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Examination of the Effects of Climate Change on Türkiye through the Google Earth Engine Platform

İklim Değişikliğinin Türkiye Üzerindeki Etkilerinin Google Earth Engine Platformunda İncelenmesi

Eren Erdogan[1]*, Volkan Yilmaz[1]

[1]*Karadeniz Technical University, Engineering Faculty, Department of Geomatics Engineering, 61080, Trabzon/Türkiye.*

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***Corresponding author:**
Eren Erdogan
erenerdogan.hrt@gmail.com

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Abstract

The objective of this research is to assess the effects of climate change on Türkiye by utilizing data catalogues provided by the Google Earth Engine (GEE) cloud-computing platform. The utilized data catalogues encompassed precipitation, Land Surface Temperature (LST), EvapoTranspiration (ET), Potential EvapoTranspiration (PET), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Vegetation Condition Index (VCI), and Forest Area Loss (FAL). Data spanning the years 2001-2022 were collected, and analyses were conducted separately for seven geographical regions of Türkiye on both an annual and seasonal basis. Initially, trend analysis techniques were applied to the individual data sets, followed by an examination of correlations among them. Notably, significant decreasing and increasing trends were observed in annual precipitation and LST data in the Eastern Anatolia region, respectively. Furthermore, a significant increasing trend was identified in annual ET data across all regions except Eastern Anatolia. Conversely, significant increasing trends were noted in annual PET data in Eastern Anatolia and the Aegean regions. Additionally, significant increasing trends were discerned in annual NDVI, EVI, and VCI data across all regions. Experiments revealed that the ET exhibited robust correlations with the NDVI (0.77), EVI (0.79) and VCI (0.81). Furthermore, the NDVI demonstrated strong correlations with EVI (0.99) and VCI (0.96).

Keywords: *Climate change, Remote sensing, Google Earth Engine*

Özet

Bu çalışmanın amacı, Google Earth Engine (GEE) bulut bilişim platformu tarafından sağlanan veri katalogları kullanılarak iklim değişikliğinin Türkiye üzerindeki etkilerini değerlendirmektir. Kullanılan veri katalogları arasında yağış, kara yüzey sıcaklığı (LST), evapotranspirasyon (ET), potansiyel evapotranspirasyon (PET), normalize edilmiş fark bitki indeksi (NDVI), gelişmiş bitki indeksi (EVI), bitki durum indeksi (VCI) ve orman alanı kaybı (FAL) bulunmaktadır. Türkiye'nin tamamı için 2001-2022 yılları aralığını kapsayan veriler kullanılmış ve analizler ise Türkiye'nin yedi coğrafi bölgesi için yıllık ve mevsimsel olarak ayrı ayrı gerçekleştirilmiştir. İlk olarak, her bir veri setine trend analizi teknikleri uygulanmıştır, ardından da bu veri setleri arasındaki ilişkiler incelenmiştir. Özellikle, Doğu Anadolu bölgesinde yıllık yağış ve LST verilerinde sırasıyla önemli azalma ve artış eğilimleri gözlemlenmiştir. Ayrıca, yıllık ET verilerinde Doğu Anadolu dışındaki tüm bölgelerde önemli bir artış eğilimi belirlenmiştir. Bununla birlikte, yıllık PET verilerinde Doğu Anadolu ve Ege bölgelerinde önemli artış eğilimleri gözlemlenmiştir. Ayrıca, yıllık NDVI, EVI ve VCI verilerinde tüm bölgelerde önemli artış eğilimleri saptanmıştır. Öte yandan, ET verisi ile NDVI (0.77), EVI (0.79) ve VCI (0.81)verileri arasında güçlü bir korelasyon olduğu sonucuna varılmıştır. Ayrıca, NDVI verisinin EVI (0.99) ve VCI (0.96) verileriyle ile yüksek korelasyonlu olduğu tespit edilmiştir.

Anahtar kelimeler: *İklim değişikliği, Uzaktan algılama, Google Earth Engine*

1. Introduction

Climate change has become an increasingly concerning issue worldwide in recent years. Greenhouse gas emissions caused by human activities lead to an increase in temperature in the atmosphere, which adversely affects the climate system. Factors such as natural disasters, heatwaves, water scarcity, and changes in natural cycles, particularly in recent years, have prompted people to pay more attention to this issue. The global effects of climate change have brought issues such as rising temperatures, sea-level rise, negative impacts on agriculture, and changes in precipitation patterns (Aksay et al., 2005). Türkiye's intricate climatic structure renders it one of the countries most susceptible to the effects of climate change. Due to its geographical location and diverse geographic conditions, different regions of Türkiye may be affected differently by climate change (Öztürk, 2002). The effects of climate change on Türkiye include increasing temperatures, rising sea levels, increased rainfall, and the retreat of mountain glaciers (Şen et al., 2013).

To understand the impact of global climate change on a region, it is necessary to focus on multiple factors, including precipitation, surface temperature, evaporation, plant health etc. Different factors are interconnected and exhibit relationships with each other. For example, an increase in surface temperature triggers an increase in evaporation. The increased evaporation leads to a higher loss of moisture for plants, contributing to the formation of arid environments. Additionally, if the increased evaporation is not balanced by precipitation, drought and water scarcity are likely to occur. Moreover, the rising surface temperatures negatively affect plant health and contribute to the formation of arid environments. Due to these types of relationships, considering several factors at the same time is crucial for obtaining successful and accurate results when examining the effects of climate change on a region (Şen et al., 2013; Demirbaş & Aydın, 2020; Sarvia et al., 2021).

1.1 Literature Review

A detailed literature review shows that many studies investigating the effects of climate change in different countries were conducted on a country or specific regional basis (Bolch, 2007; Kundu & Dutta, 2011; Karmeshu, 2012; Hu et al., 2020; Sediqi, 2020; Dabbagh, 2021; Sarvia et al., 2021; El-Shirbeny et al., 2022) or on various lakes and rivers (Torres-Batlló et al., 2020; Zhao et al., 2021). The study conducted by Bolch (2007) determined that climate change had an impact on glaciers in mountains through the use of spectral indices calculated from satellite imagery. Kundu and Dutta (2011) conducted a time-series analysis of the Normalized Difference Vegetation Index (NDVI) using National Oceanic & Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data, revealing that certain regions in the Churu area were undergoing desertification due to climatic reasons. Karmeshu (2012) conducted trend analysis of temperature and precipitation data for the United States from 1900 to 2011. Hu et al. (2020) examined agricultural drought in Australia from 2010 to 2014 using the Temperature Rise Index (TRI) derived from Land Surface Temperature (LST) data. Sediqi (2020) investigated the impact of climate change on flood risk in Kabul city using spectral indices derived from satellite images from 2009 to 2019. The study concluded that flood risk poses a significant problem for Kabul city. Torres-Batlló et al. (2020) evaluated factors affecting the water level of Lake Poopo by analysing evaporation, NDVI, and precipitation from 2002 to 2014 through MODIS and CHIRPS data. Dabbagh (2021) analysed the temporal variation of drought in the Erbil region of Iraq using indices calculated from satellite images of 2009 and 2017. The study identified moderate drought in 2009, and severe and extreme drought effects between 2011 and 2017. Sarvia et al. (2021) examined the impact of climate change on plant health in the Piedmont region of Italy from 2001 to 2019 using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. Zhao et al. (2021) conducted a drought analysis based on surface temperature in the Yellow River region from 2003 to 2019. The study used remote sensing data on the GEE platform and calculated drought indices, including the Temperature Condition Index (TCI), Vegetation Condition Index (VCI), Vegetation Health Index (VHI), and Temperature-Vegetation Drought Index (TVDI). It was found that the drought level was highest in the northwest and lowest in the southwest and southeast of the Yellow River basin. El-Shirbeny et al. (2022) investigated evaporation and vegetation cover in Arab countries from 2005 to 2020 using MODIS and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data obtained from the Google Earth Engine (GEE) platform.

When it comes to the studies in Türkiye, it can be observed that these studies generally focused on a single factor (Ustaoğlu, 2009; Başoğlu & Telatar, 2013; Molavizadeh, 2014; Turan, 2018), specific geographical regions (Çelik, 2016; Şapolyo, 2017; Demirbaş & Aydın, 2020; Tokgöz, 2020; Başaran, 2021), and a few cities (Namkhai, 2019; Selçuk, 2021; Kafes, 2022). Ustaoğlu (2009) investigated the influence of climate change on hazelnut fields during the period of 1993-2007. The author used MODIS data to determine the spatial distribution of hazelnut plants and also used the Global Topography 30sec (GTOPO30) digital elevation model as the meteorological data. Başoğlu and Telatar (2013) examined the effects of precipitation and temperature changes on agriculture in Türkiye. Changes in precipitation were found to have a positive effect on agriculture, while changes in temperature had a negative effect.

Molavizadeh (2014) investigated the drought conditions in Türkiye between 2004 and 2013 using the indices obtained from MODIS data. The research revealed severe drought at the meteorological level in 2007-2008 and 2013-2014, and the obtained TCI values were higher for the years 2007, 2008, and 2012, suggesting that these years could be potential drought years. Çelik (2016) performed a drought analysis for the Mediterranean region covering the years 2000-2014. The study used the NDVI, Enhanced Vegetation Index (EVI), and VCI derived from MODIS TERRA satellite data. Şapolyo (2017) analysed the temperature data obtained from stations in the Aegean region. The analysis indicated significant increases in temperatures between April and October. An increasing trend was observed in all four seasons, however, the increase observed at all stations in summer was significant. Namkhai (2019) analysed meteorological data within the Çatlayan Dam Lake basin using statistical methods. Tokgöz (2020) examined the trend of precipitation and temperature station data in the Black Sea region. For this purpose, the Innovative Sen method, Mann-Kendall test (MKT), and Spearman's rho test were applied to 16 observation stations' data from 1960 to 2015. Başaran (2021) examined the changes in forest areas in the Mediterranean region using the GEE platform. The study investigated the impact of various variables, including NDVI, precipitation, temperature, LST, aerosol optical depth, ozone, fire, and population data, on forest loss. Selçuk (2021) evaluated the effects of climate change on temperature and reference evapotranspiration (ET) using data obtained from meteorological stations in Malatya province. As a result, an increase in ET values was observed in conjunction with global changes. Kafes (2022) calculated the NDVI and performed a time-series analysis in the Longoz Forests of Kırıkkale province using the GEE platform. The calculations were based on Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) data.

1.2 Motivation

To the best of our knowledge, studies examining the effects of climate change in Türkiye mainly focused on specific regions, and there are no comprehensive studies that covered the entire country and addressed the multiple key elements of climate change at the same time. Hence, this study aimed to determine the effects of climate change in Türkiye through satellite data analysis conducted on the GEE platform. In this study, precipitation, LST, ET, potential evapotranspiration (PET), forest area loss (FAL), NDVI, EVI, and VCI data were used as important indicators in determining the effects of climate change. The relationships between these parameters were also investigated. Through these analyses, it was aimed to provide an important resource for identifying the effects of climate change.

2. Material and Methods

2.1 Study Area

Türkiye, located between the 36-42° North latitude and 26-45° East longitude, was selected as the study area in the current study. Although the aim of this study was to examine the effects of climate change throughout Türkiye, it also focused separately on each of the country's seven geographical regions. This method allowed for better understanding of the effects of climate change, as Türkiye encompasses various climatic and environmental conditions. Figure 1 illustrates Türkiye and its geographical regions. Türkiye is situated between the temperate and subtropical zones due to its three-sided border with seas, the alignment of mountains, and the diversity of its terrain. These factors have given rise to various climate types across the country.

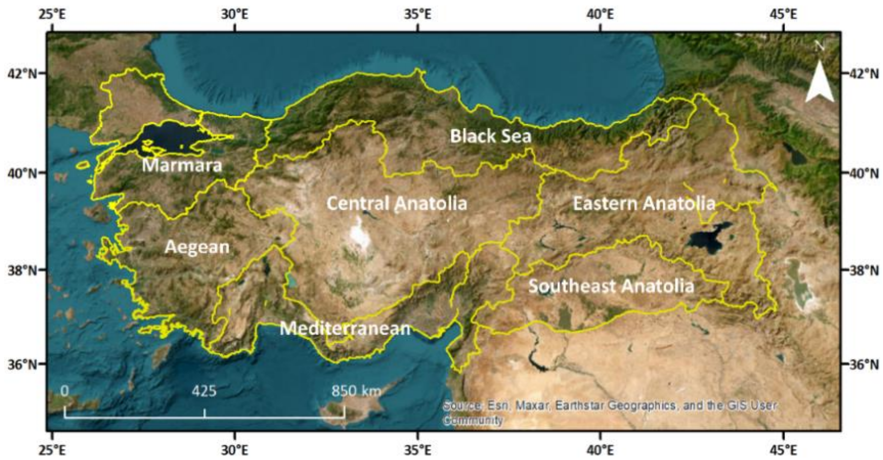

Figure 1. Türkiye and its geographical regions

Coastal areas experience milder climates influenced by the seas, while the Northern Anatolian Mountains and the Taurus Mountains act as barriers, preventing sea influences from reaching inland regions. As a result, the inland areas of Türkiye exhibit characteristics of a continental climate (Eken et al., 2008).

2.2 Google Earth Engine Platform

GEE is a web-based platform developed by Google for the examination and analysis of the Earth's surface using various satellite data. GEE enables the collection and processing of satellite imagery and other geographic data from around the world in a cloud-based platform. Its extensive data catalogue includes satellite images such as Landsat, Sentinel, MODIS, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), as well as a wide range of other data such as National Agriculture Imagery Program (NAIP) data, CHIRPS climate data, precipitation, sea surface temperature, and elevation data. The processing, evaluation, and analysis of these large datasets can be done quickly in an online environment thanks to the GEE platform (Yıldız, 2022). All operations such as processing, scaling, and visualization of GEE data are performed through the API structure. The Code Editor, which is one of the components of GEE, enables algorithm development through the JavaScript API. With the developed algorithm, the data to be used can be processed, classified, scaled, and visualized.

2.3 Data Used

The ID, resolution, and available date range information of the precipitation, land surface temperature, ET, vegetation index, and global forest change data collection used in the study are summarized in Table 1.

Table 1. Information about the data collections used in the study

Category	Collection ID	Available date range	Resolution
Precipitation	UCSB-CHG/CHIRPS/DAILY	01.01.1981-31.12.2023	5566 m
Land surface temperature	MODIS/061/MOD11A1	24.02.2000-27.01.2024	1000 m
Evapotranspiration	MODIS/006/MOD16A2	01.01.2001-09.01.2024	500 m
Vegetation index	MODIS/061/MOD13Q1	18.02.2000-01.01.2024	250 m
Global forest change	UMD/hansen/global_forest_change_2022_v1_10	01.01.2000-01.01.2022	30.92 m

2.3.1 Precipitation Data Collection

This study utilized data collection with ID: UCSB-CHG/CHIRPS/DAILY for the analysis of precipitation. The CHIRPS data was produced by the United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Centre to provide up-to-date datasets for trend analysis and drought monitoring. This data collection contains various types of worldwide precipitation data such as rain, snow, and hail. It consists of daily precipitation data, which is highly valuable for examining precipitation data within a region and predicting future precipitation trends. This dataset provides precipitation data from 1981 to the present day and has a resolution of 5566 m. The characteristics of the precipitation band used in this study are presented in Table 2.

Table 2. Characteristics of the precipitation data used (Earth Engine Data Catalog, 2023a)

Name	Unit	Min	Max	Description
precipitation	mm/day	0	1444.34	Precipitation

2.3.2 Land Surface Temperature Data Collection

The data collection with ID: MODIS/061/MOD11A1 was used for the analysis of LST. This dataset, produced from NASA's MODIS satellite imagery, is an important source of data used to monitor surface temperature variations and related climate change. It provides daily LST and emission values in a grid of 1200 x 1200 km. The data set provides LST data from February 24, 2000, to January 27, 2024. Its resolution is 1000 m (Earth Engine Data Catalog, 2023b). The characteristics of the LST_Day_1km band used in the current study are presented in Table 3. Although the LST data was originally in Kelvin (as shown in Table 3), the analysis involved converting the LST values to °C.

Table 3. Characteristics of the LST_Day_1km band used (Earth Engine Data Catalog, 2023b)

Name	Unit	Min	Max	Scale	Description
LST_Day_1km	K	7500	65535	0.02	Daytime land surface temperature

2.3.3 Evapotranspiration Data Collection

The data collection with ID: MODIS/006/MOD16A2 was used in the current study for the analysis of ET. It is a dataset that includes data obtained from MODIS satellite sensor. This dataset provides information about Earth's surface water and energy cycles, and it is specifically used for monitoring hydrological processes such as surface water evaporation, plant transpiration, and surface water consumption. It is a composite product generated at a pixel resolution of 500 m for an 8-day period. It contains pixel values for two ET layers as total ET and total PET. The dataset includes evapotranspitation data spanning from January 1, 2001, to January 1, 2023. Table 4 presents information about the characteristics of the ET and PET bands used in this study.

Table 4. Characteristics of the ET and PET bands used (Earth Engine Data Catalog, 2023c)

Name	Unit	Min	Max	Scale	Description
PET	$kg/m^2/8day$	-32767	32700	0.1	Total potential evapotranspiration
ET	$kg/m^2/8day$	-32767	32700	0.1	Total evapotranspiration

2.3.4 Vegetation Indices Data Collection

The data collection with ID: MODIS/006/MOD13Q1 was used in the current study for the analysis of NDVI and EVI vegetation indices. This data collection, generated from MODIS satellite imagery, is used to monitor and analyse vegetation changes worldwide. It contains two main vegetation layers: NDVI and EVI. The dataset is a composite product produced at a pixel resolution of 250 m for a 16-day period. The dataset provides data from February 18, 2000, to January 1, 2024. The characteristics of the NDVI and EVI bands used in the study are provided in Table 5.

Table 5. Characteristics of the NDVI and EVI bands used (Earth Engine Data Catalog, 2023d)

Name	Min	Max	Scale	Description
NDVI	-2000	10000	0.0001	Normalized difference vegetation index
EVI	-2000	10000	0.0001	Enhanced vegetation index

Let R and NIR be the red and near infrared band, the NDVI and EVI bands used were calculated as (Jiang et al., 2008);

$$NDVI = \frac{NIR - R}{NIR + R}$$
$$EVI = 2.5\,\frac{NIR - R}{NIR + 2.4R + 1} \tag{1}$$

2.3.5 Global Forest Cover Change Data Collection

In the study, data collection identified as UMD/hansen/global_forest_change_2022_v1_10 was used to analyse the changes in forested areas. Having a spatial resolution of 30.92 m, this data was derived from the time-series analysis of Landsat images. The data set covers the period from January 1, 2000, to January 1, 2022 (Earth Engine Data Catalog, 2023e). The bands and features of the dataset used in the study are provided in Table 6.

Table 6. Characteristics of the global forest cover change data used (Earth Engine Data Catalog, 2023e)

Name	Unit	Min	Max	Description
treecover2000	%	0	100	Tree canopy cover in 2000, encompassing all vegetation that exceeds a height of 5 m.
loss	-	-	-	Forest loss is characterized as a disturbance involving stand replacement, which denotes a transition from a forested state to a non-forested state.
lossyear	-	0	22	The year in which a significant event of gross forest cover loss occurred.
gain	-	-	-	The increase in forest cover from 2000 to 2012 is defined as the opposite of loss.

2.3.6 Calculation of Vegetation Condition Index

The VCI is one of the most preferred indices in studies analysing drought. VCI values typically range between 0 and 100. As the values approach 0, the health of the vegetation decreases, while approaching 100 indicates an improvement in vegetation health (Çelik, 2016). VCI is computed as (Zambrano et al., 2016);

$$VCI = \frac{NDVI_s - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{3}$$

where, $NDVI_s$ is the smoothed NDVI. $NDVI_{max}$ and $NDVI_{min}$ denote the multi-annual maximum and minimum, respectively.

2.4 Trend Analysis in Time-Series Data

This study used the MKT to examine the trends in time-series data. As a non-parametric statistical test used to identify trends in a data series, this test is a robust tool for detecting increasing or decreasing trends in a data series and is particularly employed in fields such as hydrology, meteorology, environmental sciences, and agriculture. In climate change studies, the MKT is especially preferred for determining long-term changes in parameters like temperature, precipitation, snow cover, vegetation, and other variables. Therefore, the MKT is considered a crucial tool for making accurate climate change predictions and foreseeing future impacts (Alhaji et al., 2018).

3. Results and Discussion

Figures 2-8 show the annual total precipitation, annual average LST, annual total ET, annual total PET, annual average NDVI-EVI, annual average VCI and total FAL in Türkiye between the years 2001-2022, respectively. Illustrated in Figure 2 is the decreasing trend in total precipitation in Türkiye from 2001 to 2022, indicating a sustained pattern of declining water availability. This trend raises concerns regarding potential impacts on agriculture, water resources, and ecosystem health in the region. Conversely, Figure 3 demonstrates an increasing trend in the annual average LST in Türkiye between 2001 and 2022. This outcome aligns with expectations driven by rising global temperatures resulting from factors like climate change and human activities, contributing to the warming of Earth's surface, encompassing both urban and natural landscapes. Figures 4 and 5 depict an increasing trend in both ET and PET from 2001 to 2022, aligning well with anticipated trends associated with global warming.

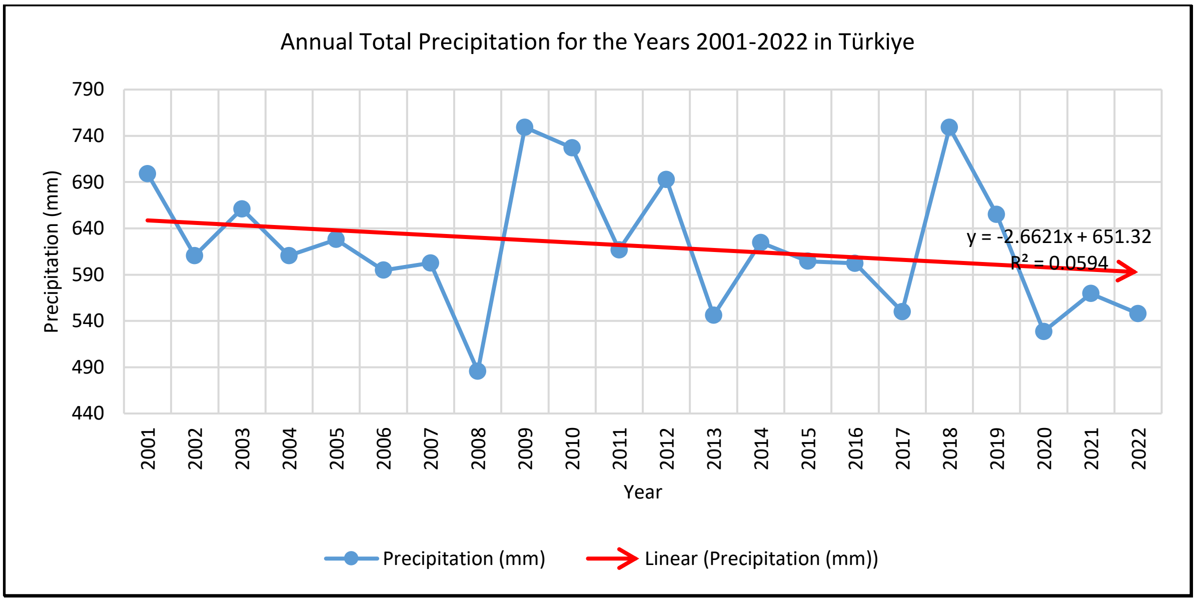

Figure 2. Annual total precipitation for the years 2001-2022 in Türkiye

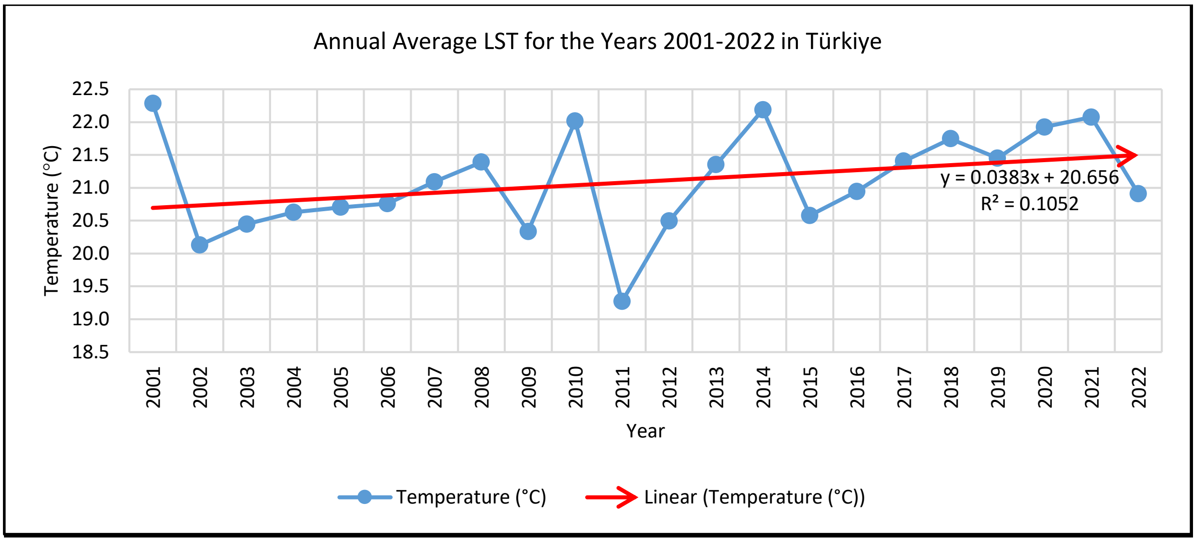

Figure 3. Annual average LST for the years 2001-2022 in Türkiye

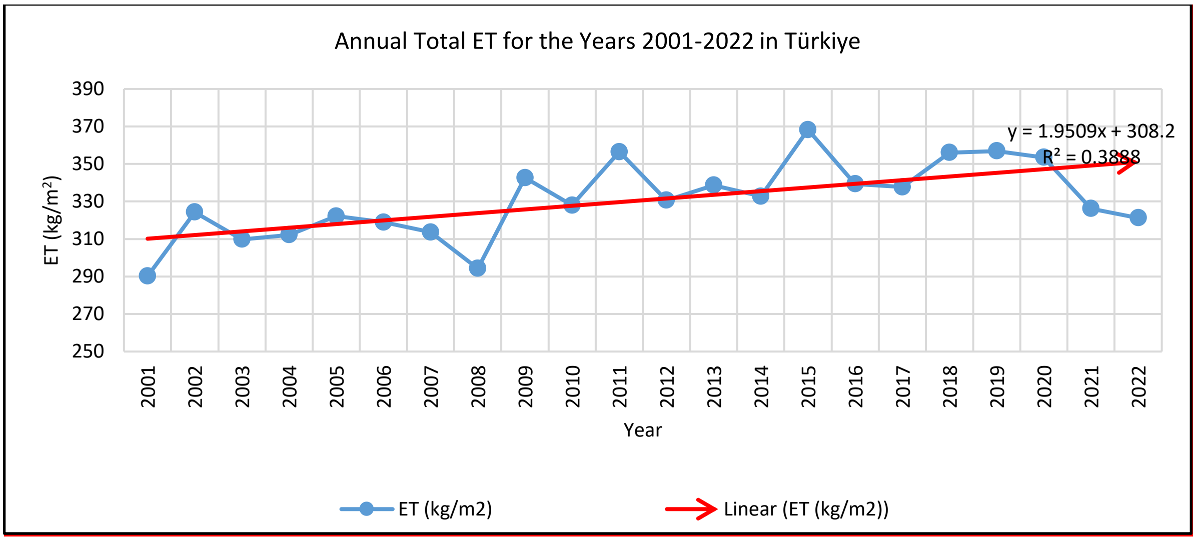

Figure 4. Annual total ET for the years 2001-2022 in Türkiye

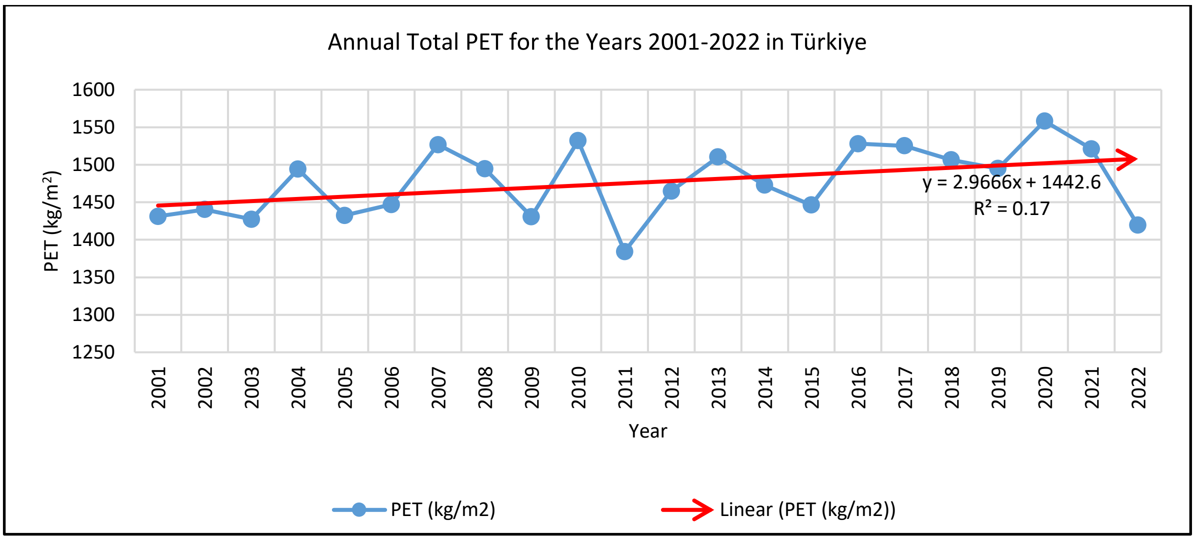

Figure 5. Annual total PET for the years 2001-2022 in Türkiye

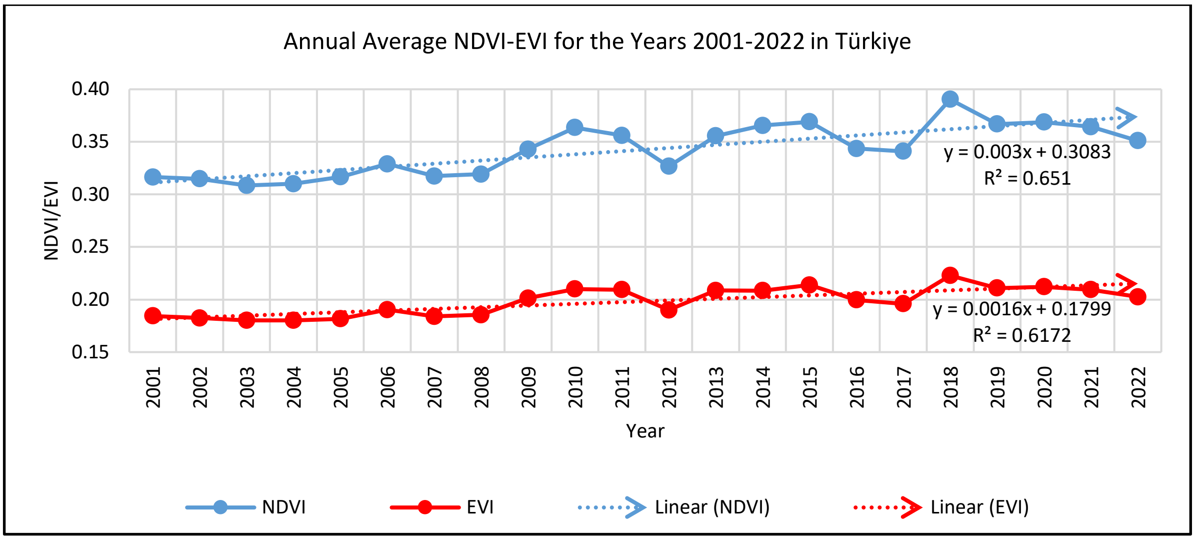

Figure 6. Annual average NDVI-EVI for the years 2001-2022 in Türkiye

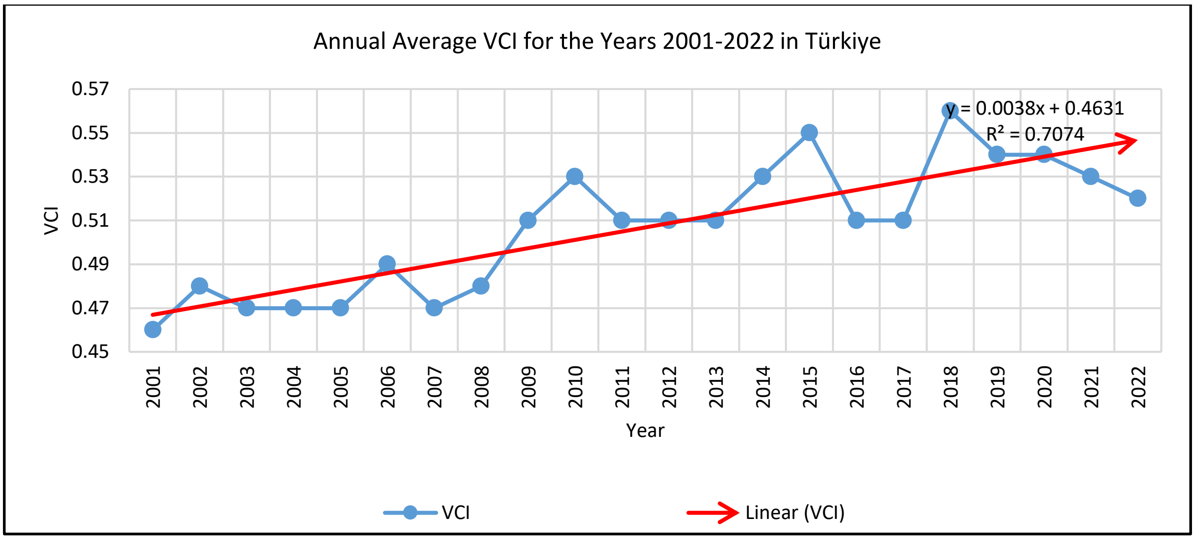

Figure 7. Annual average VCI for the years 2001-2022 in Türkiye

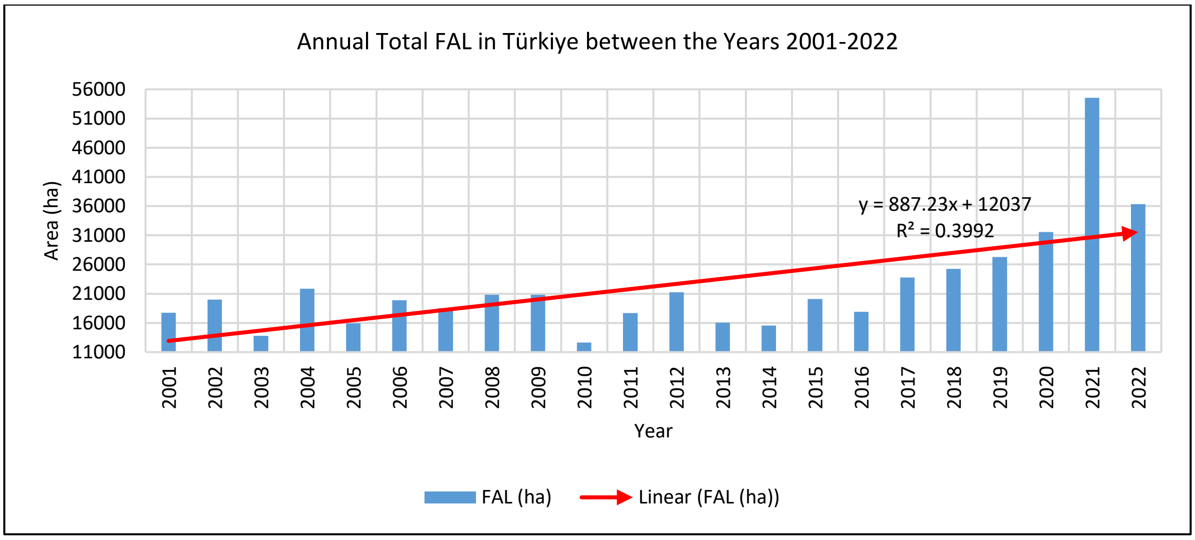

Figure 8. Annual total FAL in Türkiye between the years 2001-2022

Figure 6 illustrates an increasing trend in both the NDVI and EVI between 2001 and 2022. The steeper slope of the NDVI trend line compared to the EVI indicates a more rapid change in NDVI values over the given period, suggesting a potentially stronger vegetation response to environmental conditions captured by the NDVI, highlighting higher sensitivity or greater variability compared to the EVI. The VCI also displays an increasing trend from 2001 to 2022, evident in Figure 7. Figure 8 reveals a rise in FAL in Türkiye from 2001 to 2022, raising concerns about the state of the country's forest ecosystems. This emphasizes the imperative need for effective conservation and sustainable land management strategies in the face of these trends. Figure 9 shows the annual total PCP, annual average LST, annual total ET and annual total PET maps for the years 2001 and 2022, whereas Figure 10 shows the annual average NDVI, EVI, VCI maps as well as the forest area gain/loss map from 2001 to 2022.

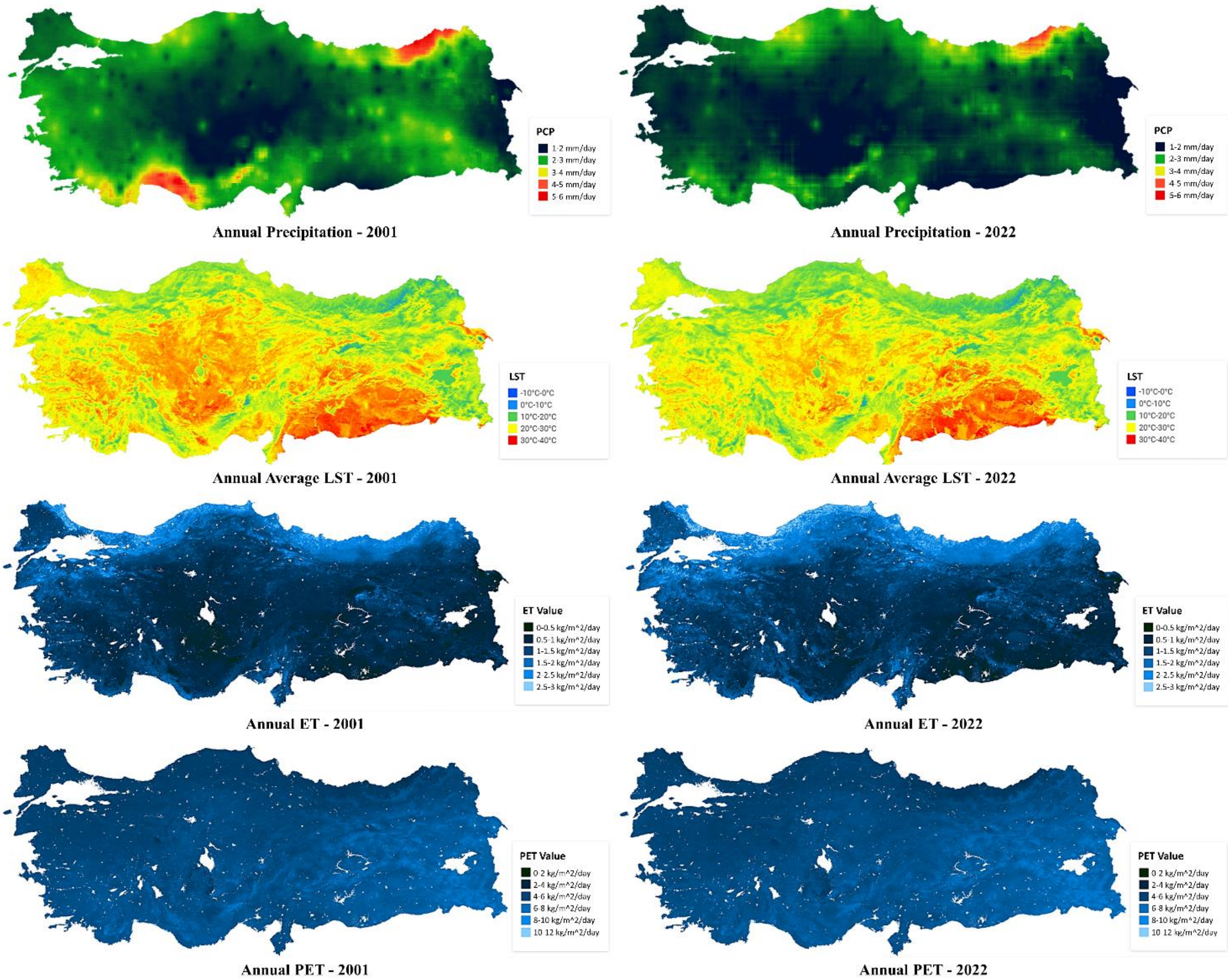

Figure 9. Annual total PCP, annual average LST, annual total ET and annual total PET maps for the years 2001 and 2022

As previously noted, this research examined variations in precipitation, LST, ET, PET, NDVI, EVI, VCI, and FAL on a regional level. Unfortunately, the graphs specific to each of Türkiye's seven regions are not featured in this article due to page limitations. Instead, the change in these factors are illustrated through graphs representing the entire country (see Figures 2-8). The MKT was applied to the data that was obtained for these factors from the GEE platform. This test was conducted separately for the data corresponding to the seven geographical regions of Türkiye, both annually and seasonally, within a 95% confidence interval. Accordingly, situations where $1.960 < Z$ indicate an increasing trend over 95% confidence interval, situations where $Z < -1.960$ indicate a decreasing trend over 95% confidence interval, and situations where $-1.960 < Z < 1.960$ indicate a decreasing or increasing trend below 95% confidence interval. Tables 7-14 show the MKT results for the precipitation, LST, ET, PET, NDVI, EVI, VCI and FAL data, respectively.

As seen in Table 7, a significant decreasing trend in annual precipitation data is observed in one geographic region (Eastern Anatolia). There is a significant increasing trend in summer precipitation data in five geographic regions (Mediterranean, Aegean, Central Anatolia, Marmara, and Black Sea). However, for autumn precipitation data, a significant decreasing trend is found in all regions except Southeast Anatolia.

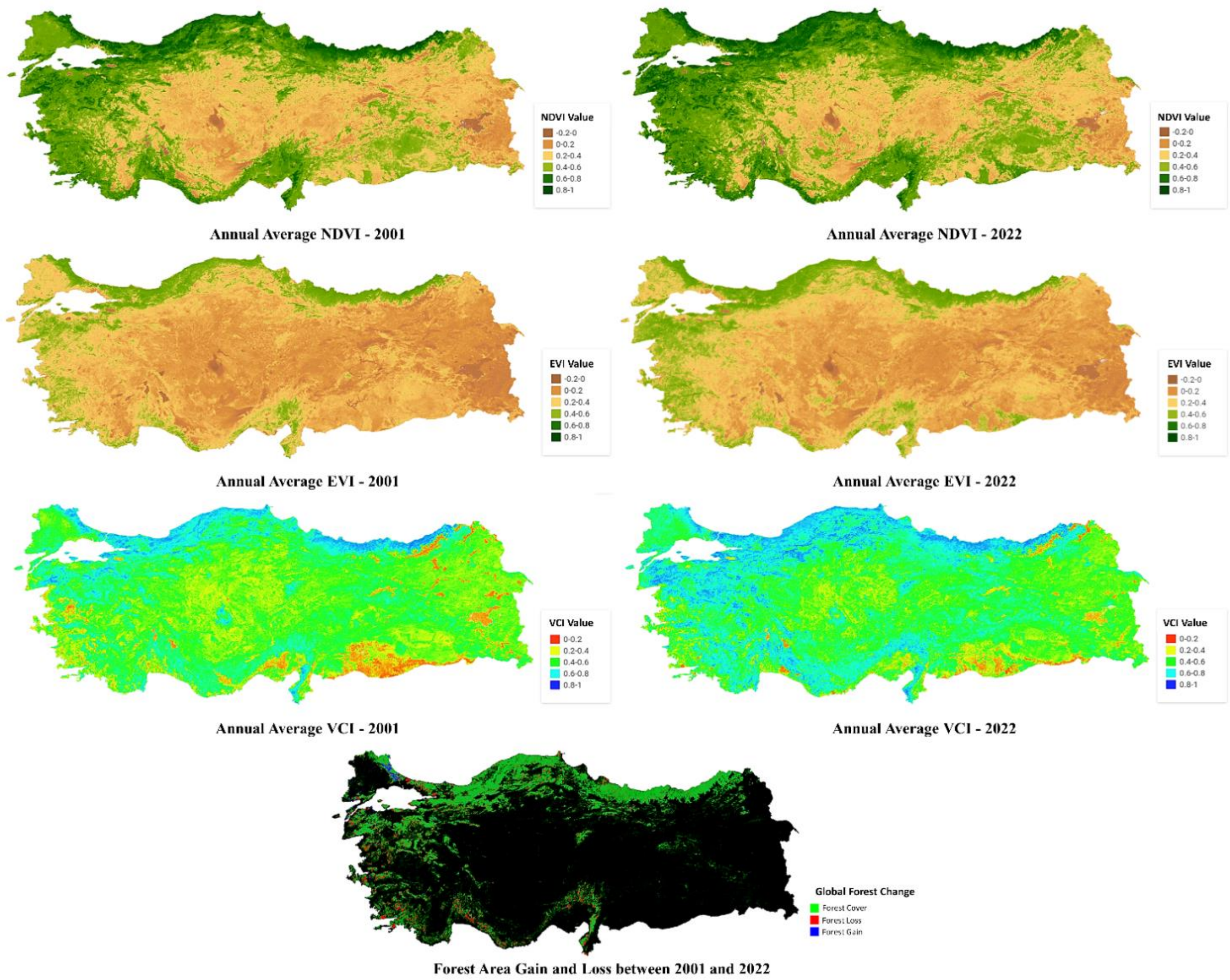

Figure 10. Annual average NDVI, EVI and VCI maps for 2001 and 2022; and forest area gain/loss map from 2001 to 2022

Table 7. MKT results for the precipitation data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	-1.523	-2.763	-1.128	-1.241	0.000	-0.338	-0.338	0	1
	Spring	0.000	-0.846	0.677	0.000	0.451	1.635	1.072	0	0
	Summer	2.989	-0.564	0.620	3.102	3.215	2.312	2.538	5	0
	Fall	-2.538	-2.312	-1.523	-2.933	-2.707	-2.425	-2.820	0	6
	Winter	-0.677	-1.128	-0.959	-1.128	0.000	-0.113	-0.282	0	0
	Increasing	1	0	0	1	1	1	1		
	Decreasing	1	2	0	1	1	1	1		

As can be observed in Table 8, there is a significant increasing trend in annual LST data in one geographic region (Eastern Anatolia Region). For summer LST data, a significant decreasing trend is found in four geographic regions (Aegean, Central Anatolia, Marmara, and Black Sea). In autumn, there is a significant increasing trend in LST data in two geographic regions (Mediterranean and Eastern Anatolia). Additionally, for winter LST data, significant increasing trends are identified in two geographic regions (Eastern Anatolia and Marmara).

As depicted in Table 9, the data reveals notable trends in annual ET across different geographic regions. The findings indicate a significant increasing trend in annual ET for six regions, including the Mediterranean, Southeast Anatolia, Aegean, Central Anatolia, Marmara, and Black Sea regions. Similarly, during the summer season, there is a significant upward trend in ET for the same six regions. Additionally, in winter, a noteworthy increasing trend in ET is observed in four regions: Mediterranean, Eastern Anatolia, Southeast Anatolia, and Marmara.

Table 8. MKT results for the LST data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	1.495	2.481	0.677	0.197	1.044	0.987	0.734	1	0
	Spring	0.677	1.552	0.197	0.000	0.282	-0.338	0.395	0	0
	Summer	-1.354	1.382	-0.564	-2.763	-2.172	-2.763	-2.059	0	4
	Fall	2.738	2.481	1.184	1.664	1.608	1.777	0.790	2	0
	Winter	1.721	2.143	1.466	1.552	1.410	2.285	1.834	2	0
	Increasing	1	3	0	0	0	1	0		
	Decreasing	0	0	0	1	1	1	1		

Table 9. MKT results for the ET data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	2.312	1.805	2.481	2.763	2.651	3.891	3.666	6	0
	Spring	1.241	1.635	1.523	1.128	0.592	1.579	1.579	0	0
	Summer	3.158	0.620	2.145	3.384	2.707	3.921	2.059	6	0
	Fall	0.846	-0.169	1.748	1.297	0.395	0.733	1.552	0	0
	Winter	2.369	2.312	3.303	1.805	1.748	2.030	1.579	4	0
	Increasing	3	1	3	2	2	3	2		
	Decreasing	0	0	0	0	0	0	0		

As evident in Table 10, there is a significant increasing trend in annual potential PET data in two geographic regions, namely Eastern Anatolia and the Aegean. Additionally, for spring PET data, a meaningful upward trend is identified in one geographic region, the Aegean. Similarly, in summer, there is a significant increasing trend in PET data in one geographic region, the Southeast Anatolia.

Table 10. MKT results for the PET data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	1.861	2.651	1.128	2.199	1.805	1.410	1.297	2	0
	Spring	1.466	1.128	0.480	2.143	0.902	1.523	1.184	1	0
	Summer	-0.677	1.805	2.312	-1.072	0.169	-1.015	-0.113	1	0
	Fall	1.184	0.790	-0.451	1.579	1.015	0.902	0.790	0	0
	Winter	0.733	1.128	1.072	1.861	1.466	1.748	1.184	0	0
	Increasing	0	1	1	2	0	0	0		
	Decreasing	0	0	0	0	0	0	0		

Table 11 depicts that, there is a noteworthy ascending trend in annual NDVI data across all geographical regions. In spring, an evident upward trend in NDVI is observed in all regions except for Central Anatolia. Similarly, during the summer, a significant rising trend in NDVI is noted in all regions except for Eastern Anatolia. In the autumn season, there is a meaningful increase in NDVI data in all regions except for Marmara. As for winter NDVI data, a substantial upward trend is identified in all regions except for Central Anatolia.

Table 11. MKT results for the NDVI data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	3.821	3.311	3.572	4.127	2.975	4.259	3.946	7	0
	Spring	2.819	1.988	2.750	3.361	1.901	2.537	2.247	6	0
	Summer	3.889	1.638	4.390	4.155	3.821	3.927	4.648	6	0
	Fall	3.908	2.158	3.580	3.034	2.432	1.887	3.870	6	0
	Winter	3.035	3.180	2.963	2.948	1.646	3.629	2.576	6	0
	Increasing	5	4	5	5	3	4	5		
	Decreasing	0	0	0	0	0	0	0		

Table 12. MKT results for the EVI data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	3.477	3.554	3.364	3.430	2.889	4.151	3.874	7	0
	Spring	2.289	2.036	2.507	3.083	1.682	2.450	1.666	5	0
	Summer	3.336	1.052	4.185	3.823	3.913	4.613	3.354	6	0
	Fall	4.229	2.850	3.878	2.573	2.970	1.962	3.274	7	0
	Winter	2.440	3.348	2.830	2.319	1.313	2.862	2.486	6	0
	Increasing	5	4	5	5	3	5	4		
	Decreasing	0	0	0	0	0	0	0		

As depicted in Table 12, there is a notable upward trend in annual EVI data across all geographic regions. During the spring season, a meaningful increase in EVI is observed in five geographic regions, including the Mediterranean, Eastern Anatolia, Southeast Anatolia, Aegean, and Marmara regions. In the summer, a significant rise in EVI data is noted in all regions except for Eastern Anatolia. Likewise, for autumn EVI data, there is a substantial increasing trend across all geographic regions. Regarding winter EVI data, a significant upward trend is evident in all regions except for Central Anatolia.

Table 13 shows that, there is a significant increasing trend in annual VCI data across all geographical regions. For spring VCI data, a significant increasing trend is observed in five geographic regions (Mediterranean, Eastern Anatolia, Southeast Anatolia, Aegean, and Marmara). During the summer season, a significant increasing trend in VCI data is found in all regions except for Eastern Anatolia. Similarly, for autumn VCI data, there is a significant increasing trend in all geographical regions except for Marmara. As for winter VCI data, a significant increasing trend is identified in all geographic regions.

Table 13. MKT results for the VCI data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	4.082	3.698	4.098	3.966	3.213	4.175	4.939	7	0
	Spring	2.886	2.070	2.712	3.282	1.955	2.604	1.783	5	0
	Summer	3.954	1.357	3.779	4.064	3.808	4.326	4.418	6	0
	Fall	3.932	2.012	3.724	2.827	2.635	1.640	3.915	6	0
	Winter	3.966	2.849	3.041	3.196	2.008	3.771	2.771	7	0
	Increasing	5	4	5	5	4	4	4		
	Decreasing	0	0	0	0	0	0	0		

As seen in Table 14, there is a significant increasing trend in annual FAL data in three geographic regions (Mediterranean, Aegean, and Black Sea), and a significant decreasing trend in one geographic region (Southeast Anatolia).

Table 14. MKT results for the FAL data

		REGIONS								
		Mediterranean	Eastern Anatolia	Southeast Anatolia	Aegean	Central Anatolia	Marmara	Black Sea	Increasing	Decreasing
MKT (Z)	Annual Total	3.497	-0.677	-2.312	3.609	1.917	0.508	3.891	3	1
	Increasing	1	0	0	1	0	0	1		
	Decreasing	0	0	1	0	0	0	0		

Correlation analysis was applied to precipitation, LST, ET, PET, NDVI, EVI, VCI, and FAL data obtained from the GEE platform. The correlation analysis was conducted according to Pearson's correlation method. This analysis was performed using data representing the entire Türkiye. The correlation coefficient (CC) obtained from the analysis reveals the relationship between the two data sets examined. A CC approaching 1 indicates a strong positive relationship between the data sets, approaching -1 indicates a strong negative relationship, and approaching 0 indicates no relationship between the data sets. Table 15 shows the CCs indicating the pair-wise relationships between all the factors used in the study. The strongest correlations are highlighted with red in the table.

As seen in the table, in general, the relationships between these factors are diverse and intricate. For instance, precipitation tends to have a negative correlation with LST, PET, and FAL, but a positive weak correlation with ET, NDVI, EVI, and VCI. LST, on the other hand, exhibits negative correlations with precipitation and ET, a strong positive correlation with PET, and various weak correlations with NDVI, EVI, VCI, and FAL. ET shows a negative correlation with LST and positive, albeit weak, correlations with precipitation, PET, and FAL, along with very strong correlations with NDVI, EVI, and VCI. These interconnections highlight the interdependence and complexity of environmental variables, emphasizing the need for a comprehensive understanding of the intricate relationships within ecosystems.

Table 15. CCs computed for all the factors used

	Precipitation	LST	ET	PET	NDVI	EVI	VCI	FAL
Precipitation	1							
LST	-0.03	1						
ET	0.13	-0.17	1					
PET	-0.23	0.63	0.11	1				
NDVI	0.10	0.36	0.77	0.31	1			
EVI	0.11	0.30	0.79	0.27	0.99	1		
VCI	0.11	0.28	0.81	0.32	0.96	0.95	1	
FAL	-0.31	0.27	0.11	0.24	0.35	0.32	0.37	1

4. Conclusion

The aim of this study is to examine the impacts of climate change on Türkiye through data catalogues provided by the GEE cloud-computing platform for the years between 2000 and 2022. To this aim, trend analysis was conducted on various data sets, revealing notable patterns. In Eastern Anatolia, there were significant decreases in annual precipitation and increases in annual LST. Across all regions except Eastern Anatolia, there was a significant increase in annual ET. Conversely, Eastern Anatolia and the Aegean regions showed significant increases in annual PET. Moreover, annual NDVI, EVI, and VCI demonstrated significant upward trends across all regions. Annual FAL showed noteworthy increases in the Mediterranean, Aegean, and Black Sea regions. The experiments highlighted strong correlations among ET, NDVI, EVI, and VCI, as well as a robust correlation between PET and LST.

The GEE data catalogues play a crucial role in uncovering the global implications of climate change by granting access to an extensive collection of geospatial data. These catalogues offer researchers the ability to analyse a wide range of satellite imagery, climate data, and environmental factors, facilitating in-depth examinations of lasting patterns and changes. This data-driven method enhances our comprehension of the worldwide impact of climate change, assisting scientists, policymakers, and communities in formulating precise approaches for both mitigation and adaptation.

In order to leave a healthier and more sustainable world for future generations, it has become necessary to work on combating climate change. Therefore, it is essential to increase research efforts and generate more sustainable projects to raise public awareness on this issue. While the present study delved into examining the impacts of climate change on Türkiye, specifically exploring variables such as precipitation, LST, ET, PET, NDVI, EVI, VCI, and FAL, it is essential to acknowledge certain limitations. Notably, this study did not extensively investigate other influential variables, including urbanization, alterations in water resources (such as lakes and rivers), shifts in land use, among others. This gap in the research scope serves as a limitation, emphasizing the need for future studies to broaden their focus and encompass a more comprehensive range of factors influencing climate change dynamics. By expanding the scope to include these variables, future studies may contribute to a more holistic understanding of the intricate factors at play, thereby informing more effective strategies for climate change mitigation and adaptation.

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