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Assessment of the long-term effects of climate on vegetation in 25 watersheds in dry and semi-dry areas, Algeria

Hadjer Keria[1] · Ettayib Bensaci[2] · Asma Zoubiri[2]

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Abstract
It is necessary to understand vegetation evolution and its sensitivity to the global climate, particularly with regard to ecosystems and environmental balance. 25 watersheds were selected in Algeria for this study. Here, the vegetation index (NDVI) and climatic variables (precipitation and temperature) were used to verify the temporal-spatial patterns and impact of the time difference from 1981 to 2021 by applying the correlation coefficient and time delay analysis. The NDVI showed a significant decline, especially in recent years, and spatial differences in NDVI in all areas of study were narrow (slope values from 0.0005 to 0.04), decrease in surface water area from year to year was observed in all regions. The vegetation index was negatively associated with low rainfall and high temperatures. The vegetation's reaction to temperature has been greater than that too rainfall. In general, a time lag in the vegetation response was found over a time period of at least 1 month. This study provided new insights into variations in vegetation change and the importance of vegetation recovery.

Keywords Climatic factors · NDVI · Vegetation dynamic · Correlation · Algeria

1 Introduction

Climate change stands as a pivotal force shaping vegetation transformation, a critical component in environmental equilibrium. Consequently, investigating these impacts has emerged as a paramount global challenge (Zhang et al. 2013; Liu et al. 2019). Conversely, anthropogenic environmental activities play a significant role in altering vegetation dynamics (Wang et al. 2015). Moreover, shifts in long-term environmental conditions are poised to yield profound ramifications for extant plant diversity patterns, particularly amidst escalating global warming (Wang et al. 2020a). Broadly, the effects

✉ Hadjer Keria
hadjer.keria@univ-msila.dz

[1] Laboratory of Biodiversity and Biotechnological Techniques for the Valorisation of Plant Resources (BBT_VPR), Department of Natural and Life Sciences, University of Mohamed Boudiaf, M'sila 28000, Algeria

[2] Department of Natural and Life Sciences, University of Mohamed Boudiaf, M'sila 28000, Algeria

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of temperature and rainfall are already discernible in natural systems, with the magnitude of these impacts varying across different regions (Wang et al. 2020b).

In the forthcoming decades, climate change is poised to induce notable alterations in wind patterns, temperature, and ecological conditions, consequently precipitating a significant shift in the dynamics of sandy desert environments. Such changes could potentially foster the expansion of vast sandy desert areas across the Earth's surface. Understanding the behavior of vegetation and its impact on ecosystems in the context of global warming is imperative for accurately forecasting ecosystem dynamics and devising effective strategies to mitigate wind-induced soil erosion (Parteli 2022). Vegetation plays a pivotal role in preserving and assessing ecosystems (Zhou et al. 2014; Eisavi et al. 2015), with numerous studies focusing on diverse aspects such as assessing CO_2 levels and their influence on vegetation greenness (Liu et al. 2022), evaluating drought severity in watershed regions (Zhan et al. 2022), and analyzing the effects of temporal lag (Ding et al. 2020; Qin et al. 2023). These ongoing changes exhibit a long-term, irreversible trend that has been unfolding over time, necessitating comprehensive studies on temporal and spatial variations to monitor natural transformations (Seddon et al. 2016; Liu et al. 2017; Zhao et al. 2020). Furthermore, the Normalized Difference Vegetation Index (NDVI) serves as a reliable benchmark for studying these changes (Myneni et al. 2002).

Within the climate system, precipitation and temperature stand as pivotal determinants of plant growth across various regions (Martiny et al. 2006). However, this system's perturbations disrupt the natural balance of ecosystems and hasten environmental degradation through processes such as desertification and other ecological challenges (Islam et al. 2021). Numerous studies have highlighted temporal disparities between vegetation and climate indicators, as well as the diverse impacts of time lags resulting from extreme weather events on vegetation growth in different locales (Xu et al. 2014; Liu and Lei 2015; Li et al. 2018; Luo et al. 2020). Examining this relationship on a monthly scale, in contrast to long-term investigations, can enhance understanding of the factors constraining vegetation development (Luo et al. 2020). While investigating concurrent associations can aid in mitigating the impacts of climate variability, it may not fully capture the processes through which plants respond to environmental stimuli (Vicente-Serrano et al. 2013; Pan et al. 2018; Zhang et al. 2020).

Comprehending the response of vegetation to climate conditions over time stands as a significant and pressing challenge, particularly amidst the conditions and alterations brought about by the increasingly extreme global climate (Jong et al. 2013). Temporal gaps further complicate this task (Wu et al. 2015). This reveals a complex spatial response of these landscapes to climate factors, which vary depending on the type of vegetation present (Ding et al. 2020).

In this context, our primary objective is to assess the impact of climate on the long-term dynamics of vegetation, spanning the period from 1981 to 2021. Leveraging remote sensing data and meteorological data, we focused on 25 distinct regions across Algeria. The specific aims of this research are as follows: (1) To delineate spatial alterations in vegetation indices over 40 years across the 25 different regions of Algeria; (2) To investigate the temporal relationship between the NDVI index and climate parameters; (3) To utilize the Normalized Difference Vegetation Index (NDVI) to analyze the effects of climatic variations on vegetation growth, identifying both widespread independent effects and common impacts of such changes; and (4) To ascertain the enduring effects of temporal delays on vegetation dynamics.

2 Materials and methods

2.1 Study area

The study area is situated in northern Africa, covering a total expanse of 2,381,741 km^2. It stretches 1200 km from east to west along the Mediterranean Sea and nearly 2000 km from north to south. Algeria's northern region is characterized by a Mediterranean climate featuring hot summers and relatively mild, rainy winters. In contrast, the southern regions endure a climate of hot summers and cold winters, with scant rainfall on the high plains south of the Atlas Mountains. With the Sahara Desert enveloping 80% of the nation, summer temperatures can soar to extreme levels, while winter temperatures typically remain warm during the day and cold at night, occasionally dropping as low as 5 °C. The study encompasses a diverse array of wetlands, each with unique hydrological characteristics. Table 1 presents details of the physical attributes of these basins, including average rainfall and annual temperatures. Prominent sites include Makta Marsh, Greater Sabha, Lake Tilamine, Arzew Salt, Boughezoul Dam, Chott Zehrez Chergui, Chot Ech Chergue, Dayet El Ferd, Chutt Zehres Gharbi, and Chott El Hodna, all classified as semi-arid. However, distinct hydrological disparities distinguish areas such as Shut Chott Melghir, Beni Bahdel Dam, Bougara Dam, Bouhanifia Dam, Chorfa Dam, Cheliff Dam, Dahmoni Dam, Gargar Dam, Karrada Dam, Ksob Dam, and Sarno Dam. Despite their semi-arid classification, these sloping basins present specific challenges in water management. Furthermore, the study area encompasses arid environments such as Chott Marouane and Chott Ain El Beida, characterized by irregular hydrology. Notably, Chott Marouane is acknowledged as a crucial habitat for birds and biodiversity, contributing to the region's hydrological complexity. Additionally, permanent sites like El Golea and Chott Ain El Beida are situated within a semi-arid context (Fig. 1). The selection of wetlands in Algeria for study purposes was based on their environmental and economic significance, particularly considering their designation by Ramsar, an international organization committed to the conservation and sustainable utilization of wetlands.

2.2 Dataset

2.2.1 NDVI dataset

The Landsat archives provide globally consistent and temporally accurate data with a resolution of 30 m and a 16-day revisit cycle (Irons et al. 2012; Claverie et al. 2015). In this study, we accessed and analyzed all Landsat data using the Google Earth Engine (GEE) platform, which offers cloud-based accessibility (Gorelick et al. 2017). From 1981 to 2021, we compiled a time series consisting of cloud-free images spanning January to December. Landsat datasets 5, 7, and 8 were utilized, with surface reflectance adjusted using "USGS Landsat Surface Reflectance Tier 1" data. Additionally, atmospheric correction and masking for clouds, water, shadows, and snow were performed using CFMASK (Zhu et al. 2015; Kennedy et al. 2018).

We employed LandTrendr, a chronological classification method available in GEE, for detecting and analyzing vegetation changes. LandTrendr identifies short-term events and elucidates long-term patterns by separating spectral trajectories based on satellite observations or spectral indices (Kennedy et al. 2010). Utilizing Landsat data, we tracked

Table 1 The physical characteristics and climate of the basins

Watershed	Watershed area (ha)	Water quality	Hydrological cadency	Latitude (N)	Longitude (E), (W)	Annual precipitation (mm)	Annual temperature (°C)	Climate
Macta Marsh	44.500	Salty	Permanent	35° 38′ 52″	00° 06′ 16″ W	300–400	20	Semi-arid
Great Sebkha	56.870	Salty	Permanent	35° 31′ 29″	00° 47′ 12″ W	300–370	18.7	Semi-arid
Telamine Lake	2.399	Salty	Permanent	35° 44′ 09″	00° 22′ 57″ W	300–390	18.5	Semi-arid
Arzew saline	5.778	Salty	Permanent	35° 41′ 25″	00° 19′ 22″ W	300–400	18.2	Semi-arid
Boughezoul Dam	9.058	Salty	Permanent	35° 41′ 55″	02° 47′ 34″ E	500–550	14.7	Semi-arid
Chott Zehrez Chergui	50.985	Salty	Permanent	35° 12′ 59″	03° 31′ 58″ E	320–335	14.9	Semi-arid
Chott Ech Chergui	855.500	Salty	Permanent	34° 16′ 09″	00° 33′ 25″ E	410–420	15.3	Semi-arid
Dayet El Ferd	3.323	Salty	Permanent	34° 29′ 55″	01° 14′ 23″ W	400–500	15.4	Semi-arid
Chott Zehrez Gharbi	52.200	Salty	Permanent	34° 56″	02° 48′ 06″ E	320–350	14.9	Semi-arid
Chott El Hodna	362.000	Salty	Permanent	35° 26′ 04″	04° 41′ 54″ E	250–270	18.9	Semi-arid
Chott Melghir	551.500	Salty	Irregular	34° 10.631″	06° 17.322″ E	65–100	21.2	Arid
Beni Bahdel Dam	54.630	Salty	Irregular	34° 42′ 42.70″	1° 30′ 13.24″ W	400–500	15	Semi-arid
Bougara Dam	11.320	Salty	Irregular	36° 32′ 26″	3° 5′ 7″ E	340–360	16.2	Semi-arid
Boughrara Dam	175.450	Salty	Irregular	34° 88′ 3854″	01° 67′ 6169’ W	400–500	15.2	Semi-arid
Bouhanifia dam	34.52	Salty	Irregular	35° 16′ 39″	0° 3′ 36″ W	400–450	17.4	Semi-arid
Chorfa Dam	70.210	Salty	Irregular	35° 25′ 55″	0° 14′ 43″ W	400–500	17	Semi-arid
Cheliff Dam	50.000	Salty	Irregular	35° 59′ 00″	0° 24′ 47″ W	380–400	18.3	Semi-arid
Chott Marouane	337.700	Salty	Irregular	34° 02′ 433″	5° 58′ 748″ E	60–100	21.6	Arid
Dahmoni dam	39.520	Salty	Irregular	35° 41′ 67″	14° 76′ 29″ E	450–470	15.5	Semi-arid
Gargar Dam	358.280	Salty	Irregular	35° 55′ 52″	0° 59′ 15″ E	400–420	18.4	Semi-arid
Karrada Dam	65.000	Salty	Irregular	36° 05′ 1162″	00° 38′ 5519″ E	440–440	18	Semi-arid
Ksob Dam	22.72	Salty	Irregular	35° 58′ 05″	04° 42′ 33″	250–270	18.7	Arid
Sarno Dam	21.250	Salty	Irregular	35° 29′ 94′ 99″	00° 59′ 0768″ W	420–430	17.3	Semi-arid
El Golea	18.947	Salty	Permanent	20° 25′ 00″	02° 95′	35–70	22.9	Arid

Table 1 (continued)

Watershed	Watershed area (ha)	Water quality	Hydrological cadency	Latitude (N)	Longitude (E), (W)	Annual precipitation (mm)	Annual temperature (°C)	Climate
Chott Ain El Beida	6.853	Salty	Irregular	31° 57′ 30″	31° 59′ 2″	30–80	22.2	Arid

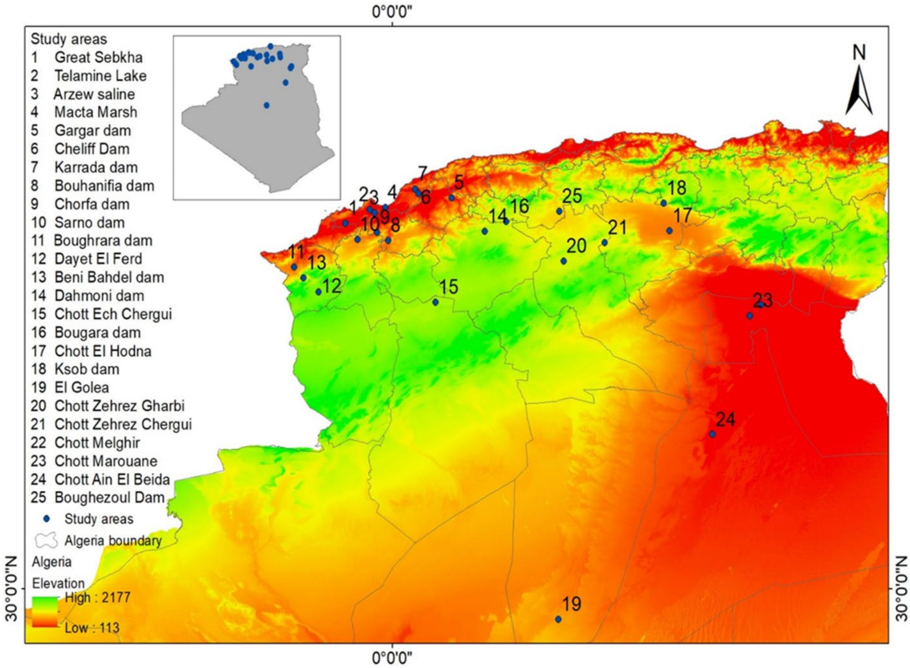


Fig. 1 Distribution of the 25 watersheds in Algeria

vegetation changes over 40 years using Normalized Difference Vegetation Index (NDVI) values, which were available throughout the year at a spatial resolution of 30 m.

While the 30-m resolution of Landsat data enabled comprehensive analysis over the study duration, it's essential to acknowledge the potential benefits of using higher-resolution datasets. Fine-grained data could reveal additional insights and nuances in vegetation dynamics, particularly in areas with complex land cover patterns or at smaller scales. However, during our study timeframe, access to such datasets was limited, necessitating the use of Landsat data to fulfill our research objectives. Incorporating higher-resolution datasets in future research endeavors holds promise for further enhancing our understanding of vegetation dynamics and ecosystem processes.

2.2.2 Climate dataset

We utilized temperature records with a precision of 0.05° sourced from the Climate Forecast System Reanalysis (CFSR) and precipitation datasets from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) project, both available on a daily basis. These datasets were accessed through the Climate Engine platform (http://climateengine.org). CHIRPS data proved valuable for calculating multi-annual and growing season total rainfall averages, aiding in time series trend analysis and drought monitoring. Additionally, we obtained multi-annual and seasonal mean temperatures, with resolutions of 1/5° and 3/10° respectively, from the National Center for Environmental Prediction's CFSR datasets. These temperature records were then integrated and reprocessed alongside Normalized Difference Vegetation Index (NDVI) data spanning from 1981 to 2021.

2.3 Methods

2.3.1 Regression analysis of long-term vegetation index

The linear regression model utilized to evaluate NDVI and climate (precipitation and temperature) variation trends at each pixel's scale can be defined as follows (Hu et al. 2019):

$$\mathrm{Slope} = \frac{\mathrm{n} \times \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{i} \times \mathrm{NDVI_i} - \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{i} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{NDVI_i}}{\mathrm{n} \times \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{i}^2 - \left(\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{i}\right)^2} \tag{1}$$

where *NDVIi* represents either the yearly average or the highest NDVI value, n indicates the length of the NDVI time series, and i denotes the ranking of years within the study period from 1 to 30. The slope indication and its value illustrate the trend and magnitude of increase for the NDVI data sequence. The incline value signifies the mean annual NDVI over the study years. When the incline is greater than 0, NDVI reflects an escalating trend, indicating an increase or improvement in vegetation cover. Conversely, when the incline is less than 0, the NDVI time series tends to decline, suggesting a deterioration in vegetation health, with vegetation color turning brown or soil degradation occurring. The significance test for the orientation of the NDVI parameter was conducted using a t-test, where a statistically significant trend was defined as $P < 0.05$ (Gao et al. 2022).

2.3.2 Normalization data

To evaluate the spatial and temporal disparities of NDVI, precipitation, and temperature, we employed min–max normalization, which scales the values between 0 and 1. The formulas for min–max normalization are as follows (Luo et al. 2020):

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{2}$$

here, x represents the true value, x_{min} and x_{max} denote the lowest and highest values of the dataset, and $x\prime$ represents the normalized value after min–max normalization.

2.3.3 Correlation analyses among the vegetation index and climatic change

We computed the relationship between temperature, rainfall, and NDVI to assess vegetation responses to climate variables, following the methodology outlined below (Bhuyan et al. 2017):

$$r_k(x, y) = \frac{\sum_{i=1}^{n-k} \left[\left(x_i - \overline{x}\right) \times (y_i - \overline{y})\right]}{\sqrt{\sum_{i=1}^{n-k} (x_i - \overline{x}) \times \sum_{i=1}^{n-k} (y_i - \overline{y})}} \tag{3}$$

with $r_k(x, y)$, which represents the sequence of correlation analyses between NDVI and climatic factors, n indicating the span of the chain, x_i representing the NDVI time series, k denoting the time lapse, y_{i+1} representing the temperature or rainfall time series with a k time lag.

Previous research has indicated that the period of climate and plant changes usually falls within a monthly range; the relationship between vegetation and climate changes in season periods can be used to determine time differences or time lag. Climate variables like temperatures and precipitation have a direct impact on vegetation, which affects the timing of plants' growth and changes throughout the year (Peng et al. 2019; Zhe and Zhang 2021). Thus, delays or presentations of certain seasons can be monitored for normal conditions. In addition, significant changes in typical climatic conditions can delay the growing season by three months, having a drastic impact on the ecosystem. Using available data on vegetation and climate change, this relationship can be analyzed, and the temporal effects of climate change on the plant environment determined (Chen et al. 2014; Wu et al. 2015).

3 Results

3.1 The temporal-spatial distributions for NDVI during the past 40 years

The NDVI results exhibit notable spatial variations throughout the period from 1981 to 2021 (Fig. 2). Approximately 59.6% of the total greenery area exhibits an NDVI level lower than 0.45, with particularly low values identified in regions such as Chott Ech Chergui, Arzew Saline, Chott Melghir, and Chott Merouane. Conversely, NDVI values exceeding 0.45 are distributed across numerous regions, accounting for a total of 40.4%, although the increase is relatively modest. Notably, the highest NDVI values are observed in areas including Macta Swamp, Great Sebkha, Sarno Dam, Chott Zehrez Chergui, and Karrada Dam. Additionally, negative NDVI values predominantly characterize water bodies, as depicted in Fig. 2. These water sources have also experienced reductions in their aerial extent, with some disappearing over time. Remarkably, the volume of surface water bodies has declined annually across all regions, likely attributed to various factors such as agricultural expansion, indiscriminate use of chemical substances, grazing activities, infrastructure development (e.g., dams, hydroelectric projects), and urbanization, all contributing to a significant reduction in vegetation. Consequently, the ratio of NDVI vegetation has undergone marked changes over the past four decades. The observed distribution pattern of NDVI trends in each location highlights a strong correlation among vegetation indices, elevation, and water availability. Spatial disparities in NDVI across all study regions remained consistent (slope values ranging from 0.0005 to 0.04) throughout the study period (1981–2022).

3.2 The association between the vegetation index and climatic changes

In arid and semiarid regions, changes in vegetation and climatic variables are intricately intertwined. According to Fig. 3, partial correlation analysis between Normalized Difference Vegetation Index (NDVI) values and rainfall (NDVI-P) exhibited negative associations across all watersheds, while the relationship varied for temperature (NDVI-T), with positive correlations observed in certain areas (such as Chott Zehrez Chergui, Chott Ech Chergui, Dayet El Ferd, Chott Zehrez Gharbi, Chott El Hodna, Beni Bahdel Dam, Chott Merouane, Dahmoni Dam, Golea, Gargar Dam, and Ksob Dam) during the period 1981–2021. Furthermore, NDVI-T displayed a declining trend over this period, indicating that higher temperatures do not necessarily promote plant growth, and the beneficial effects of climate change on natural vegetation diminish over time.

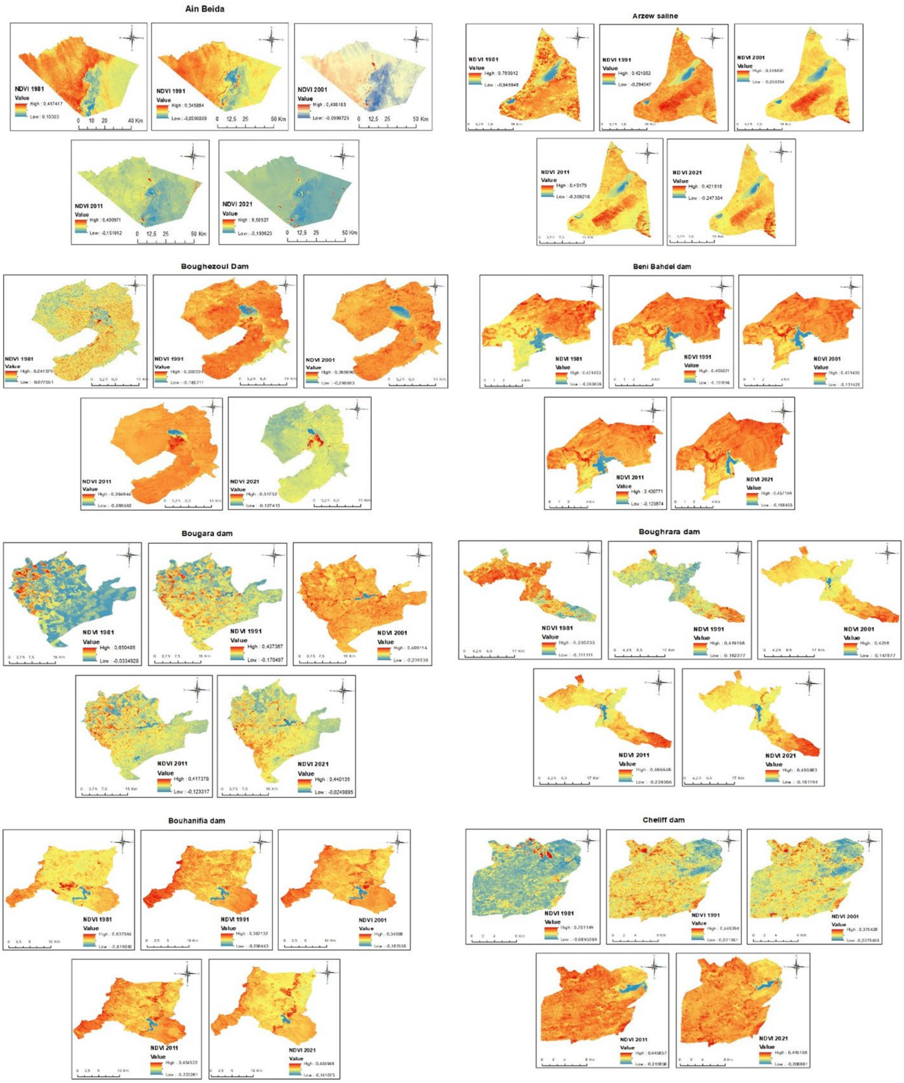


Fig. 2 Patterns of NDVI change trends in 25 basins in Algeria from 1981 to 2021, with yearly average NDVI change

In general, NDVI exhibited a stronger correlation with temperature than with precipitation. This could be attributed to the dry and semiarid climatic conditions, where the influence of temperature on vegetation was more significant than that of rainfall on vegetative cover. Additionally, analysis of specific seasonal relationships revealed that NDVI in spring exhibited the highest positive association with temperature and rainfall. This suggests that NDVI decreases with increased rainfall and temperature in spring, especially in recent years. Conversely, NDVI showed a significant positive correlation with rainfall and temperature in all wetlands during autumn, except for Chott Melghir, Chott Merouan, Golea, Chott Houdna, Chott Zehrez Chergui, and Chott Zehrez Gharbi.

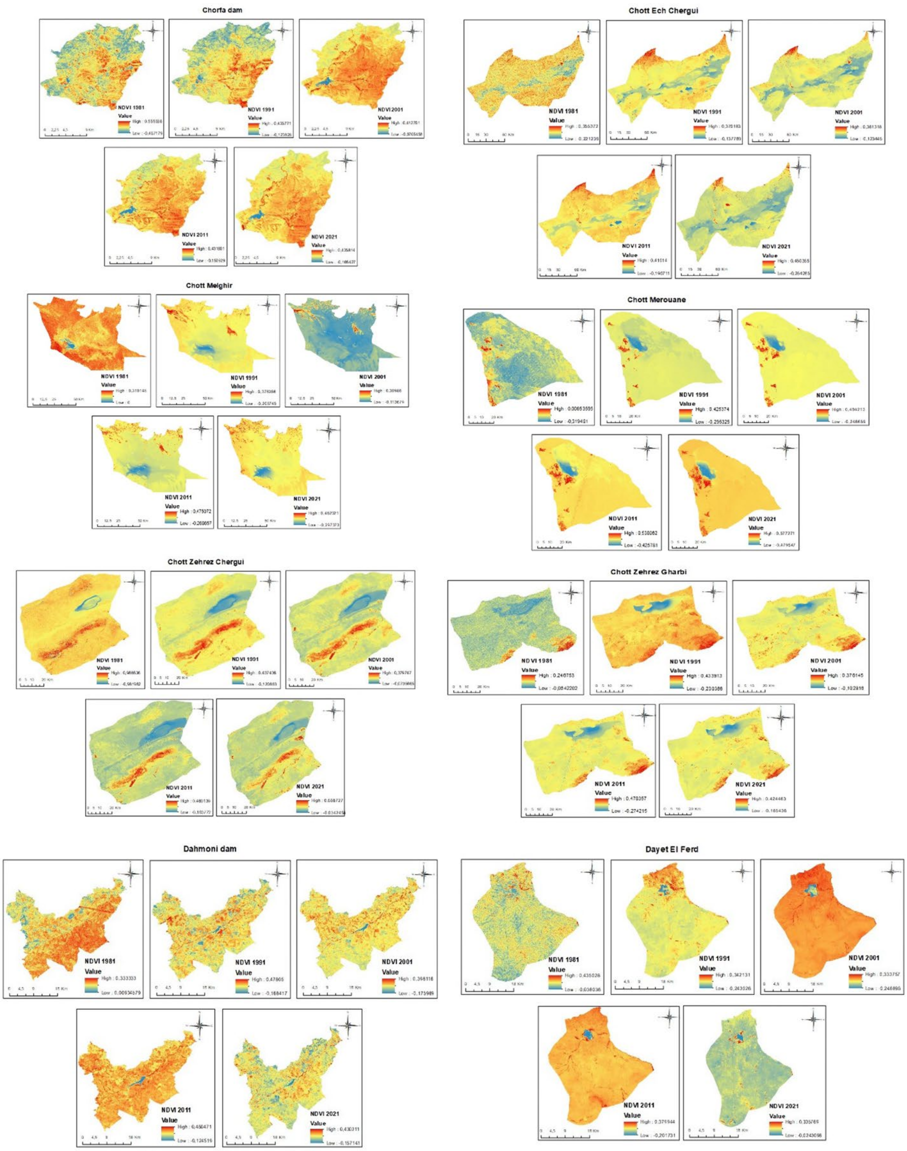
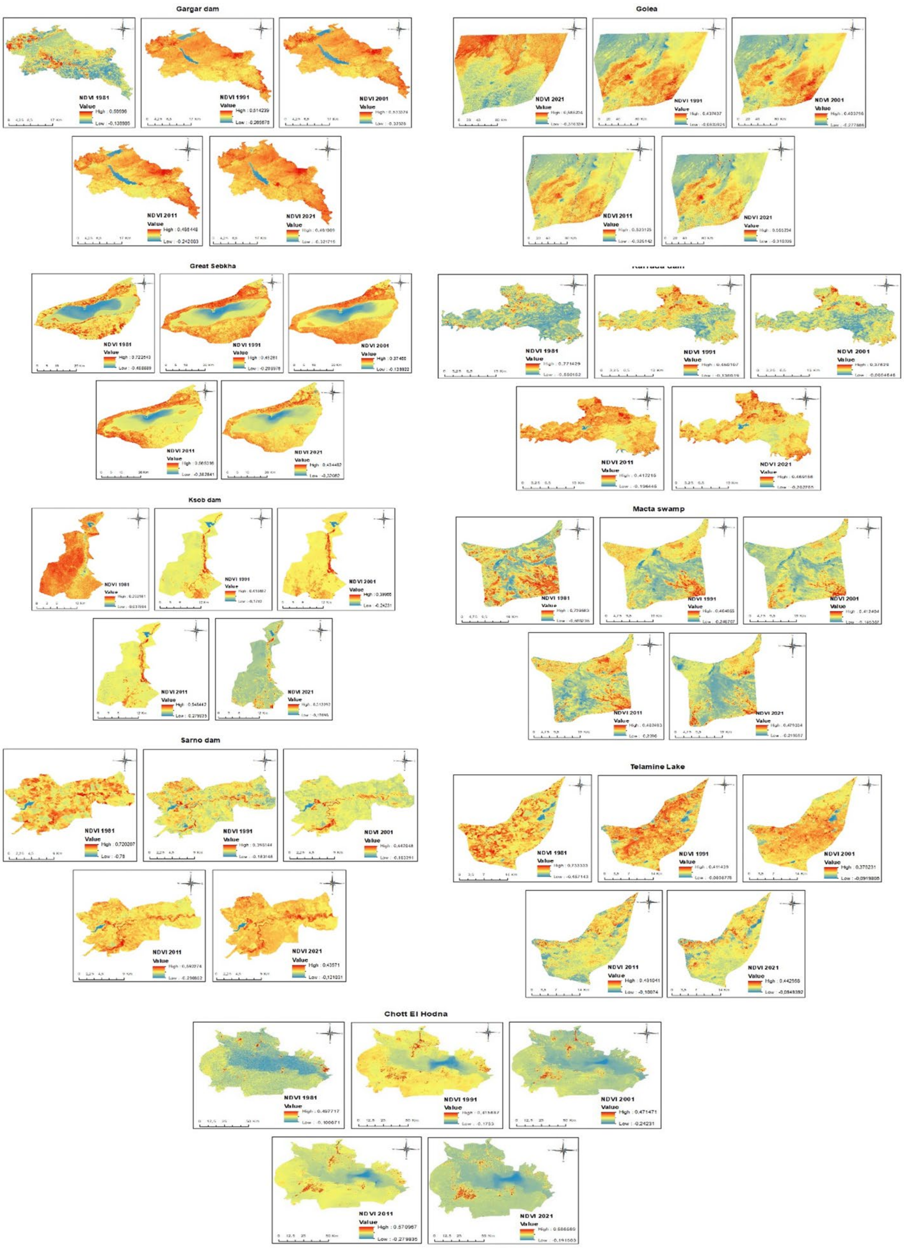


Fig. 2 (continued)

However, the link between NDVI and rainfall and temperature were weaker in summer, particularly with temperature.

The intricate interplay between NDVI and climatic variability was elucidated through month-level NDVI data and the normalization of rainfall and temperatures across 25 water bodies from 1981 to 2021 (Fig. 4). While temperatures exhibited smooth cyclical changes across the basins, cyclical precipitation changes were more widely dispersed. Maximum NDVI readings did not consistently align with climate data trends, suggesting significant



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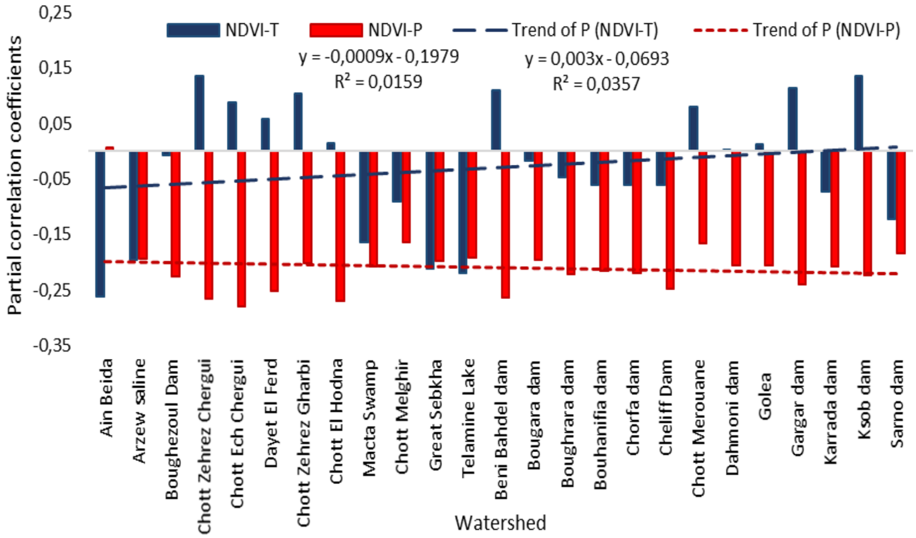


Fig. 3 The factor of partial correlation of growth season between NDVI, rainfall, and temperature in the 25 watersheds during 1981–2021

delays over the study period. These findings indicate that the influences of rainfall and temperature on NDVI in these basins exhibit temporal delays.

3.3 Long-time impact response for NDVI with rainfall/temperature variations

The effects of the delay period are being examined by considering annual and seasonal coherence factors between NDVI and climate indicators in basins, as depicted in Tables 2 and 3. Annual correlations between NDVI and rainfall across all basins showed negative associations, with similar negative correlations observed across all seasons. There appears to be an uneven distribution, with this correlation's impact being more pronounced in autumn. From September to December, rainfall appears to correlate somewhat with the climatic drought experienced in spring, attributed to a lack of rainfall from mid-March to June. Conversely, temperature exhibited positive correlations in many basins throughout the seasons; however, plant density decreased due to higher temperatures and reduced rainfall in spring and autumn.

Furthermore, these analyses revealed significant seasonal variations in plant growth within the basins, with delays in plant growth attributed to delayed rainfall. At times, this delay resulted in a 1–3 months lag in recording due to the delayed NDVI response to climate changes. Vegetation also displays periodic fluctuations, corresponding to variations in temperature and precipitation. While the overall functions of these two components, along with temperature and precipitation, govern periodic vegetation adjustments, the maximum value of NDVI during a given period does not precisely align with precipitation and temperature, indicating a slight delay (Fig. 5). Additionally, periods of abundant rainfall were not necessarily linked to low NDVI values.

Moreover, significant annual changes were observed, with the Normalized Difference Vegetation Index (NDVI) declining in 1989–1998 across all regions and rising

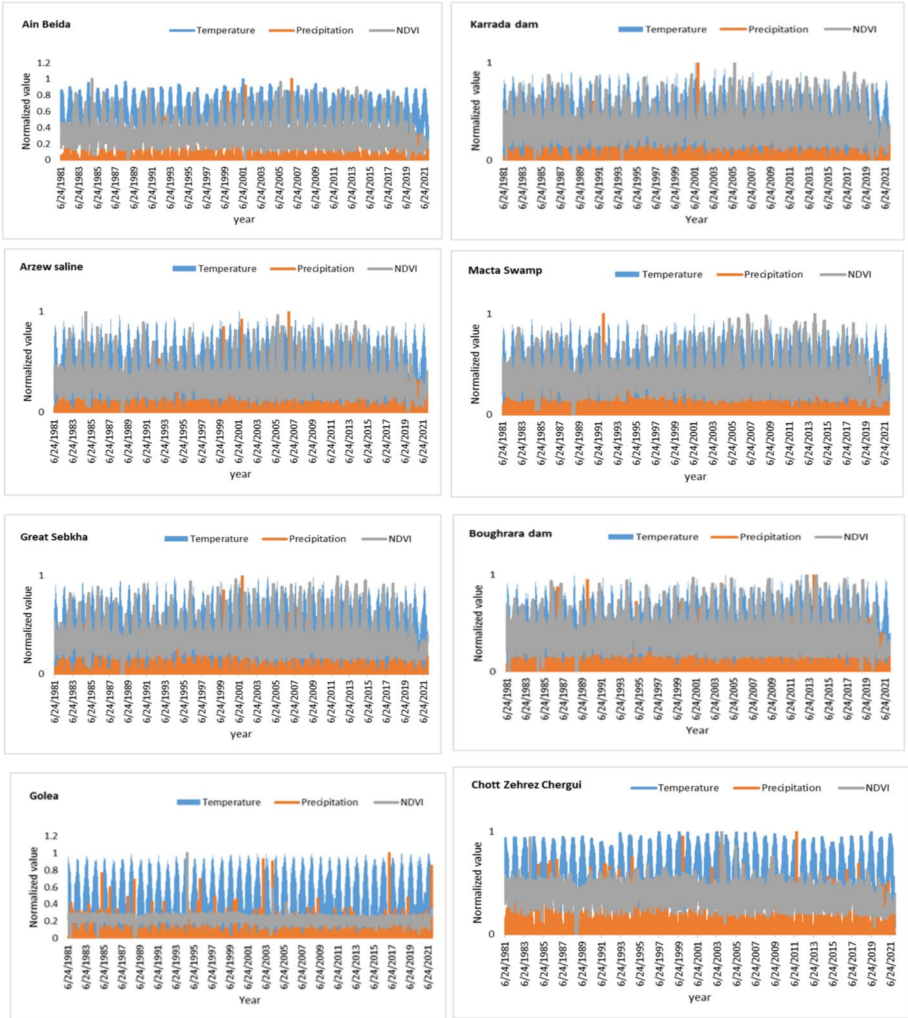
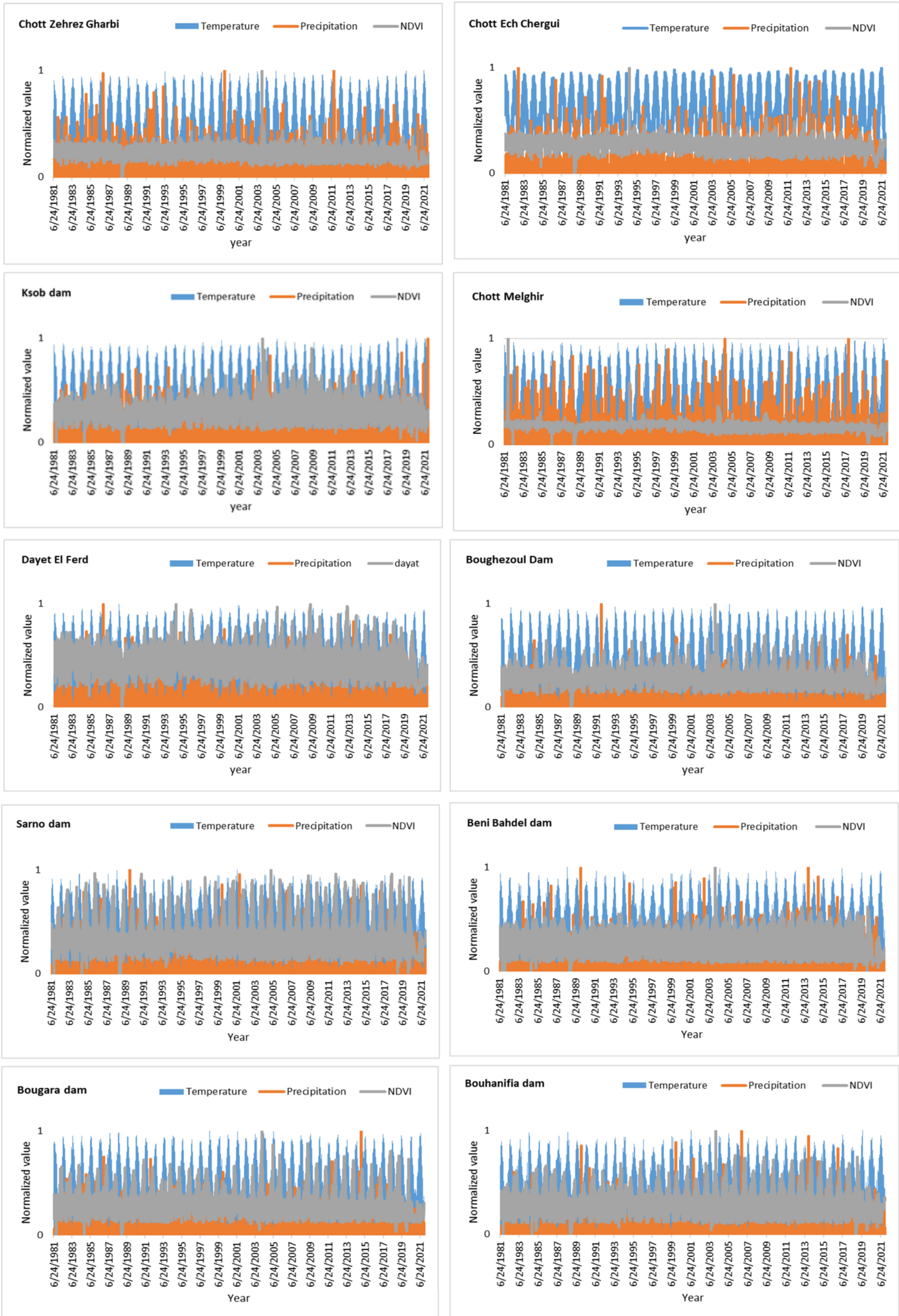


Fig. 4 Standardized long-term fluctuations in NDVI and climatic variables (rainfall and temperature) across the 25 watersheds in Algeria during 1981–2021

in 1994–1996 compared to the preceding period. These changes highlight the impact of delays in vegetation response to changes in temperature and precipitation.

3.4 Spatial distribution and influence of climatic factors on vegetation cover

Figure 6 depicts the spatial correlation between vegetation growth and climatic factors over 40 years, illustrating that NDVI values are strongly correlated with temperature and rainfall across more than 95% of the greenery area ($p < 0.05$). The correlation between NDVI and temperature is less than 0.4 over approximately 85% of the vegetation area. During these periods (Fig. 6a), which exhibit negative effects on vegetation



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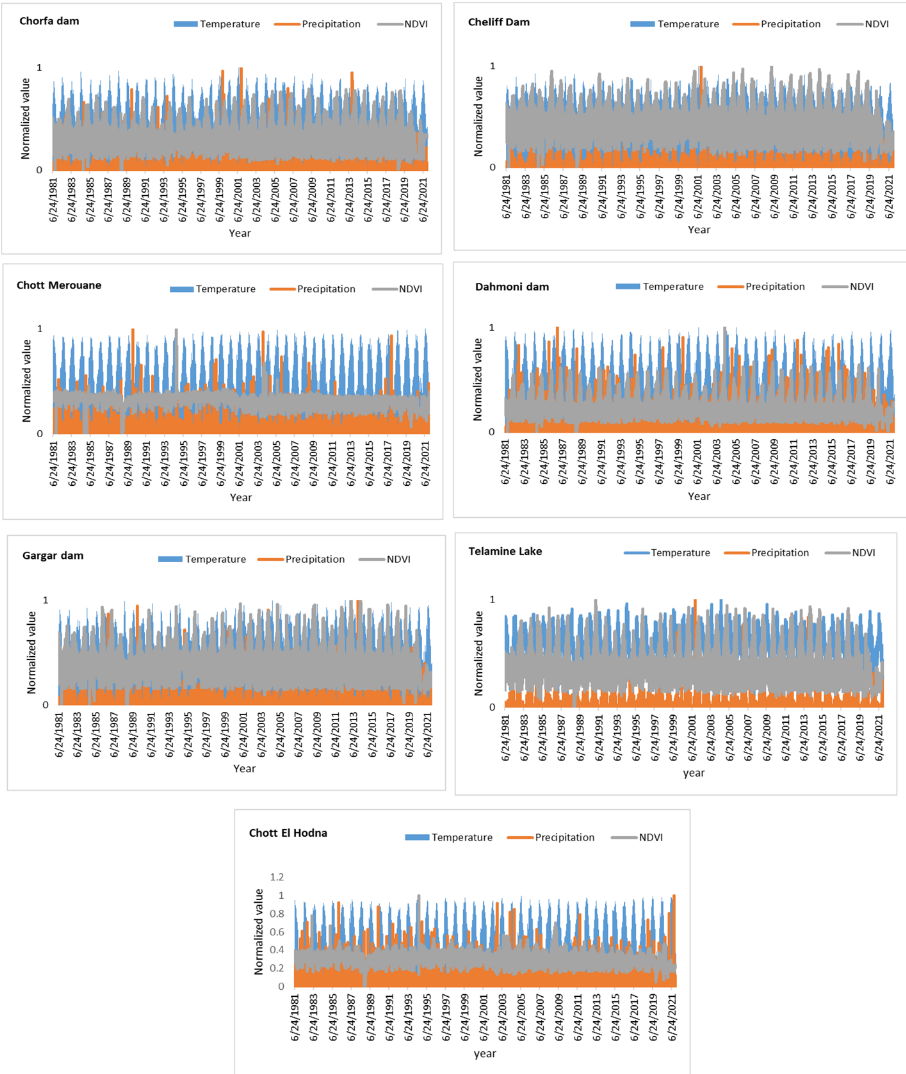

Fig. 4 (continued)

across all regions, the corresponding NDVI-P relationship displays a similar pattern (Fig. 6b), suggesting an increasing negative response to vegetation cover and the beneficial impact of rainfall. Specifically, NDVI-P exhibits more than 70% negative or transitioning from positive to negative changes, particularly in recent years, indicating that precipitation is the primary driver of vegetation density in these regions. However, it should be noted that 45% of the NDVI-T changes from improvement to deterioration, indicating a significant shift in vegetation productivity due to climate warming in these areas.

Table 2 The correlation coefficient among climatic indicators and the vegetation indices

Basins	Correlation coefficient		
	NDVI-T	NDVI-P	R^2
Ain Beida	−0.26187	0.007151	0.0106
Arzew Saline	−0.19597	−0.1938	0.0096
Boughezoul Dam	−0.00785	−0.22668	0.0237
Chott Zehrez Chergui	0.135913	−0.26638	0.0518
Chott Ech Chergui	0.088362	−0.27977	0.0439
Dayet El Ferd	0.058209	−0.25218	0.0191
Chott Zehrez Gharbi	0.104216	−0.20293	0.0339
Chott El Hodna	0.014254	−0.26994	0.04
Macta Swamp	−0.16343	−0.20898	0.0073
Chott Melghir	−0.09173	−0.16453	0.0005
Great Sebkha	−0.21125	−0.19904	0.0047
Telamine Lake	−0.21915	−0.19317	0.0155
Beni Bahdel Dam	0.109324	−0.2635	0.0013
Bougara Dam	−0.01723	−0.19687	0.0175
Boughrara Dam	−0.04696	−0.22146	0.0034
Bouhanifia Dam	−0.061	−0.21703	0.0016
Chorfa Dam	−0.06196	−0.22078	0.005
Cheliff dam	−0.06187	−0.24869	0.0098
Chott Merouane	0.079735	−0.16671	0.0917
Dahmoni Dam	0.000705	−0.20711	0.0072
Golea	0.011864	−0.20599	0.0442
Gargar Dam	0.114363	−0.23949	0.0034
Karrada Dam	−0.07234	−0.20797	0.002
Ksob Dam	0.135599	−0.2246	0.0049
Sarno Dam	−0.12339	−0.18363	0.0047

4 Discussion

The NDVI in all areas where the study was conducted showed a marked decrease from 1981 to 2021. The relationship and effects of the time difference between climate variables and vegetation coverage have been studied in 25 areas of Algerian water bodies, which hold significant importance and are crucial for comprehending environmental processes in these regions (Zhou et al. 2018; Bai et al. 2020). Vegetation in these areas is strongly linked to climate change (Roerink et al. 2003; Piao et al. 2006; Chu et al. 2019).

According to the research outcomes, the positive relationship between temperature and NDVI turned negative during the study period, indicating that the positive effect of rising temperatures on greenery cover has diminished over time. This negative impact is likely the main cause of the drought experienced in the watersheds over the last few decades. While temperature may indirectly affect vegetation water, it remains an important factor influencing poor vegetation growth. The negative correlation of NDVI-P covered 70% of the study area, with its negative effect evident in all regions, consistent with NDVI-T. This persistent and increasing negative effect, particularly in recent years, highlights the drought affecting these basins. It underscores the importance of

Table 3 Seasonal correlations between climatic conditions and NDVI (NDVI-P, NDVI-T) in the Basins

Basins	NDVI- T			NDVI-P		
	Autumn	Spring	Summer	Autumn	Spring	Summer
Ain Beida	−0.01	0.11	0.15	0.03	−0.012	−0.010
Arzew Saline	−0.01	0.001	−0.23	−0.20	−0.023	−0.023
Boughezoul Dam	0.03	0.001	0.13	−0.20	−0.027	−0.022
Chott Zehrez Chergui	0.10	0.04	0.10	−0.22	−0.033	−0.02
Chott Ech Chergui	0.13	0.04	0.07	−0.21	−0.029	−0.029
Dayet El Ferd	0.04	0.10	0.20	−0.23	−0.029	−0.022
Chott Zehrez Gharbi	0.11	0.02	0.05	−0.017	−0.023	−0.022
Chott El Hodna	0.05	0.07	0.03	−0.022	−0.031	−0.024
Macta Swamp	0.03	0.15	0.08	−0.021	−0.025	−0.023
Chott Melghir	−0.08	0.08	0.08	−0.013	−0.029	−0.014
Great Sebkha	0.06	0.19	0.07	−0.021	−0.026	−0.021
Telamine Lake	0.001	−0.21	0.03	−0.020	−0.026	−0.020
Beni Bahdel Dam	0.10	0.13	0.19	−0.025	−0.029	−0.022
Bougara Dam	0.06	−0.12	0.06	−0.025	−0.025	−0.019
Boughrara Dam	0.12	0.03	0.17	−0.022	−0.026	−0.019
Bouhanifia Dam	0.05	−0.07	0.12	−0.022	−0.025	−0.024
Chorfa Dam	0.04	−0.07	0.08	−0.020	−0.027	−0.023
Cheliff dam	0.04	−0.09	0.10	−0.023	−0.027	−0.024
Chott Merouane	0.01	0.09	0.001	−0.013	−0.026	−0.019
Dahmoni Dam	0.11	0.12	0.26	−0.022	−0.027	−0.023
Golea	−0.03	0.02	−0.06	−0.018	−0.026	−0.023
Gargar Dam	0.26	0.17	−0.09	−0.023	−0.029	−0.023
Karrada Dam	0.12	−0.05	−0.22	−0.020	−0.025	−0.018
Ksob Dam	0.08	0.16	−0.05	−0.018	−0.025	−0.020
Sarno Dam	0.06	−0.18	−0.09	−0.021	−0.024	−0.20

precipitation, especially in vegetation growth, as a crucial driver. Hence, it can be emphasized that rainfall and temperature play pivotal roles in determining vegetation dynamics and interpreting them effectively, particularly in dry and semi-dry areas (Gao et al. 2022).

Additionally, it’s important to note the decrease in water levels in these basins. These changes may lead to the disappearance of many water bodies, as evidenced in the Dayet El Ferd and Great Sebkha basins, which are currently experiencing unprecedented drought. These results also indicate that the warming climate has diminished its positive effect on vegetation growth over time.

Vegetation response to climate change varies greatly, influenced by environmental patterns and climate conditions (Filippa et al. 2019). However, it’s crucial to acknowledge that climatic factors alone are insufficient in the presence of human factors, such as agricultural and urban land expansion and overgrazing, which also impact vegetation growth (Xu et al. 2016; Luo et al. 2018; Ma et al. 2019). These aspects will be the focus of future studies, along with examining the overall relationship between vegetation and other impacts, such as relative humidity, evaporation, topographic, and demographic factors.

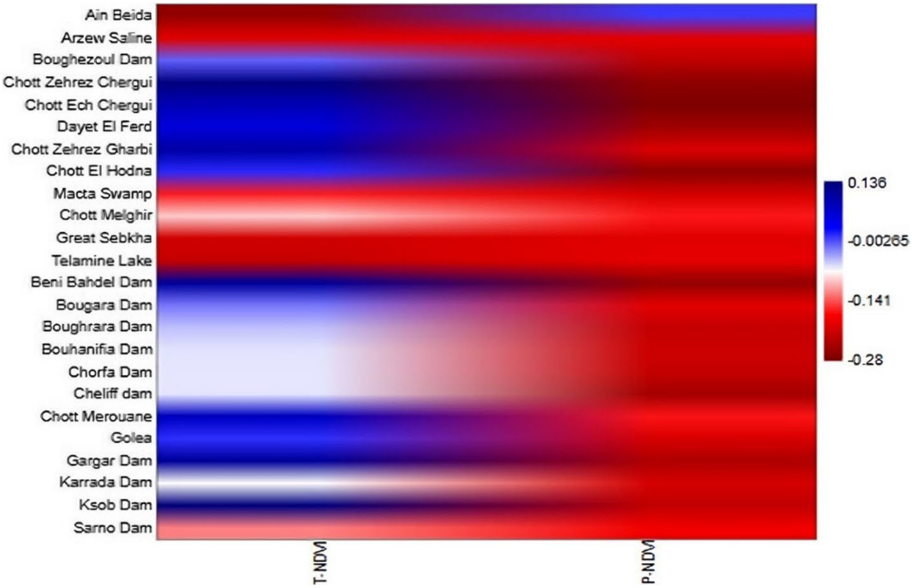

Fig. 5 Time-lag transfer matrix among NDVI and climate factors in 25 Algerian watersheds from 1981 to 2021

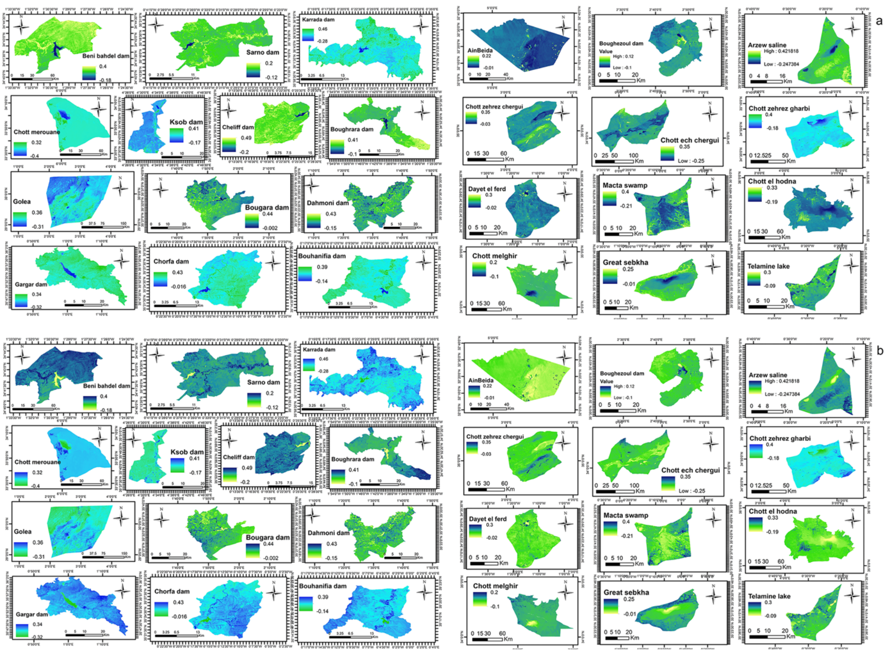

Fig. 6 The Pearson correlation distribution pattern between both the multi-year average vegetation indices (NDVI) and the climatic factors temperature (**a**), and rainfall (**b**) in 25 basins from 1981 to 2021

5 Conclusions

Studying climate changes and their time lag to comprehension, vegetation index dynamism, and the vulnerability of ecological systems to climate change is of great importance. This study, encompassing 25 regions of watersheds, concluded that climatic conditions have exhibited a significantly drier trend that has intensified in recent years. Consequently, vegetation has shown a downward trend, attributed to reduced rainfall and increased temperatures observed from 1981 to 2021. To delve deeper into this phenomenon and investigate the association between NDVI and climatic conditions, a partial correlation approach was employed. This analysis revealed the extent of degradation of vegetation and the prevalence of drought across all areas.

It's noteworthy that these basins have experienced a decline in water levels, raising concerns about the potential disappearance of many of them. This concern is particularly evident in the Dayet El-Ferd and Great Sebkha basins, which are currently grappling with an unprecedented drought. Additionally, the findings of this study suggest that the warming climate has gradually diminished its positive effect on vegetation growth over time. Notably, the vegetation index's response to temperature was found to be less pronounced compared to rainfall.

Given these findings, it becomes imperative to determine the ecological absorptive capacity through further study in these areas. These results underscore the importance of implementing policies aimed at restoring vegetation and managing vegetation recovery, especially considering the changing landscape of these regions. By prioritizing such initiatives, we can better address the challenges posed by climate change and safeguard the ecological integrity of these vital ecosystems.

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Declarations

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