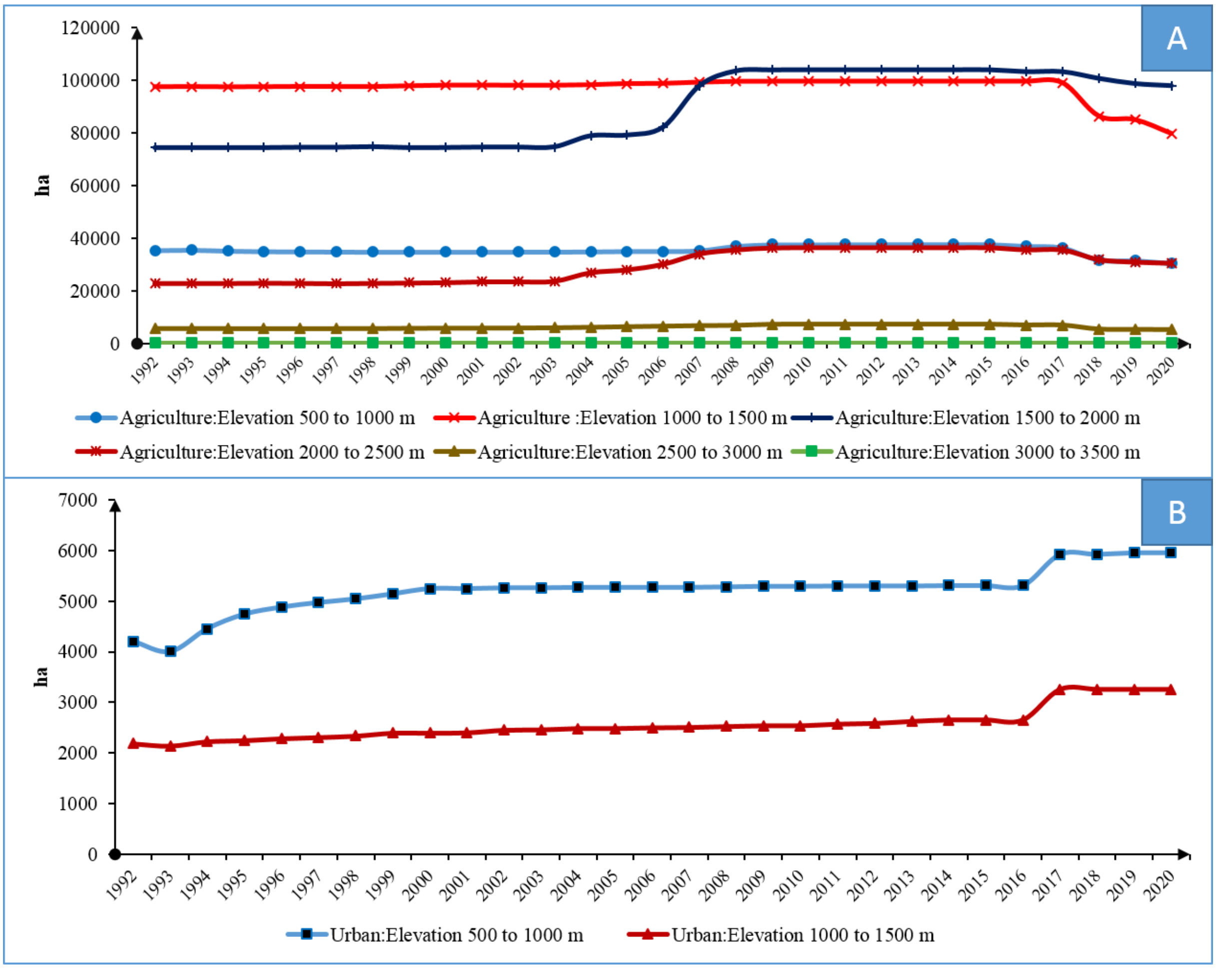

Figure 3. Evolution of the agricultural (**A**) and urban area (**B**) in the different altitudes of Ziz watershed during the period 1992-2020 using WEAP.

The zone with the largest agricultural land is the downstream zone of the HAD in altitudes of 1000 to 1500 m, with an area of 97,539 hectares (Figure 3A). Despite the relative drying up of the dam, this zone remains in a favorable position, with water consumption reaching about 12,400 m3/ha, the highest water consumption in the valley [39] . The Haut-Ziz zone, upstream of the dam in altitudes of 1500 to 2000 m, is the second zone in terms of agricultural land, with an area of 74,327 hectares. However, this zone has experienced an increase in agricultural land since 2003 and surpassed the downstream zone of the dam from 2007, reaching a maximum value of 103,963 hectares and occupying the first place. This zone draws its water resources from the groundwater through individual motor pumps, as precipitation mainly falls as snow on the high reliefs of the North and West, with relatively short duration due to high sunlight on the high reliefs.

Water scarcity is a major problem in the Tafilalet plain, downstream of the Ziz, due to the combination of the destabilization of the water table, resulting from the persistence of variations in the flow of the Ziz river, and the abuse of private and collective pumping. This scarcity threatens about 36,357 hectares of agricultural land and makes Tafilalet the most disadvantaged zone in terms of available water in the Ziz valley [39]. The analysis of the figure shows a decrease in the total surface area of agricultural land from 2017, except for altitude zones of 3000 to 3500 m where there is no agriculture. This negative trend is due to several factors, including CC, fires, reduced precipitation, and decreased groundwater, which have exacerbated the problem of drought. The factor of cement creep and the expansion of urban areas have also contributed to this trend [40]. In conclusion, Figure 3A demonstrates the importance of agricultural land in different altitude zones in the Ziz basin, as well as the challenges faced by the agricultural sector in the Tafilalet region, such as water scarcity and CC. These challenges require sustainable management of water resources and adaptation strategies to maintain agricultural productivity in this region.

3.1.2. Urban Area

The evolution of land use in the Ziz basin, in the Tafilalet region, during the period from 1992 to 2020 was illustrated in Figure 3B. The urban areas are located in the lower and middle Ziz at altitudes of 500-1500 m. It can be observed that the urban land has increased over time, and during the years 2016-2017, the increase was even more pronounced, before stabilizing afterwards (Figure 3B).

The increase in urban land reflects the population growth and development of infrastructure in the region. According to projections made by the Moroccan Urbanism Department, the Ziz valley is expected to experience an increase of nearly 93,000 inhabitants between 2004 and 2029, corresponding to an average population growth rate of +0.92% [41]. The expansion of urban areas has significant environmental impacts, including the loss of agricultural land, habitat fragmentation, and increased demand for resources, such as water and energy. Additionally, urbanization can contribute to CC through the emission of greenhouse gases from transportation, buildings, and industry. To mitigate the negative impacts of urbanization, it is important to adopt sustainable urban development strategies, such as compact urban design, green infrastructure, and renewable energy sources. These strategies can help to reduce resource consumption and emissions while promoting economic and social development [42]. In conclusion, the increase in urban land area in the Ziz basin reflects population growth and development of infrastructure, which has significant environmental impacts. Sustainable urban development strategies are needed to mitigate these impacts and promote economic and social development in the region.

3.1.3. Barren or Sparse Vegetation

Figure 4A shows the evolution of land use in the Ziz basin, in the Tafilalet region, during the period from 1992 to 2020. The barren or sparse category is a class that characterizes arid and semi-arid zones [43]. The surface area decreases as altitude increases, from the bottom of the Ziz basin to the top, but it has not changed much over time, except in the altitude range of 1000-1500 m where it increased by 16,791 hectares and decreased by 23,133 hectares in the altitude range of 1500-2000 m in 2020.

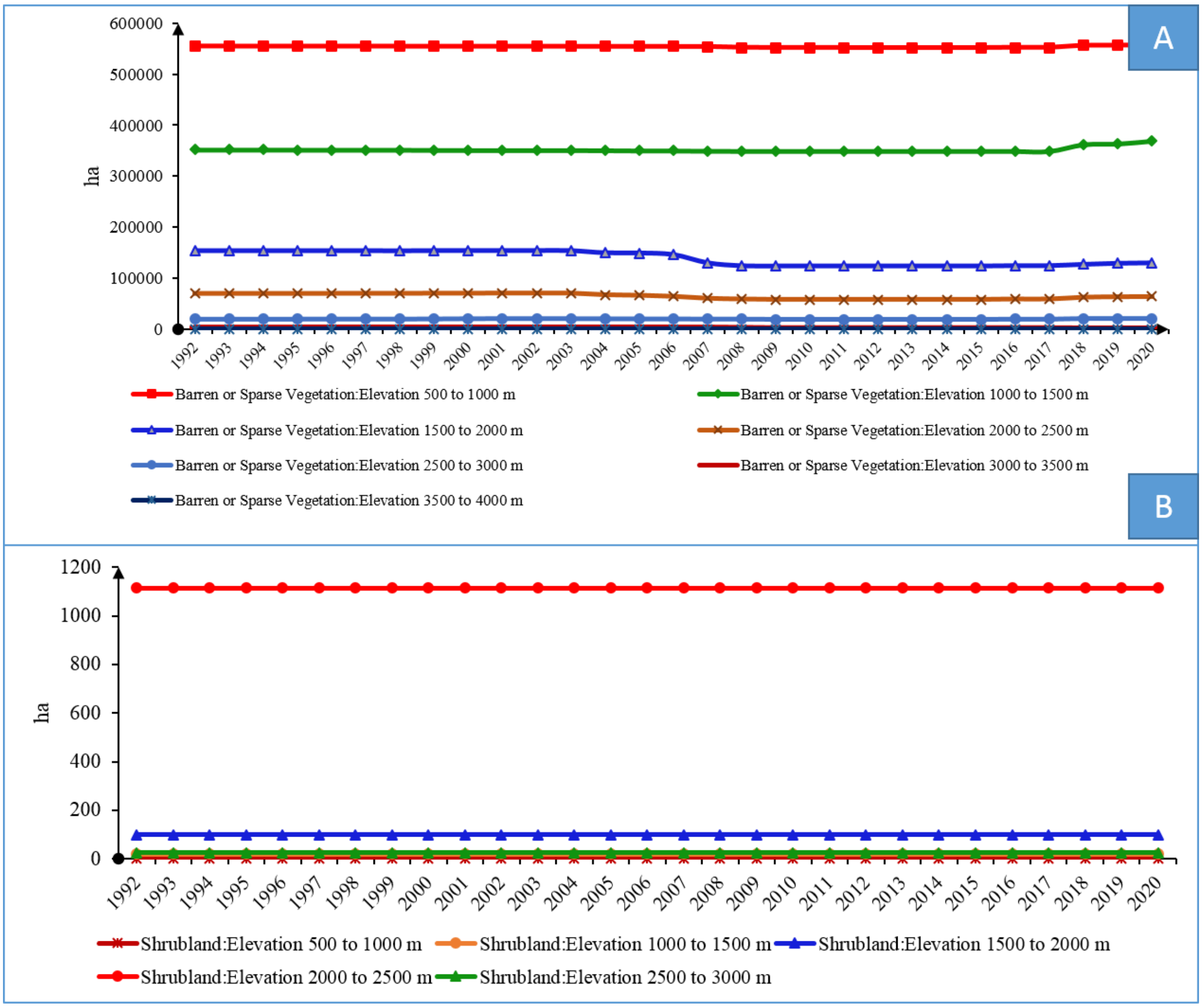

Figure 4. Evolution of the Barren and the shrub land area in the different altitudes of Ziz watershed during the period 1992-2020 using WEAP.

The barren land category is typically dominated by natural vegetation, such as shrubs, thorns, and grasses, and is characterized by low productivity and a high vulnerability to degradation and desertification. The decrease of this land category with increasing altitude is likely due to the higher precipitation and more favorable environmental conditions at higher altitudes, which can support more vegetation growth. However, the increase in barren or sparse land area at the altitude range of 1000-1500 m may be attributed to human activities, such as overgrazing, deforestation, and land degradation, which can lead to the conversion of productive land to barren or sparse land [44]. The decrease in barren or sparse land area at the altitude range of 1500-2000 m may be due to vegetation regrowth and natural land restoration processes, or to human interventions, such as reforestation and conservation efforts. It is important to monitor and manage the barren or sparse land category to prevent land degradation and desertification, which can have significant environmental, social, and economic impacts. Sustainable land management practices, such as conservation agriculture, agroforestry, and soil and water conservation, can help to improve land productivity and resilience, while reducing the risk of land degradation [45]. In conclusion, the barren or sparse land category in the Ziz basin decreases with increasing altitude, but has not changed much over time, except for some fluctuations in specific altitude ranges. Sustainable land management practices are needed to prevent land degradation and desertification, and to promote land productivity and resilience in the region.

3.1.4. Shrub Land

The Shrubland category, which is a vegetation type dominated by shrubs, is mainly determined by climatic conditions, water availability, and soil substrate in semi-arid regions [46]. The largest area of this category, covering 1114 hectares, is located at altitudes between 2000-2500 m (Figure 4B). The change in the surface area of this type of vegetation cover is much less significant than the previous categories.

Shrublands are important ecosystems that provide various ecological functions, such as soil conservation, carbon sequestration, and biodiversity conservation [47]. They also provide important resources for local communities, such as fuelwood, medicinal plants, and grazing lands for livestock [48]. The stability of the Shrubland category in the Ziz basin over time may be attributed to the relatively stable climatic and environmental conditions at higher altitudes, which are more favorable for vegetation growth and development. However, the Shrubland category is also vulnerable to land degradation and desertification due to overgrazing, deforestation, and other human activities that can lead to soil erosion and loss of vegetation cover [44]. To maintain the ecological and socio-economic functions of Shrublands, it is important to adopt sustainable land management practices that promote vegetation restoration and conservation, while supporting the livelihoods of local communities. These practices may include reforestation, agroforestry, and sustainable grazing management, as well as the promotion of alternative livelihoods, such as ecotourism and non-timber forest products [49]. In conclusion, the Shrubland category in the Ziz basin is mainly located at altitudes between 2000-2500 m and has remained relatively stable over time. Sustainable land management practices are needed to prevent land degradation and desertification, while promoting the conservation and sustainable use of Shrublands in the region.

3.1.5. Forest

The forest category, which represents forested areas, covers a total area of 407 hectares in the study area and is located in the northern part of the Ziz basin, upstream of the river. The forested area has remained stable throughout the study period (Figure 5A). This can be attributed to its relatively favorable climatic conditions compared to the rest of the Ziz territory.

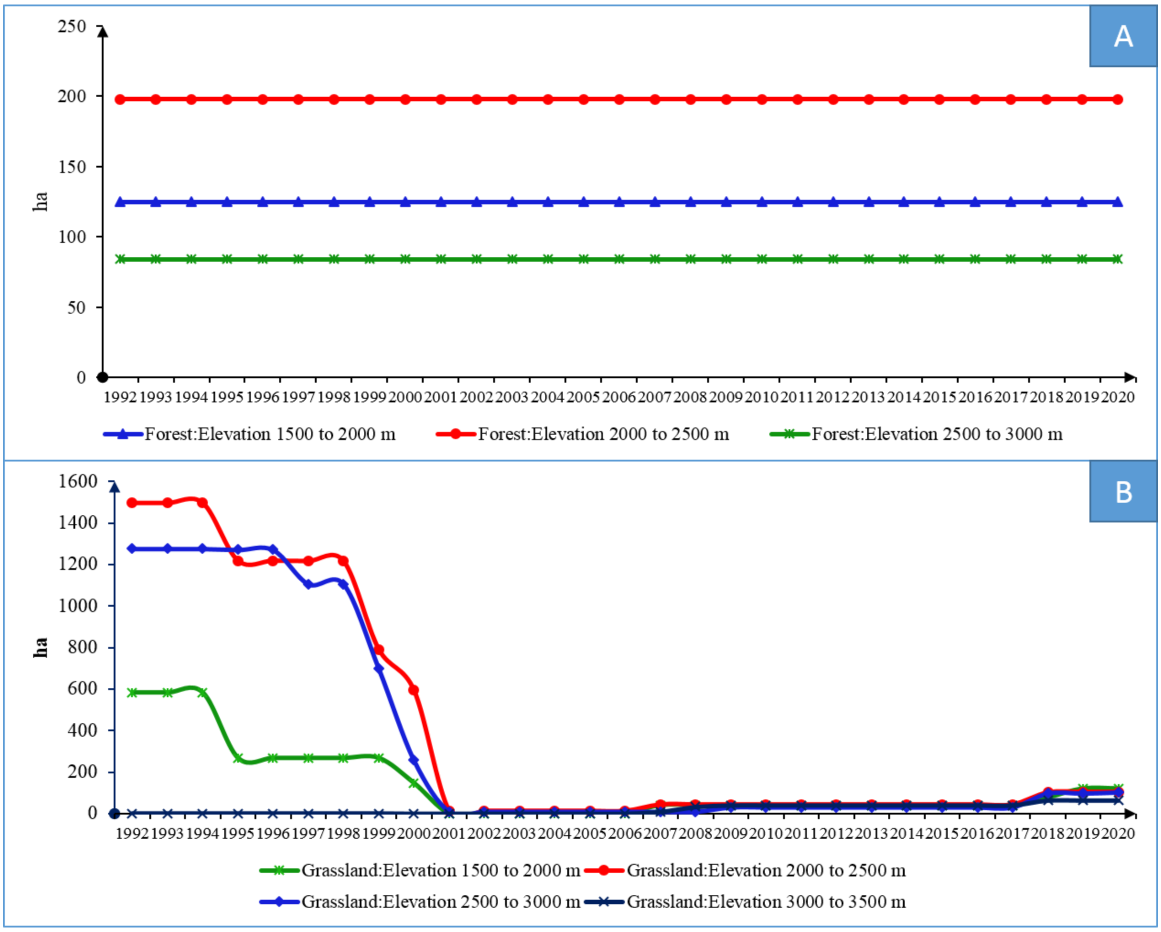

Figure 5. Evolution of the forest the grassland area in the different altitudes of Ziz watershed during the period 1992-2020.

Forests are important ecosystems that provide a wide range of ecological, social, and economic benefits, such as carbon sequestration, biodiversity conservation, and wood products [50]. In arid and semi-arid regions, forests are particularly important for their role in regulating water resources, reducing soil erosion, and providing habitat for wildlife. The stability of the forested area in the Ziz basin can be attributed to its unique location and climatic conditions, which are more favorable for forest growth and development. However, forests in the region are also vulnerable to degradation and deforestation due to human activities, such as overgrazing, logging, and land conversion for agriculture and urbanization [51]. To maintain and enhance the ecological and socio-economic functions of forests in the Ziz basin, it is important to adopt sustainable forest management practices that promote forest restoration and conservation, while supporting the livelihoods of local communities. These practices may include reforestation, forest conservation, and sustainable wood harvesting, as well as the promotion of alternative livelihoods, such as ecotourism and non-timber forest products [49]. In conclusion, the forested area in the Ziz basin is relatively small, covering only 407 hectares, and has remained stable throughout the study period. Sustainable forest management practices are needed to prevent deforestation and degradation, while promoting the conservation and sustainable use of forests in the region.

3.1.6. Grassland

The Grassland category, which represents natural grassy areas, is mainly located in the northern part of the basin, at altitudes between 1500 m and 3000 m (Figure 5B). The figure indicates a decrease in the surface area of this category over time, almost disappearing in 2001, followed by a reappearance in 2002 and 2007 at elevations between 3000-3500 m.

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Grasslands are important ecosystems that provide important ecological functions, such as soil conservation, carbon sequestration, and biodiversity conservation [52]. They also provide important resources for local communities, such as grazing lands for livestock. However, overgrazing and other human activities can lead to the degradation of grasslands, reducing their productivity and resilience [53]. The decrease in the surface area of the Grassland category in the Ziz basin can be attributed to overgrazing, which is the most significant threat to natural grasslands in the region [54]. The high density of livestock in the upper Ziz communities has led to the progressive degradation of natural grasslands and the exhaustion of edible grass species [54]. This can lead to a loss of soil fertility, soil erosion, and the loss of vegetation cover. To address the degradation of grasslands in the Ziz basin, it is important to adopt sustainable land management practices that promote sustainable grazing management, as well as the restoration and conservation of natural grasslands.

3.1.7. Open Water

The Open Water category represents open water bodies, covers an area of 550 hectares, and has remained stable throughout the study period (Figure 6). It is located in the middle of the Ziz basin.

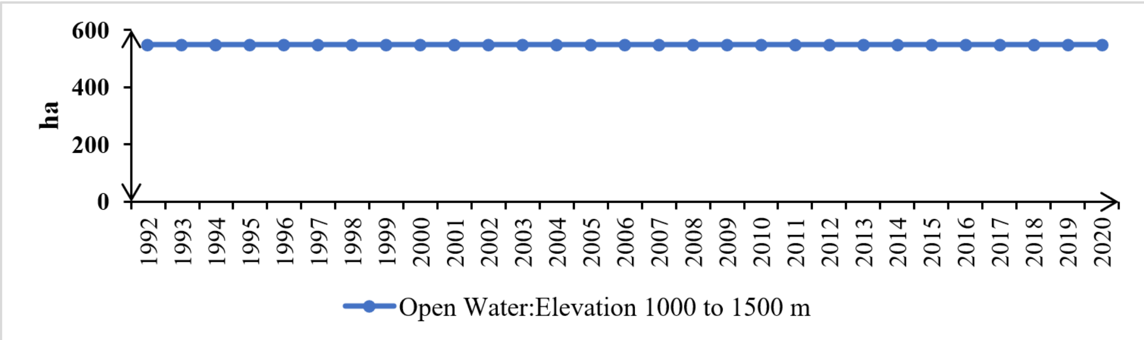

Figure 6. Development of the open water area in the different altitudes of Ziz watershed during the period 1992-2020.

Open water bodies are important ecosystems that provide various ecological functions, such as water storage, habitat for aquatic species, and flood control. They also provide important resources for local communities, such as water for irrigation and domestic use [55]. The stability of the Open Water category in the Ziz basin over time can be attributed to the natural characteristics of the water bodies, which are relatively resistant to changes in land use and climate. However, open water bodies in the region are also vulnerable to pollution, over-extraction, and other human activities that can lead to water quality degradation and loss of biodiversity [56]. In the Ziz basin, the open water bodies are mainly composed of rivers and streams, including the HAD, as well as the Ramsar sites of the Tafilalet oasis [57]. These water bodies are important for local communities and support a wide range of aquatic and terrestrial species [58]. To maintain and enhance the ecological and socio-economic functions of open water bodies in the Ziz basin, it is important to adopt sustainable water management practices that promote water conservation and pollution prevention, while supporting the livelihoods of local communities. These practices may include the establishment of water-use regulations, the promotion of water-saving technologies, and the adoption of wastewater treatment measures [59]. In conclusion, the Open Water category in the Ziz basin covers an area of 550 hectares and has remained stable over time. Sustainable water management practices are needed to prevent pollution and degradation, while promoting the conservation and sustainable use of open water bodies in the region.

3.2. Standardized Precipitation Index (SPI) Analysis

In the light of the analyses carried out at the climatological stations in the study area, the results indicate that the SPI values vary from one year to the next (Figure 7A).

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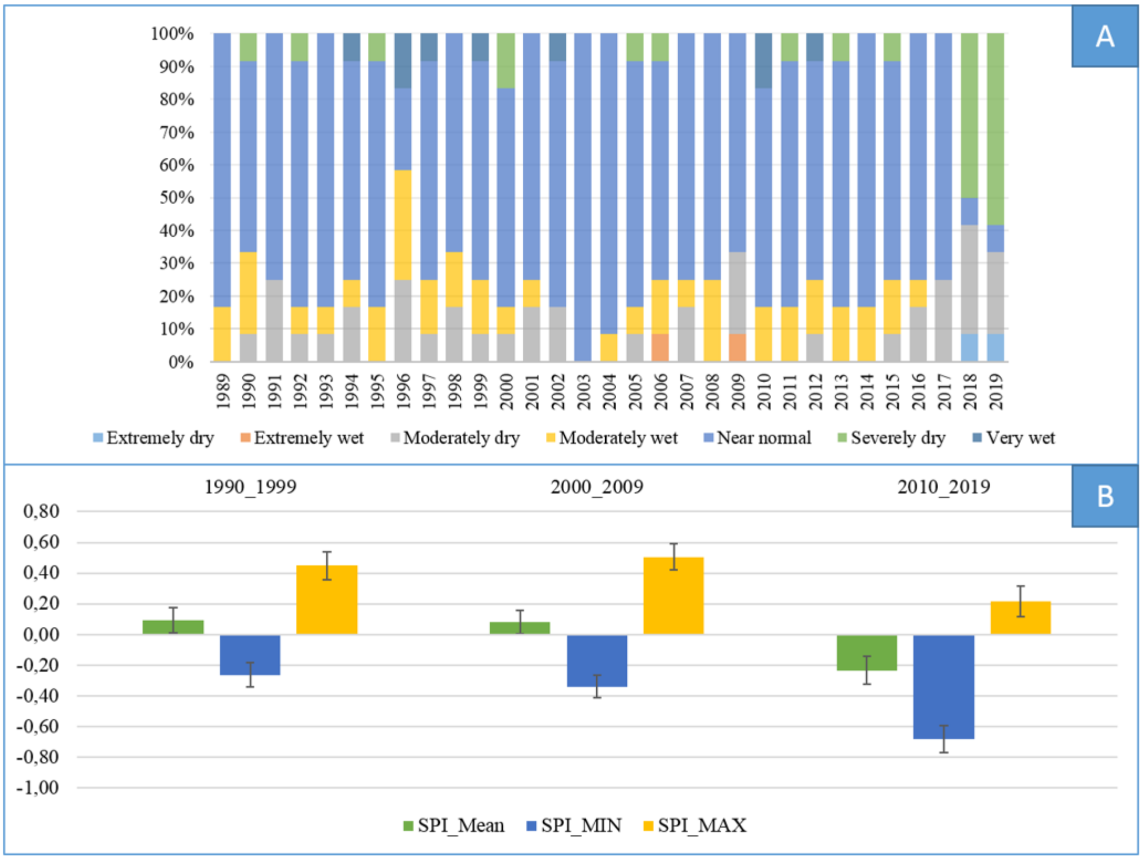

Figure 7. SPI change. **A**, Number of months for each SPI class for 30 years in Ziz watershed; **B**, SPI variation over the last three decades in Ziz watershed.

The Ziz Basin SPI is generally near normal from 1989 to 1995 with existence a restraint number of months moderately wet and moderately dry, then we notice a decrease of the months near normal and increase of the months moderately wet and appearance of the months very wet during the year 1996 (Figure 7A). From 1997 to 2017 the SPI was generally near normal, but we record the existence of severely dry months especially in the year 2000, 2005, and 2011. In 2018 and 2019, we clearly note that the climate was severely dry and mild moderately dry. Analyzing the values over three decades, we note that the value of the standardized precipitation index decreases over time during the three decades in Ziz watersheds (Figure 7B). The mean standard precipitation index decreased from 0.10 to -0.24 in the Ziz basin. From a seasonal point of view, in a Ziz basin we note that the months with an extremely dry climate are found in the spring and autumn at an equal rate (50%) and the months with an extremly wet climate are found in the spring and winter at an equal rate also 50% (Figure 8A). However, 40% of the months with a severely dry climate are in winter. The rest of the SPI classes are distributed during the seasons in somewhat varying proportions.

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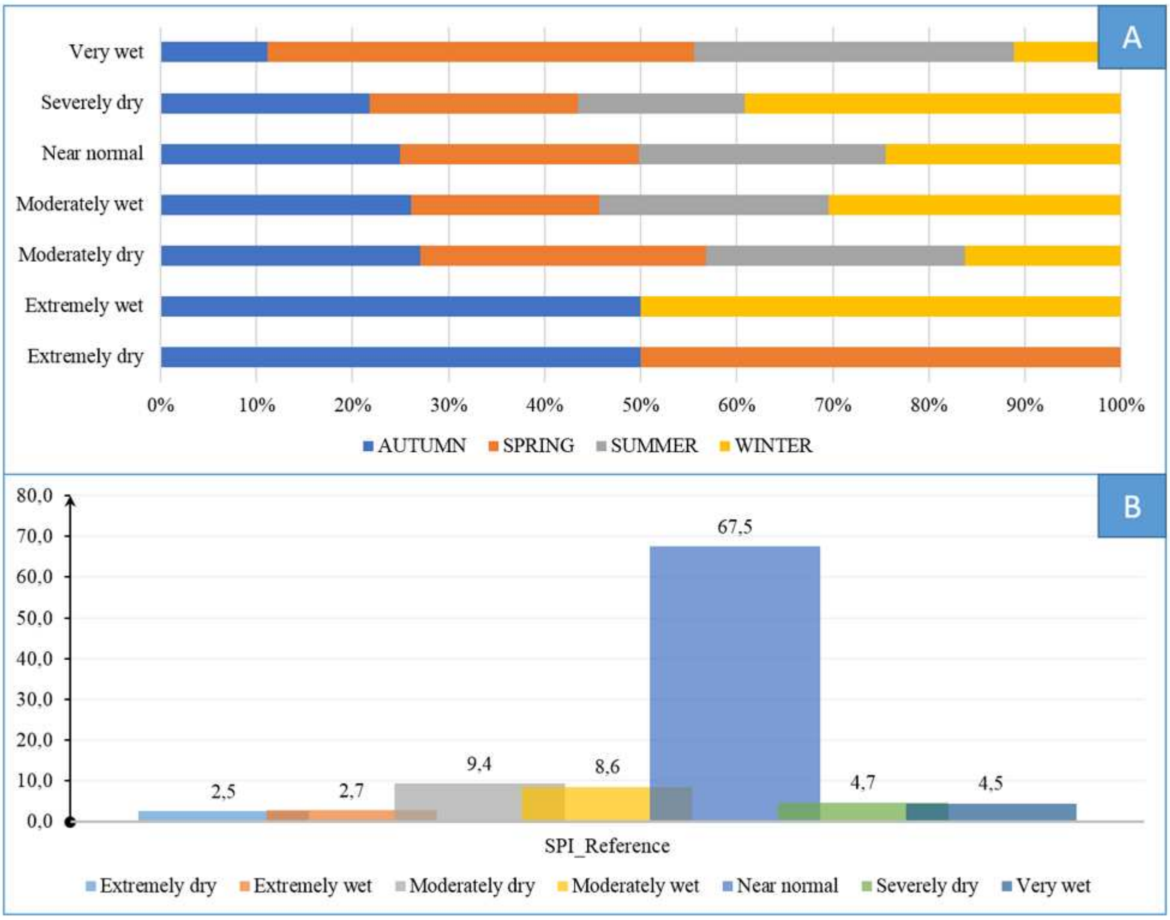

Figure 8. Percentage repartition of SPI by season in Ziz watershed (A) and years with drought/wetness categories Reference (B).

The calculation and analysis of the annual SPI at the Ziz basin level shows that normal years represent 67.5% of the study period (1948-2020), while dry years where total precipitation was below average represent 16% and vary according to intensity (Figure 8B). The extremely dry year was 1984, the most severe droughts are those of 1981, 1986, 2000-2001, 2013, 2017, 2020, and the years marked by a moderately dry climate are 1950, 1961, and 1983 (Figure 8B).

The percentage of wet years is around 15.8%, the years 1963 and 1972 were characterized by an extremely wet climate, while the years with a very wet character are 1949, 1976 and 1996. These findings conclude that the study area experienced dry weather conditions during the decades 1980, 2000 and 2010. This is consistent with the results of studies conducted by [60] on the Ziz Basin and by [8] on Morocco, and which have observed the presence of the same years of drought distributed with a different severity during the three decades mentioned above.

The distribution of months according to the SPI classes analyzed in the Ziz catchment, showed that the number of months characterized by a near normal climate is increased during the second decade D2 (from 79 to 92) then it decreased during D3 (72 months) (Table 4). Otherwise, the number of months marked by a severely dry climate is increased during D3 from 3 to 16 and there are extremely dry months appearing during D3 (months).

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Table 4. Number of Months for every SPI class over 3 decades in the Ziz catchment.

SPI (Mean/Watershed) ZIZ	D1 (1990_1999)	D2 (2000_2009)	D3 (2010_2019)
Extremely dry	0	0	2
Extremely wet	0	2	0
Moderately dry	12	11	14
Moderately wet	21	10	13
Near normal	79	92	72
Severely dry	3	4	16
Very wet	5	1	3

The Future SPI in the context of CC for Morocco was studied under the CMIP6 (Coupled Model Intercomparison Project Phase 6) scenario using the MPI-ESM1-2-LR model, with consideration of the SSP126, SSP245, SSP370 and SSP585 scenarios. These scenarios represent different possible pathways of future greenhouse gas emissions and socio-economic development (Figure 9). The SPI provides information on the severity and duration of precipitation deficits and help to inform water management and agricultural planning in the face of CC impacts. The results show a significant variation in the number of dry or wet months according to different CC scenarios in the Ziz basin. In the SSP126 scenario, there is a significant increase in the number of moderately wet months and a significant decrease in the number of moderately dry months. Extremely wet months have strongly increased while extremely dry months have slightly increased. However, for the SSP245 scenario, there is a significant increase in the number of moderately wet months and a significant decrease in the number of moderately dry months. Very wet months have strongly increased while extremely dry months have slightly decreased. In the SSP370 scenario, there is a decrease in the number of moderately wet months and an increase in the number of moderately dry months. Extremely dry months have slightly increased while extremely wet months have slightly decreased. In terms of SSP584 scenario, there is an increase in the number of moderately wet months and a decrease in the number of moderately dry months. Extremely dry months have slightly increased while extremely wet months have slightly decreased.

Overall, the SSP245 and SSP126 scenarios show a significant increase in the number of moderately wet months and a significant decrease in the number of moderately dry months, while the SSP370 scenario shows the opposite trend. The SSP584 scenario shows a slight increase in extremely dry months and a slight decrease in extremely wet months, while the SSP126 scenario shows a strong increase in extremely wet months. These trends vary according to the scenarios, and it is important to consider these results to better understand the potential impacts of climate change on the studied region.

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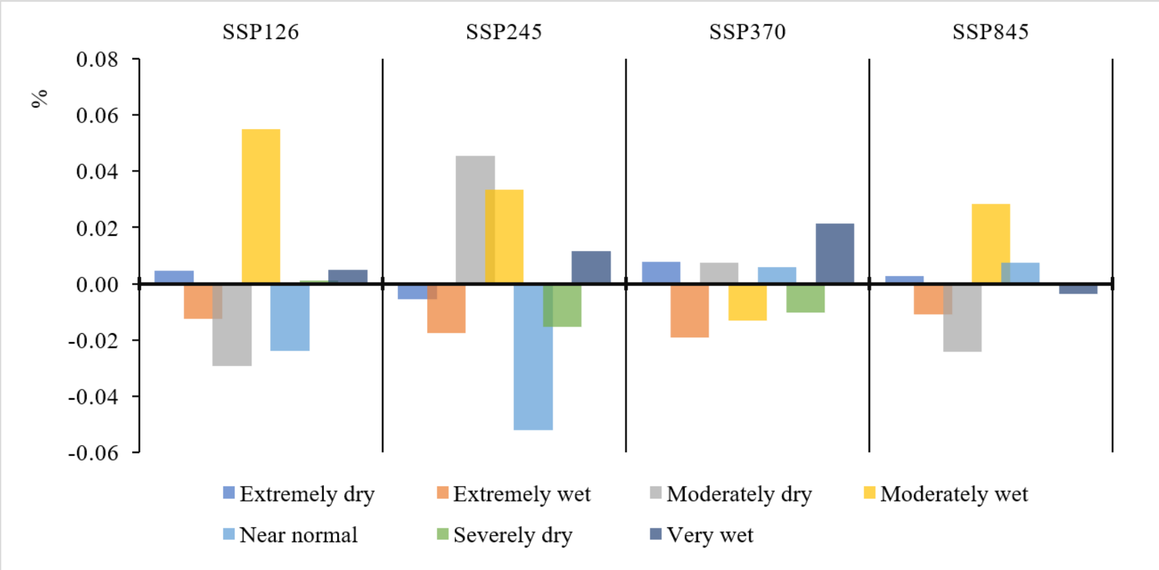

Figure 9. Percentage of years with the following drought/wetness categories.

3.3. Prediction Future for Precipitations and Temperature

The Intergovernmental Panel on Climate Change (IPCC) has developed five climate scenarios, known as Shared Socio-economic Pathways (SSPs), to gain better insights into possible future climate trends. These scenarios represent different levels of greenhouse gas (GHG) emissions: two scenarios with very low and low emissions (SSP119 and SSP126), one scenario with intermediate emissions (SSP245), and two scenarios with high and very high emissions (SSP370 and SSP585).

The analysis of precipitation scenarios in the study area, compared to reference years reveals a decrease in the percentage of precipitation by -13.5% in the case of SSP126 and up to -30% in the worst-case scenario, according to the pessimistic SSP585 (Figure 10A). This trend was also observed for each altitude range (Figure 10B), see also Figures A2 and A3. Several studies have demonstrated that Morocco is projected to experience dry years due to CC [61,62], as well as a precipitation deficit [63,64]. Based on the findings of this analysis, it is highly likely that the future of water in this oasis will be severely compromised.

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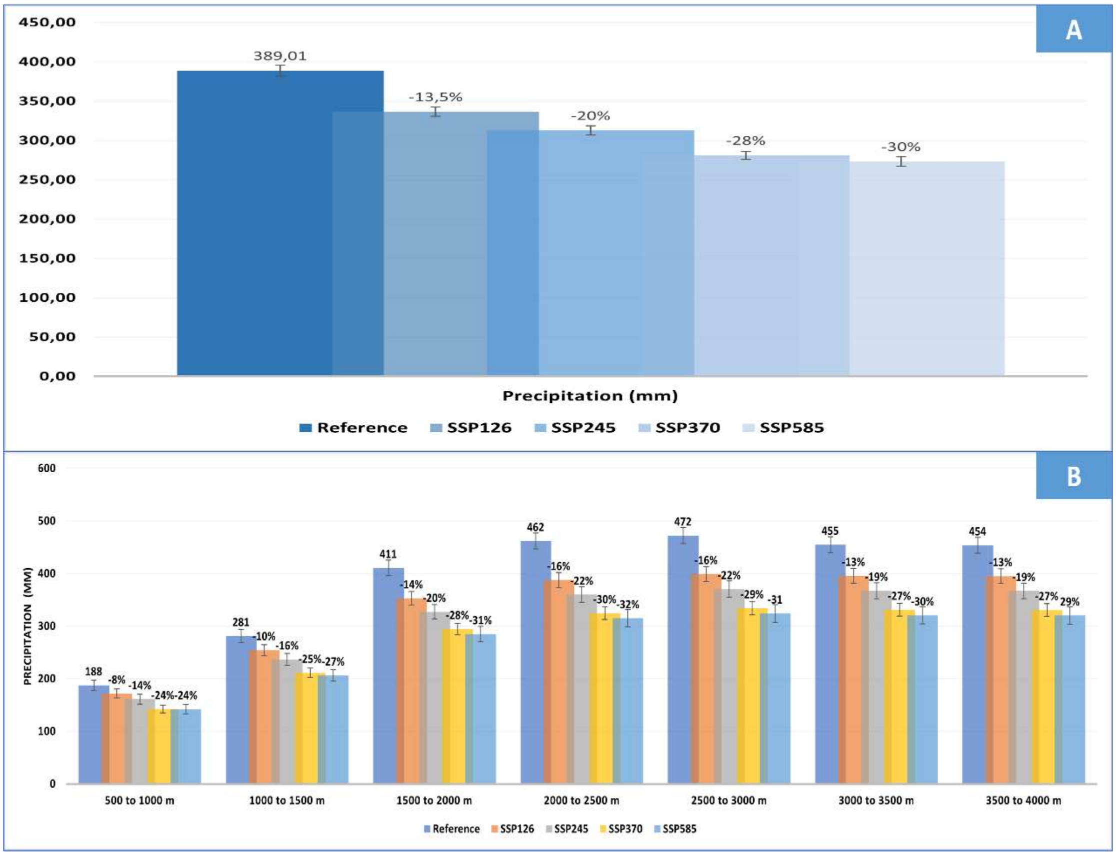

Figure 10. Precipitation development scenarios in the Ziz watershed compared to reference years for the whole period (**A**) and for each altitude range (**B**).

3.4. Correlation between SPI and SGI

To assess the relationship between the two hydrometeorological drought indices (SPI and SGI), a drought case analysis was performed on three groundwater monitoring wells in the HAD zone, two wells in the Foum Tillicht zone, and two wells in the Radier Erfoud zone, for a study period from 1989 to 2022. We calculated the correlation coefficient between SPIs weighted on the corresponding station for each well and SGIs, taking into account eight accumulation periods (1, 3, 6, 9, 12, 18, 24, and 48 months). Figure A4 compares the monthly variation of drought indices in the Middle Ziz zone, specifically for the HAD station, during the study period. The accumulation periods of 12, 18, 24, and 48 months were chosen because the highest correlations between SPI and SGI are found in these aggregation periods. The blue color indicates wet climatic conditions, while the red color indicates dry climatic conditions. The first part of the analyzed period from 1989 to 1996 was characterized by normal to wet climatic conditions with groundwater drought episodes observed in observation wells, particularly in 1990 in well 29/48 and in 1993 in well 39/48, as well as in 1992 and 1993 for well 1208/48. The period between 1997 and 2007 was marked by numerous drought events according to both indices throughout the study period. There is a high agreement on the timing and intensity of drought between SPI and SGI, particularly during the years 2001-2003 and 2005-2007, where distinct groundwater drought episodes appeared in observation wells, with their number varying from one well to another. After 2007 until 2012, groundwater levels returned to normal, with the climate being characterized by moderately to extremely wet conditions. The period between 2013 and 2015 was marked by extreme groundwater drought. Climatic droughts began in 2020 and extended beyond the period covered by this study.

For Tillicht station at the top of the Ziz watershed (Figure A5), and during most of the study period, normal to extremely wet conditions were maintained at the surface, but from 2020, a moderate drought episode began and continued beyond the period covered by this study. However, groundwater experienced distinct drought periods of different intensities and durations. Some periods were observed at the end of 1993, the end of 1994, and the end of 2000 for well 597/39, and in 2002 for both wells 597/39 and 599/37. Then, in 2005-2006, drought episodes were observed in wells 592/39 and 597/39, but the period marked by high intensity and duration is the period between 2013-2016, particularly in wells 592/39 and 599/39.

For Radier Erfoud station, the first year of the study period in 1989 was characterized by extreme groundwater droughts, followed by two periods of moderate to severe climatic drought, the first in 1993-1994 and the second in 1998-2007 (Figure A6). The latter having a high impact on piezometric levels in well 525/57, particularly from the end of 2003 to the end of 2006, and in well 448/57, during the end of 2003, then the beginning and end of 2005.

Groundwater levels returned to normal levels before the severe drought of 2014 at well 448/57. The last part of the analyzed period from 2022 was characterized by extreme climatic conditions during the accumulation periods of 3, 6, 9, and 12 months. The high correlation coefficients for most wells in the study area and specific accumulation periods (6, 9, 12, 18, 24, and 48 months) indicate that precipitation has a clear impact on groundwater indicators, which is consistent with other recent studies [37,40,65,66]. These results can help water managers better understand the effects of CC on groundwater resources and develop adaptive management strategies to mitigate the potential impacts of drought events on water supply and quality.

It should be noted, however, that the relationship between precipitation and groundwater levels can be complex and can be influenced by a variety of factors such as geology, soil properties, land use, and groundwater recharge rates. Therefore, it is important to consider these factors when interpreting the results of drought analyses and developing management strategies for groundwater resources.

In addition to the SGI and SPI indices, other indices such as the Standardized Precipitation Evapotranspiration Index (SPEI) and the Standardized Runoff Index (SRI) can also be used to assess the impacts of climate variability and change on water resources. These indices take into account not only precipitation but also evapotranspiration and runoff, which can provide a more comprehensive picture of the hydrological cycle and its response to climatic variability. Overall, the use of standardized drought indices can provide valuable information for water resources management and planning, particularly in areas where groundwater resources are vulnerable to CC and variability. However, it is important to use these indices in conjunction with other hydrological and geological data to fully understand the complex interactions between climate and groundwater resources.

Table 5 shows Pearson correlation coefficients between the Standardized Precipitation Index (SPI) and groundwater levels at different monitoring stations in the region.

Table 5. The statistical associations between SGI values and SPI using Pearson Correlations.

		PEARSON CORRELATIONS							
STATION	**Well**	**SPI 1**	**SPI 3**	**SPI 6**	**SPI 9**	**SPI 12**	**SPI 18**	**SPI 24**	**SPI 48**
HAD	SGI29/48					,280*	,429**	,504**	
	SGI39/48						,316**	,463**	
	SGI120848							,312**	,315**
Foum Tillicht	SGI597/39			,183*	,222**	,223*			-,548**
	SGI592/39			,173*	,219**	,242**	,203*	,187*	
Radier Erfoud	SGI525/57					,217**	,326**	,393**	,719**
	SGI448/57		-,234*	-,326**	-,319**	-,237*			,310*
**. correlation is significant at the 0.01 level (2-tailed).									
*. correlation is significant at the 0.05 level (2-tailed).									

The correlations are significant at different levels of significance (0.01 and 0.05) and can be interpreted as follows:

- At the HAD station, there are significant positive correlations between groundwater levels and SPI for SPI 9, 12, 18, and 24. The highest correlation coefficients are observed for SPI 6 and 9,

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with coefficients of 0.504 and 0.429, respectively. This indicates that groundwater levels at this station are significantly influenced by precipitation patterns over the past 6 to 24 months.

- At the Foum Tillicht station, there are significant negative correlations between groundwater levels and SPI for SPI 48. This indicates that groundwater levels at this station are significantly influenced by precipitation patterns over the past 48 months, with lower groundwater levels observed after periods of drought.
- At the Radier Erfoud station, there are significant positive correlations between groundwater levels and SPI for SPI 12, 18, and 24. There is also a significant negative correlation between groundwater levels and SPI for SPI 48. This indicates that groundwater levels at this station are significantly influenced by precipitation patterns over the past 12 to 48 months.

Overall, the results suggest that there is a significant relationship between groundwater levels and precipitation patterns at different time scales, with longer-term precipitation patterns (e.g. SPI 48) having a stronger influence on groundwater levels than shorter-term patterns (e.g. SPI 6). These findings can be useful for improving water management strategies in the region, particularly during periods of drought.

The results of the correlation analysis between the SPI and groundwater levels index (SGI) at different monitoring stations in the region are consistent with previous studies that have shown a significant relationship between precipitation patterns and groundwater recharge. According to Srinivasan et al. [67], the SPI has been widely used as a tool for drought monitoring and prediction and has been shown to be a reliable indicator of groundwater recharge in arid and semi-arid regions. Similarly, Zhang et al. [68] reported significant correlations between groundwater levels and SPI at different time scales in the North China Plain, with longer-term SPI values having a stronger influence on groundwater levels than shorter-term values.

The positive correlations between groundwater levels and SPI at the HAD and Radier Erfoud stations are consistent with the findings of previous studies that have shown a positive relationship between precipitation and groundwater recharge. According to Scanlon et al. [69], groundwater recharge in arid and semi-arid regions is primarily dependent on precipitation, with a lag time between precipitation events and the response of groundwater levels. The negative correlation between groundwater levels and SPI at the Foum Tillicht station for SPI 48 is also consistent with previous studies that have shown that longer-term droughts can have a significant impact on groundwater recharge [67].

The results of this study have important implications for water management in the region, particularly during periods of drought. The use of SPI-based drought indices can help water managers to identify areas that are vulnerable to drought and to develop appropriate mitigation strategies. Similarly, Zhang et al.[68] suggested that the use of SPI-based groundwater recharge models can help to improve water management strategies in regions where groundwater is a primary source of water supply.

The analysis of the SPI during the study period showed a slight trend towards an increase in dry months and especially in the last decade, these results are consistent with other studies that have been done on Morocco and the Tafilalet region. According to the Ministry of Energy, Mines and the Environment [70], the vulnerability analysis has shown that the impact of CC is estimated at a 25% decrease in water resources, integrating the effect of the droughts experienced in Morocco since the 1980s. The decrease in precipitation over most of the national territory can reach 5% to 40% for the 2080s and 40% to 60% for 2080s [71,72]. Drought and precipitation of less than 100 mm are characteristic of southern and southeastern Morocco [73].

The last two years of the study period (2018-2019) are known for their harsh climate: 7 months severely dry (-1.5 > SPI, SGI > -2) and 4 months moderately dry (-1 > SPI, SGI > -1.5). This is in line with the reports of the [74], on the 2018-2019 agricultural campaign which was characterized by relatively unfavorable climatic conditions. The average accumulation of precipitation from the main stations in the recorded area was 80 mm.

It is certain that the lack of precipitation with the dependence of groundwater resources leads to a decrease of the piezometric levels, which is illustrated by the results of this study, and consequently of this decrease, the study area experienced a dry-up of wells and khattaras, the number of wells

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decreased by half [75]. Also due to the drought in recent years, the HAD in the Ziz Basin has seen a decline year over year [76,77].

The vision of the State to value the oases, improve them and develop the phoeniciciole sector by producing varieties of high quality under national and international demand, Given the vulnerability of water resources in the Tafilalet region and the water deficit for irrigation, which will decline to -419 million m3 by 2030 [17], plans and policies need to be developed to improve adaptive capacity in south-western oases.is of Morocco.

Climate Change Scenarios Adapted to the Moroccan Context and Arid and Saharan Zones

Climate change is a global phenomenon that has already had a significant impact on various sectors, including agriculture, water resources, and human health. The situation is particularly challenging in Morocco, a country that is already prone to droughts and water scarcity. Therefore, it is essential to develop CC scenarios that are specific to the Moroccan context and are adapted to the arid and Saharan zones. The Moroccan gov-ernment has been actively involved in CC adaptation efforts and has developed a nation-al strategy to mitigate the impacts of CC, which includes the identification of priority sec-tors, such as water resources, agriculture, and health, and the development of adaptation measures specific to each sector. One of the most critical steps in CC adaptation is the de-velopment of CC scenarios that can provide information on possible future climate con-ditions. These scenarios are developed based on climate models that simulate how the climate will change in response to various factors, such as greenhouse gas emissions. Several studies have developed CC scenarios for Morocco, considering the specificities of the country's climate and geography [78–80].

To develop effective adaptation measures, it is essential to consider not only the projected changes in temperature and precipitation but also their impacts on various sectors. For example, in the agriculture sector, changes in temperature and precipitation can affect crop yields, soil moisture, and pest and disease dynamics. Therefore, adaptation measures such as crop diversification, water-efficient irrigation systems, and pest management strategies need to be developed and implemented.

In conclusion, CC is a significant challenge for Morocco, particularly in the arid and Sa-haran zones. CC scenarios are essential for developing effective adaptation measures and should be used to inform decision-making processes and guide the development of sec-tor-specific adaptation measures.

Climate projections in the Ziz Watershed: Impacts and Adaptation Strategies

The Ziz Watershed, is an important agricultural area that produces a variety of crops, including dates, citrus fruits, and vegetables. However, this region is also prone to water scarcity, which is expected to be exacerbated by CC. In this article, we review recent climate projections for the Ziz Watershed and discuss potential impacts on water resources, agriculture, and ecosystems. We also highlight potential adaptation strategies that could help mitigate the impacts of CC in the region.

According to recent climate models, the Ziz Watershed is expected to experience a decrease in precipitation and an increase in temperature over the coming decades [81]. These changes could have significant impacts on the water resources of the region, as well as on agricultural production and biodiversity [82]. For example, the decrease in precipitation could lead to a reduction in surface water flows, which could negatively impact the region's ecosystems and agricultural productivity.

To adapt to these changes, several strategies could be implemented in the region. One potential approach is to increase the efficiency of irrigation systems and promote the use of drought-resistant crops [83,84]. Another strategy is to encourage the adoption of soil conservation practices, such as conservation tillage and cover cropping, which can improve soil health and increase water retention [85,86].

Overall, the impacts of CC in the Ziz Watershed are expected to be significant, and adaptation strategies will be necessary to help mitigate these impacts. By implementing sustainable water management practices and promoting the use of drought-resistant crops, the region could potentially maintain its agricultural productivity and protect its ecosystems in the face of a changing climate.

Land Use Change in the Ziz Watershed

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Land use change is a major driver of environmental change in many regions around the world. The Ziz watershed has undergone significant changes in land use over the past few decades, with implications for the region's ecology, hydrology and socioeconomic development. This article reviews the current state of knowledge about land use change in the Ziz watershed and discusses the implications of these changes for the region's sustainability and resilience.

The Ziz watershed is an arid and semi-arid region, with a hot and dry climate and limited rainfall. Historically, the region was characterized by pastoralism and rain-fed agriculture, with small-scale irrigation systems developed along the river's course. However, since the 1960s, the region has undergone significant changes in land use, with a shift towards large-scale irrigated agriculture, particularly the cultivation of date palms. This shift has been driven by government policies to promote agricultural development and has been facilitated by the construction of large-scale dams and irrigation systems.

The expansion of irrigated agriculture has had significant impacts on the region's ecology and hydrology. The conversion of natural vegetation to cropland has reduced the region's biodiversity, and increased soil erosion and sedimentation in the river. The construction of dams has also disrupted the natural flow of the river, leading to changes in water quality and quantity, and the displacement of communities living along the river's course.

The impacts of land use change on the Ziz watershed are not limited to the region's ecology and hydrology. The shift towards large-scale agriculture has also had significant socioeconomic implications, particularly for small-scale farmers and pastoralists who have been displaced by large-scale irrigation schemes. The expansion of date palm plantations has also led to labor shortages, as the cultivation of date palms requires significant manual labor.

To address these challenges, there is a need for integrated land use planning that balances the demands of agriculture with the need to protect the region's ecology and hydrology. This requires a participatory approach that engages all stakeholders, particularly small-scale farmers and pastoralists who are often marginalized in decision-making processes. It also requires the development of alternative livelihoods, particularly in sectors such as tourism and renewable energy, that can provide sustainable economic opportunities for communities in the region.

The land use change in the Ziz River Basin has significant consequences for the environment and the people living in the area. The causes of land use change include agricultural expansion, urbanization, tourism development, and the increase in the demand for wood and charcoal. The consequences of land use change include the loss of natural habitats, soil erosion, and increased pollution. The future implications of land use change include CC, water scarcity, and reduced soil productivity. The implementation of sustainable land use practices is necessary to mitigate these effects and ensure a better future for the Ziz River Basin.

The CMIP6_MPI-ESM1-2-LR_SSP model is one of the latest climate models developed for use in the IPCC Sixth Assessment Report. It is a coupled Earth system model that includes components for the atmosphere, land surface, ocean, and sea ice. This model is designed to simulate future climate scenarios under the Shared Socioeconomic Pathways (SSPs), which are a set of plausible futures that consider different levels of greenhouse gas emissions and societal responses. According to the study by [87], the CMIP6_MPI-ESM1-2-LR_SSP model has shown improvements in simulating key climate features such as the global temperature, sea level rise, and extreme events compared to its predecessor, the CMIP5 models. It has been used also in various studies, such as the assessment of future water availability in the Nile River Basin under different climate scenarios [88] and the projection of future precipitation changes in the Sahel region [89]. These studies demonstrate the potential of the CMIP6_MPI-ESM1-2-LR_SSP model for informing decision-making processes and developing climate adaptation strategies. This model is a state-of-the-art global climate model that can provide useful insights into the CC projections for Morocco. This model takes into account a wide range of factors such as atmospheric carbon dioxide concentration, land use change, and anthropogenic emissions to simulate future climate scenarios. One of the key strengths of this model is its ability to provide information on regional climate patterns, which is essential for countries like Morocco that are highly vulnerable to CC. In particular, the SSP scenarios provide a useful framework for assessing the impacts of different levels of greenhouse gas emissions on future climate outcomes. The CMIP6_MPI-ESM1-2-LR_SSP model can be a valuable tool for assessing the potential impacts of CC on the water resources of the Ziz basin, as well as for informing strategies to adapt to future changes in the region.

The CMIP6_MPI-ESM1-2-LR_SSP model is designed to provide climate projections for the North African region, including Morocco. It has been validated for the region, and the results show good agreement with observed data. The model has been used to project future climate conditions in Morocco under different scenarios.

According to the CMIP6_MPI-ESM1-2-LR_SSP model, the temperature in Morocco is projected to increase in the future, with the magnitude of the increase depending on the scenario. Under the SSP1-2.6 scenario, the temperature is projected to increase by 1.1°C by the mid-century (2041-2060) and by 2.2°C by the end of the century (2081-2100), relative to the reference period (1986-2005). Under the SSP5-8.5 scenario, the temperature is projected to increase by 2.5°C by mid-century and by 5.5°C by the end of the century.

The model also projects changes in precipitation in Morocco. Under the SSP1-2.6 scenario, there is a slight increase in precipitation in some parts of Morocco, while other areas experience a decrease in precipitation. Under the SSP5-8.5 scenario, most parts of Morocco are projected to experience a decrease in precipitation.

Morocco has adopted several programs and plans aimed at improving the agricultural sector and rationalizing irrigation water consumption, such as the "Green Morocco Plan". But encourage investors to undertake large-scale agricultural projects (phoeniciculture...) in Tafilalet, for example, it leads to an increase in well drilling and water pumping for irrigation resulting in depletion of water stocks. Therefore, governance and concerted efforts must be improved for a good management of water resources to ensure sustainable development and benefit for future generations.

4. Conclusions

Climate change (CC) and a protracted drought have had a significant impact on Morocco's water supplies, especially in the pre-Saharan region. The Tafilalet region is becoming more and more subject to challenges in this area, including rapid population growth, rising water demand, excessive groundwater use, and rising agricultural investment.

To assess land cover and elevation and to monitor and track hydroclimate drought conditions in the Ziz watershed from 1989 to 2022, three tools were used namely the WEAP model, the SPI, and the SGI. The findings show a decrease in precipitation over time, especially in the last decade (2010-2020), with the last four years (2019-2022) being the most challenging in terms of drought during the study period (SPI<-2). The relationship between SPI and SGI indicates a high correlation for most wells in the study area and specific accumulation periods, suggesting that precipitation has a clear impact on groundwater indicators. Future scenarios suggest that the study area is at high risk of CC, with the optimistic scenario SSP126 showing a decrease in annual precipitation accumulation of up to 30% by 2100. However, the minimum temperature is expected to increase by 1.08°C according to SSP126 and by 2.61°C according to SSP585, while the maximum temperature is expected to increase by 1.05°C according to SSP126 and by 2.93°C according to SSP585.

Author Contributions: S.B.S. and A.B.S. contributed to the study conception, design, and data collection and analyses. A.B.S., A.K. and M.Y.K., supervised the study. S.B.S., A.B.S. and A.K. drafted the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

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Conflicts of Interest: The authors declare that they have no financial or non-financial competing interests.

Appendix A

Table A1. Geographic coordinates of climatic stations and basins of study area (ABHZGR, 2022).

Basin	Station	Oued	X (m)	Y (m)	S (Km²)	Perimeter (Km)	Thalweg (Km)	K Compacite	Average Altitude (m)	Average Slope (%)
Ziz	Zaouia	Sidi Hamza	564 412	204 407	102	45	17	2,93	2 238	18,68
	Tillicht	Sidi Hamza	579 979	192 269	1309	199	55	2,46	1 899	10,76
	M'zizel	Ziz	560 057	185 134	1190	201	92	7,21	2 112	14,71
	Zaâbel	Ziz	597 400	174 478	4012	404	152	5,86	1 839	11,07
	HA Dam	Ziz	615 284	103 868	4417	560	183	7,6	1 808	11,12
	Erfoud	Ziz	615 284	103 869	8106	662	262	8,48	1 482	7,55
	Taouz	Ziz	632 334	36 133	13480	939	365	10,42	1 247	5,48

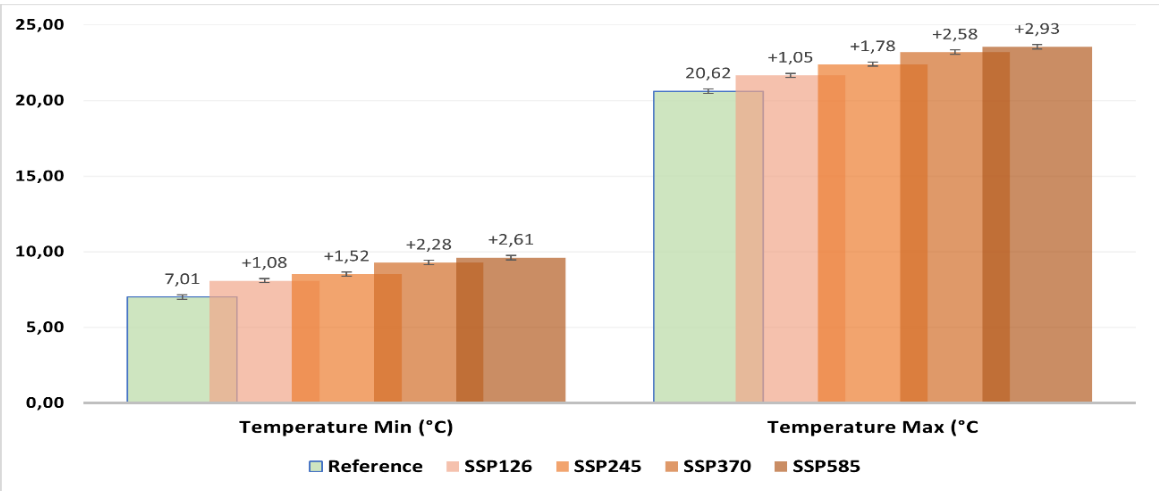

Figure A2. Development scenarios of minimum and maximum temperatures in the Ziz watershed compared to reference years.

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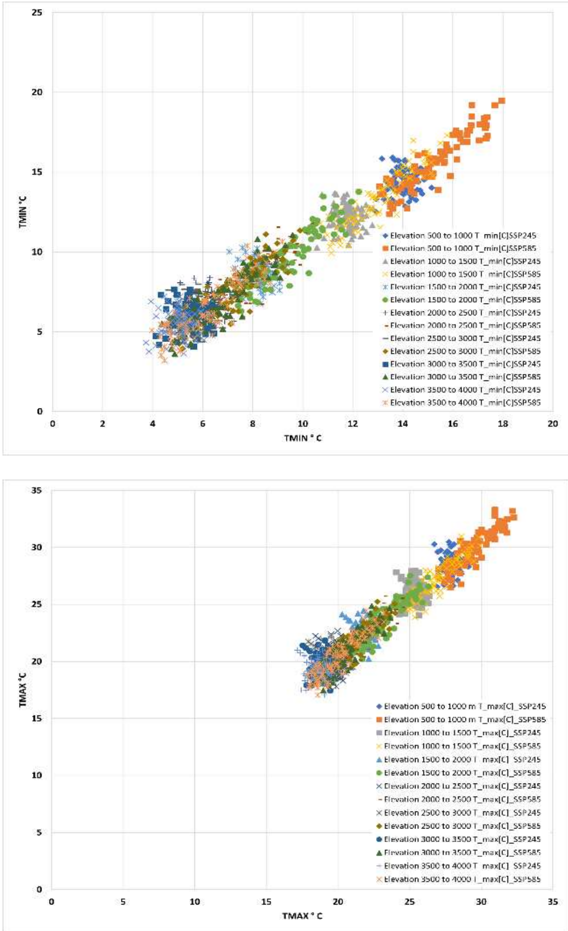

Figure A3. Development scenarios of minimum and maximum temperatures in Ziz watershed compared to reference years for each altitude range.

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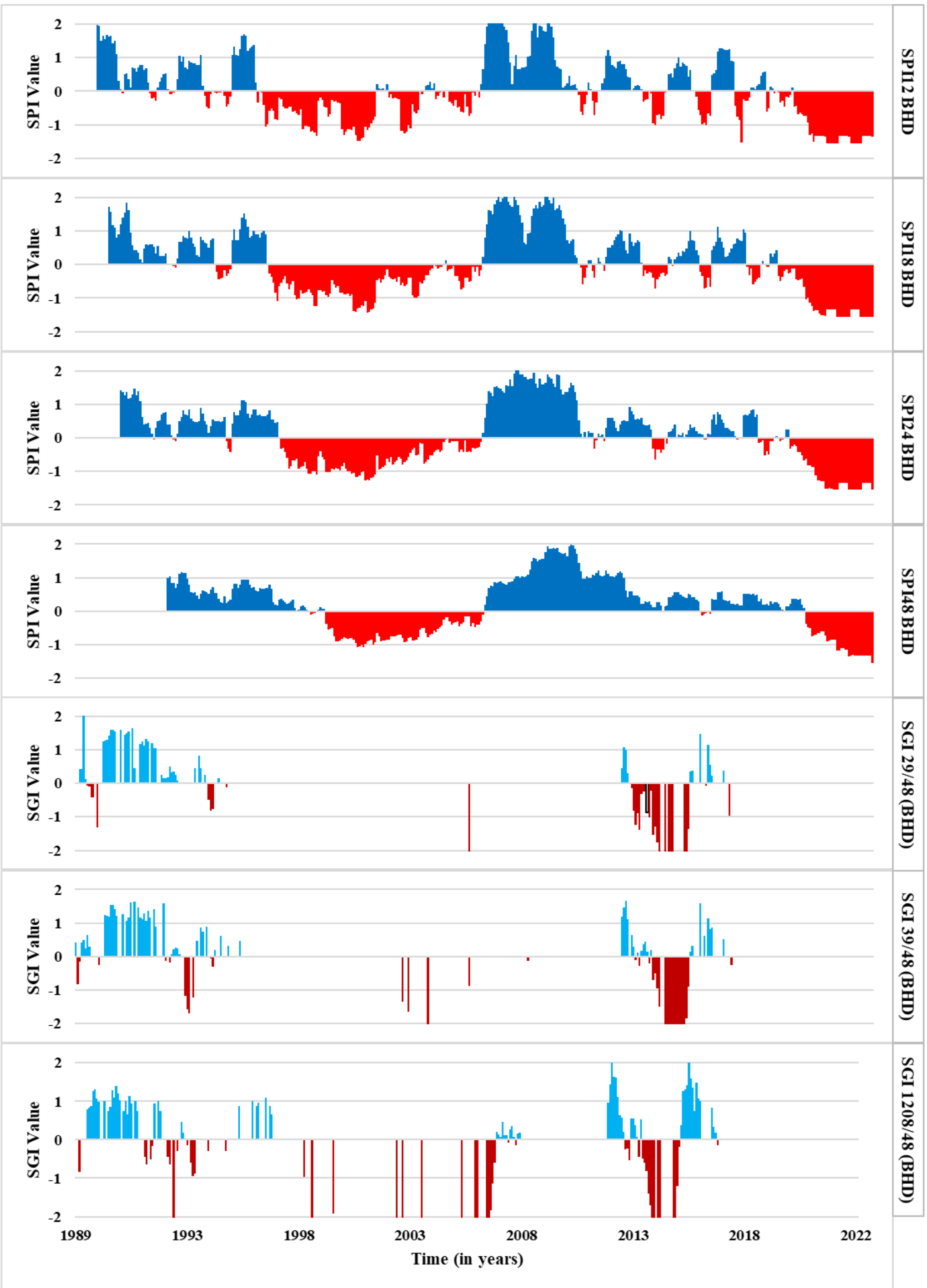

Figure A4. Chronological series of monthly drought index values with accumulation periods of 12, 18, 24, and 48 months in the Hassan Addakhil Dam zone for three groundwater monitoring wells during the period 1989-2022.

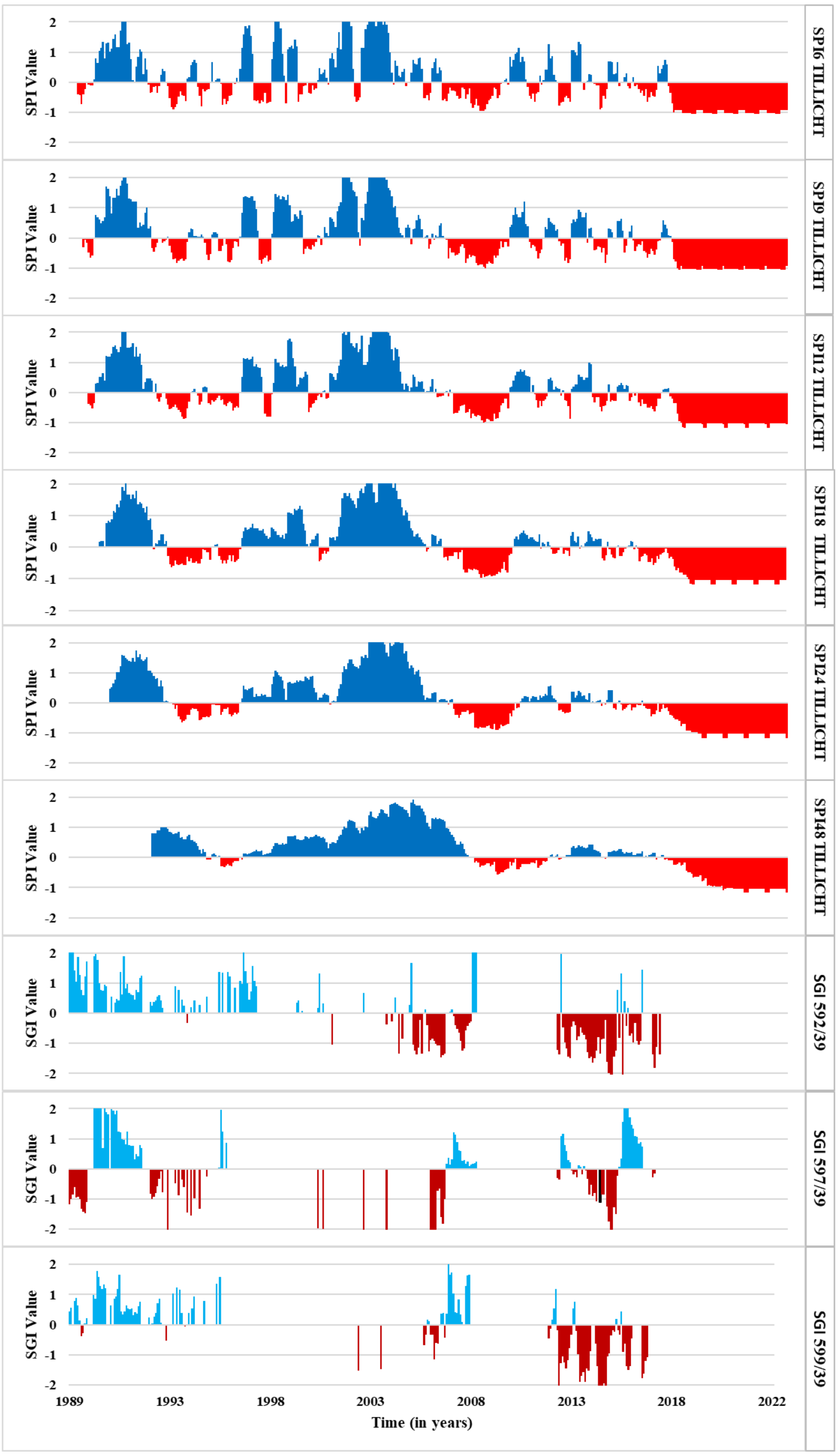

Figure A5. Chronological series of monthly drought index values with accumulation periods of 6, 9, 12, 18, 24, and 48 months for two groundwater monitoring wells in the Foum Tillicht zone during the period 1989-2022.

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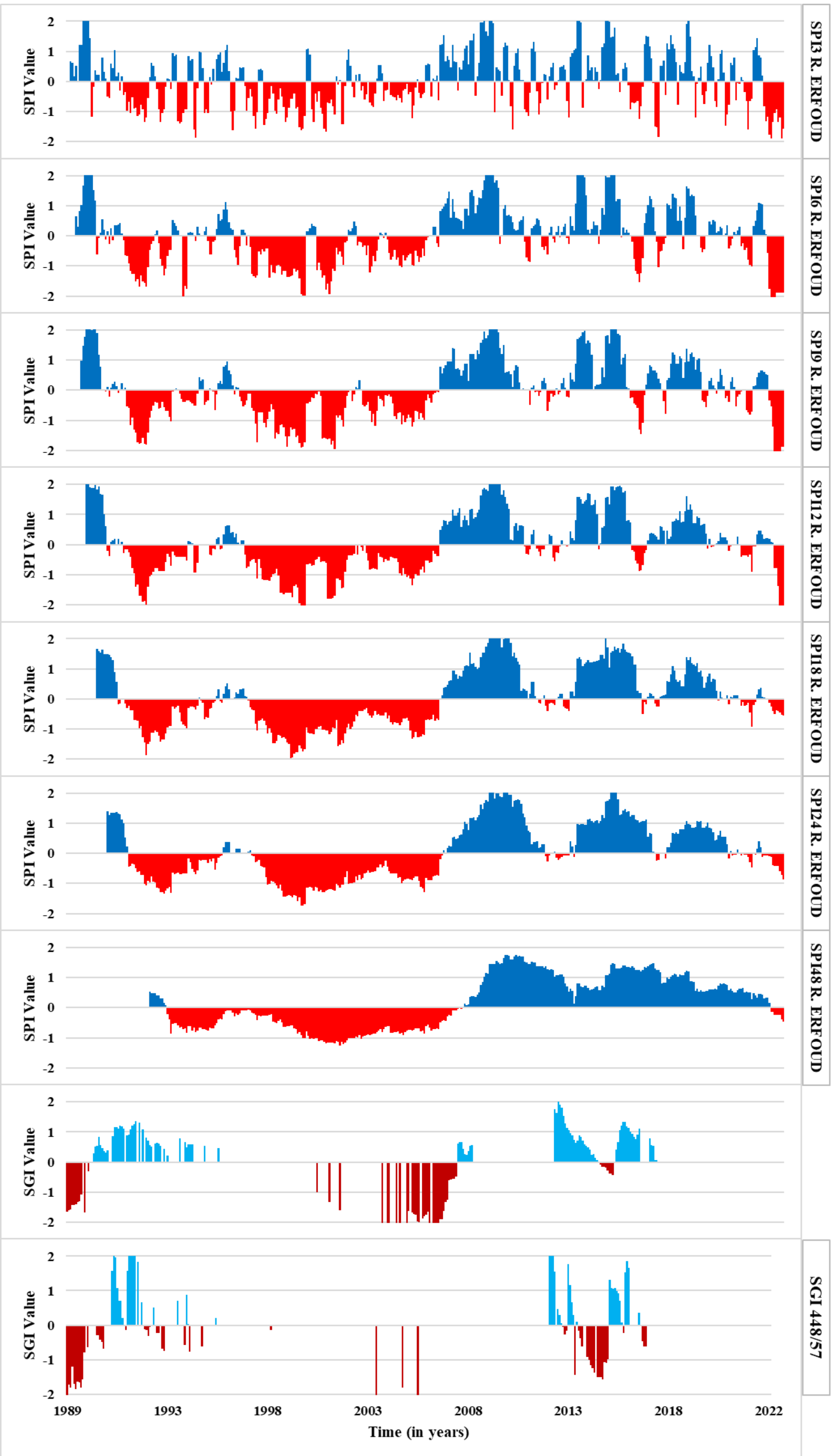

Figure A6. Chronological series of monthly drought index values with accumulation periods of 3, 6, 9, 12, 18, 24, and 48 months for two groundwater monitoring wells in the Radier Erfoud zone during the period 1989-2022. The accumulation periods were chosen based on correlations between the SPI and SGI indices for the two wells.

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